A Hydrology and Burning Management Plan for Kasanka National Park

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List of Abbreviations and Acronyms

GMA	Game Management Area
KGMA	Kafinda Game Management Area
KTL	Kasanka Trust Limited
KNP	Kasanka National Park
KRC	Kasanka Research Centre
LUP	Land Use Plan
SUERC	Scottish Universities Environmental Reactor Centre
ZAWA	Zambian Wildlife Authority

Summary

Kasanka National Park (KNP) is one of the smallest national parks in Zambia, and is privately managed by Kasanka Trust Ltd, a UK and Zambian-based charity, in partnership with the Zambian Wildlife Authority (ZAWA). KNP, which is entirely surrounded by the Kafinda Game Management Area (KGMA), is unusual within the miombo woodland landscape in that it is dominated by freshwater habitats. As such it is a refuge for specialist wetland species such as the semi-aquatic sitatunga antelope (*Tragelaphus spekii*), whilst fragments of wet evergreen mushito forest (a rare vegetation type in Zambia) provide roost habitat for seasonal influxes of migratory straw coloured fruit bats (*Eidolon helvum*). Other wetland habitats including rivers, lakes and seasonally flooded dambo wetlands are also present.

Currently KNP has no formal management plan. Current hydrological interventions include a stone weir within the central area of the papyrus swamp, designed to retain water, plus a series of furrows designed to direct rainwater runoff into Lake Wasa, which is overlooked by the main tourist lodge.

Illegal fires set by poachers are perceived as a major threat, and early burning (soon after the end of the wet season) of grassland and woodland areas has been carried out in KNP since at least 1986 to avoid later and hotter fires which are potentially harmful to woodland. These patterns of burning in KNP differ from those outside the park, where late burning prevails.

There has been a concern on the part of park management that the water resources, and therefore the wetland habitats, particularly mushito forest and papyrus swamp, may be prone to drying out as a result of short or long term climate change. Given the lack of past hydrological research in the area, it was felt that not enough was known about large scale hydrological flow pathways in the park, or what were the sources of water sustaining various habitats to enable appropriate management plans to be put in place. In addition, a scientific basis for burning was lacking. The formulation of a hydrology and burning management plan was seen as essential for informing an overall management plan for Kasanka.

Hydrological, hydrochemical and environmental sampling and monitoring was conducted between March 2005, and May 2008 in KNP and the KGMA in order to help understand what were the main sources of water contributing to the sustenance of important freshwater habitats, and potential threats to hydrological integrity. The study utilised alkalinity, and oxygen isotopes as natural tracers. A number of trial plots were established in the central area of the park, concentrated on a complex of enclosed dambo wetlands, in order to determine impacts of timing of burning in seasonal wetlands, and associated termitaria and miombo habitats.

The hydrological data collected has shown substantial spatial variability in rainfall across the park and peripheral locations within the Kafinda GMA, and also temporal variability between years. It was also discovered that the rivers and lakes all had substantial recharge from direct rainfall, but that the Kasanka and Musola stream (which flow through the central Kapabi swamp, home to a highly visible population of sitatunga antelope), had a high degree of interaction with groundwater reserves and surrounding floodplains. In contrast, the Luwombwa River, to the west of the park had very little such interaction, and flow was maintained from the large catchment outside KNP. Groundwater chemistry was generally very stable, but rapid recharge at some locations indicated variable geology.

Within the experimental burning plots plant species were recorded to provide a baseline for monitoring future change. A number of habitat, vegetation, and biomass variables were also monitored, in order to assess any effects of treatment (early or late burning).

The variables, which varied significantly in relation to burning treatment, were vegetation height, live biomass, and dead biomass. Soil Moisture varied significantly between all habitat types (but not in relation to treatment) demonstrating that miombo soils rapidly become water limited following the end of the wet season. Accumulated biomass and grazer offtake did not differ significantly in relation to Habitat type or treatment. None of the treatment effects observed as a result of early or late burning persisted into the second year as the growth season got underway.

The main conclusions of the study (and implications for water and fire management in KNP) were:

- All wetland habitats are vulnerable to drying as a result of low rainfall.
- The Kasanka and Musola rivers, important in sustaining water levels in Papyrus swamp, have high levels of groundwater input and extensive surface interaction, and therefore need protection.
- All dambos (and open waterbodies in them) are seasonal wetlands, and recharge from precipitation is important. They will shrink during dry periods, but this is a natural phenomenon.
- The system of furrows around Wasa camp are unlikely to have negative impacts on the overall hydrological balances of KNP, but there is concern that they may be increasing sediment deposition into Lake Wasa I which could possibly speed up succession from open water to swamp.
- Conductivity values suggest that nutrient enrichment is not occurring in lake Wasa I as a whole as a result of the furrows, but this is not conclusive, and even small increases in soluble reactive phosphate, for example, may cause major changes in ecology.
- The weir in the Kapabi swamp is likely to be beneficial in locally extending flooded areas and protecting swamp habitat in low rainfall years.
- There is no evidence that the presence of the weir unduly affects downstream hydrochemistry.
- Larger dams downstream on the Musola or Kasanka Rivers would not be beneficial. Continually deep water would threaten the nature of the swamp, and might lead to an expansion of ‘seepage’ and ‘estuarine’ mushito, which has lower species diversity and is less preferred as roosts for fruitbats.
- The main threats to freshwater wetland ecosystems in KNP potentially come from outside the park, if a proposed large farm scheme goes ahead and is unsympathetically managed without considering ecosystem consequences (e.g. if large scale damming of river headwaters and/or groundwater abstraction for commercial irrigation is carried out). However, uncontrolled fire encroaching into fragile but key habitats in KNP (e.g. papyrus swamp and mushito forest) could also be a threat in low rainfall years.

The early burning approach that has been followed to date is unlikely to have been detrimental to soil properties or vegetation structure, or to have compromised localised water conservation, except in those instances where it has been allowed to encroach on fire sensitive habitats such as papyrus swamp, following prolonged dry periods.

- Experimentally, the main differences seen in standing crop and biomass production were in relation to habitat type, and not as a result of treatment. However, the study was carried out during a particularly wet period, and this finding may not hold true during dryer periods.
- In miombo woodland, both early burning and late burning are associated with a greater (though not quite significant) net primary production during the subsequent growth season, than unburned miombo. Again, this might not be the case under dryer conditions.

- Extensive early burning removes a large proportion of above ground, dead biomass for a large period of the year (for up six months), potentially restricting physical habitat for a range of animals.
- In particularly dry periods this problem will be exacerbated as vegetation will senesce earlier and more rapidly, and will therefore burn earlier.
- There appears to be no significant stimulation of early biomass growth at the onset of rains as a result of early burning. There is evidence of some stimulation in miombo woodland (which has low overall biomass for grazers), but this is not statistically significant.
- Early burning is a useful option to reduce late, destructive fires, but care should be taken to preserve a mosaic of unburned areas of vegetation, by introducing strategic firebreaks, to optimise physical habitat diversity and associated biodiversity.
- Late burning will remove more biomass overall (though bare ground will be a feature for a relatively short period before the onset of rain), but is potentially much more damaging to fire-sensitive species.
- A majority of the soils in miombo, termitaria, and even some seasonally wet grassland habitats, appear to be more sensitive to rainfall than to burning treatment.
- Miombo habitat becomes water-limited very rapidly following the end of the wet season. Therefore, burning early will prevent hot fires that may damage saplings and small trees.
- There is evidence from this study to suggest that early burning practices are the best option where burning is required in terms of biomass production, at least under the recent rainfall conditions during this study.
- Biomass accumulation (a surrogate for net primary production) and offtake by grazers were not significantly affected by the timing of treatment.
- The only apparent benefit of extensive early burning of dambo grassland areas is to protect specifically targeted habitats such as papyrus and mushito.
- The major disadvantage of extensive early burning of dambo grassland is the removal of cover for the species rich rodent and small carnivore communities, and small and medium antelopes, especially sitatunga.

If staffing levels permit, the following activities would be highly beneficial in establishing long-term datasets for KNP, and would allow an assessment of future change under altered climatic conditions, or in relation to potential activities in the KGMA.

- Regular monitoring and quantification of sediment loading and flow rates into Lake Wasa via the network of furrows.
- Establishment of replicate early burn, late burn and control plots adjacent to the furrow network, followed up by sampling of hydrochemistry of water in the furrows in the early wet season to determine any effects of timing of burning on nutrient loading.
- Occasional monitoring of pH and conductivity in river and lake sites early and late in each wet season to determine any future deviation from the 'baseline' which has been established.
- Maintain experimental plot burning sequence and firebreaks between and around plots.
- Monitoring of biomass variables in response to low rainfall wet seasons.

As a result of the findings of the hydrological monitoring and burning experiments the following Management Recommendations were made:

- The weir at Fibwe Camp should be maintained to help protect fragile and important papyrus swamp from burning following low rainfall years.

- No dams any larger than the current installation at Fibwe Camp should be installed on either of the Musola or Kasanka Rivers as these may be detrimental to the ecology of the floodplains and/or their hydrochemistry.
- The furrow system which feeds into Lake Wasa I should not be extended any further until an assessment of sediment loading via furrow flow, over at least two wet seasons is carried out.
- In the meantime, it would be beneficial to clear only 50% of vegetation from the furrow system in each year during the wet season so that what remains acts as a sediment trap.
- If possible, and a fire risk is not posed, sections of dead vegetation should be left in the furrows during the dry season to enable traping of sediment transported by early rains.

Lake Wasa I is a seasonally flooded dambo and the main aim of the furrow network is to maintain water levels in the lake as the main tourist lodge overlooks it. However, all such dambo wetlands are prone to drying periodically given variable rainfall levels and over time through sedimentation and vegetation encroachment (succession), and the flora and fauna present are adapted to the system. This is natural ecological succession. The provisions made by the furrows may therefore prove futile in the long term, and more radical mechanical removal of vegetation and accumulated sediment may be the only option to maintain an open water body in the long term. Whether such management is appropriate to a National Park is, however, questionable.

- Protection of forest cover in the wider KGMA should be a priority, and KTL should actively seek to use any statutory legal instruments to help enforce this via ZAWA and the Forestry Department.
- The completion of the KGMA Land Use Plan (KGMA-LUP) will aid the identification of legally protected areas.
- Priority should also be given to the protection of the headwaters of the Kasanka and Musola Rivers, which are the most critical to the unique character of KNP, under the Kafinda Game Management Area Land Use Plan.
- Efforts should also be made by park management to lobby for legal protection of the entire headwaters of the Kasanka and Musola Rivers (currently, outside of KNP, only small portions within the KGMA are protected).

To reiterate, early burning is the best approach to protect from late uncontrolled fires. But, care should be taken to preserve a mosaic of unburned areas of vegetation.

- The practice of early burning should be continued in all habitats where it is viewed as essential to protect from late, destructive fires.
- Given the fact that the character of the wetland systems in KNP are primarily climate driven, the specific extent and timing of burning needs to be assessed by trained staff on a yearly basis. The production of ‘burning maps’ or a detailed list of areas to be burned, and at what precise time of year is not possible.
- The burning regime that has been followed until present should largely be followed.
- However, where burning is essential in miombo woodland, early burning should be prioritised:
    - In *dry* years this will prevent damage to seedlings, and will retain more biomass as physical habitat since miombo soils rapidly become water-limited (much quicker than adjoining termitaria habitat) and vegetation quickly senesces.
    - In *wet* years, this will have the advantage of stimulating early production of biomass to provide grazing opportunity where other suitable grassland habitat is still inundated by floodwater.

- Where discrete 'islands' of vegetation exist (e.g. a patch of drier termitaria surrounded by seasonally flooded grassland, or a patch of woodland), slashing and strategic burning should be used to protect such islands by introducing strategic firebreaks
- It is not possible to deduce or infer any long term effects on species composition or soil nutrient pools and soil moisture given the short term nature of the present study and the extreme wet conditions which prevailed, but future monitoring to assess change in these variables as a result of the treatments imposed should be a priority.
- Substantial strips of vegetation along river banks adjoining floodplains should be left unburned where practical, or be burned as early as possible to preserve above ground structure of the vegetation. This will be hugely beneficial to help prevent loss of nutrients as ash by surface flow during early rains, and enable trapping and retention of mineral and organic particles from the river channel during flooding.
- Overhanging vegetation by rivers and lakes, and vegetation emergent in seasonally flooded areas (but which is vulnerable to burning in the dry season) should be protected from burning to limit evaporative losses.

The two habitats which are key to the character and tourism potential of KNP, yet are most vulnerable to disturbance by burning in dry years are the **Papyrus swamp** and the **Mushito forest.**

- Scout presence should be consolidated within these areas during the dry season in order to protect the areas from illegal or uncontrolled burning.

Papyrus swamp: needs protection from burning following below average rainfall years (and especially where there are several consecutive such years).

- This could be achieved by slashing and burning firebreaks 100 to 200m from the swamp edge, coupled with very early burning of any drying peripheral grassland. It is important to maintain surrounding cover as much as possible due to its importance as sitatunga cover

Mushito forest: The main anthropogenic threat comes from uncontrolled burning:

- Burning should be avoided in the forest itself to preserve the unique microclimate and prevent peat deposits from drying and becoming susceptible to burning.
- Firebreaks should be implemented around the edges of the driest areas of forest (i.e. furthest away from the papyrus swamp), to protect from fire encroaching from adjacent grassland, and deep peat fires from setting.
- Burning at the immediate forest edge should be avoided to aid successful recruitment and growth of mushito tree species.
- There is evidence that the annual influx of fruitbats is affecting the structure and microclimate of the mushito, possibly making it more susceptible to fire encroachment. Therefore, burning for management must not be allowed to exacerbate the effect of the bats, as this might ultimately lead to their loss from KNP.

General recommendations include:

- Creation of a burning log at the end of each wet season kept in the main office.
- A definitive list of staff trained and licensed to carry out burning should be compiled and updated each year.
- Increased education amongst park staff regarding objectives of burning in KNP.
- Experimental plots (and firebreaks) need to be maintained, and burning sequences within the plots followed if long term impacts of burning are to be deduced. They will potentially provide a valuable long-term research resource for KNP.

Chapter One: Introduction

1.1 Kasanka National Park (KNP) and Kafinda Game Management Area (KGMA)

1.1.1 Physical, Climatic Biological Characteristics

1.1.1a Kasanka National Park in Zambia
Zambia lies at the centre of the Miombo ecoregion, a vegetation type that extends into the neighbouring countries of Angola, Botswana, Democratic Republic of Congo, Tanzania, Mozambique, and Zimbabwe (Smith and Allen, 2004). The woodland savannah vegetation type is dominated by leguminous tree species of the *Brachystegia*, *Julbenardia* and *Isoberlinia* genera, and has a typically species-poor ground flora. The soils of miombo woodland are typically thin, nutrient-poor, and acidic, overlaying iron-rich lateritic rock. Within KNP the laterite rock is interspersed with quartz deposits and gravel seams. Zambia has the highest Miombo coverage of any country at over 80%.

KNP is located in Central Province, Zambia (12º 30'S 30º 14'E), and is one of the smallest national parks in the country, covering approximately 420 km². It is one of only two national parks in Zambia that are privately managed (the other being the Liuwa Plains National Park), and is entirely surrounded by the KGMA. KNP is unusual within the miombo landscape in that it is dominated by freshwater habitats. As such it is a refuge for specialist wetland species such as the semi-aquatic sitatunga antelope (*Tregalaphus spekei*), whilst fragments of wet evergreen mushito forest (a rare vegetation type in Zambia) provide roost habitat for seasonal influxes of migratory straw coloured fruit bats (*Eidolon helvum*).

1.1.1b The Regional Climate
Zambia lies within the tropics, but its climate is moderated by its altitude, which averages around 1200m, but ranges from below 500m in the rift valley to over 1800 m in the Nyika Plateau (a national park park typified by undulating topography and montane habitats, which is on the border with Malawi). The climate is also moderated by heavy rainfall during the summer period.

Zambia typically has three distinct seasons: a cool dry season, running from April to July, an increasingly hot dry season running from August to November, and a hot wet season from December to March. The timing varies depending on latitude, and the rains in particular are governed by the Congo air-mass which moves south into Zambia.

KNP lies in a rainfall belt with a unimodal rainfall pattern of approximately 1200mm per year (although this varies both spatially and between years) and has an average elevation of 1050 m.

1.1.1c The Habitats of KNP
Kasanka has a woodland cover of approximately 70%. The predominant woodland type is miombo, but fragments of evergreen riverine gallery forest, wet evergreen 'mushito' swamp forest, and chipya woodland are important habitats in the park. KNP however is also important for its abundant wetland habitats, including perennial rivers, seasonal and permanent wetlands, floodplain wetlands, and lakes (see Figure 1 for locations of Rivers and Lakes).

The main wetland habitats within KNP are:

Dambos
These seasonally inundated wet grasslands, which are essentially extensive drainage networks support species such as waterbuck (*Kobus ellipsiprymnus*) and reedbuck (*Redunca arundinum*), and various wading birds.

Papyrus Swamp
Areas which are generally perennially inundated, and dominated by *Carex papyrus*. This habitat supports resident and migratory birds, and rare antelope species such as Sitatunga (*Tregelaphus spekei*). These swamp habitats are relatively extensive within the park, and also provide attractive viewing areas for visitors.

Rivers
The main perennial rivers within or bordering KNP (the Kasanka, Luwombwa, Mulembo and Musola: See Figure 1) all have headwaters outside of the park boundary: However, none of these rivers are currently dammed (both within and outside of the park) and represent relatively naturally functioning systems which support a range of fish, bird and other species. Under high flow conditions during the rainy season, the rivers maintain connectivity with backwaters, thus replenishing water levels and nutrients. Such backwaters often function as good areas for fish spawning.

Floodplains
The perennial rivers in the park all have areas of floodplain that generally become inundated during the wet season. They provide good grazing habitats (often in association with drier grassy scrub and woodland) for antelope species such as sable (*Hippotragus niger*) and puku (*Kobus vardonii*).

Lakes
Perennial and seasonal lakes and open water bodies (including sink-hole lakes) are present within the park. These open water habitats (along with certain rivers) provide habitat for hippopotamus (*H. amphibious*), and both Nile crocodile (*Crocodylus niloticus*) and slender snouted crocodile (*Crocodylus cataphractus*). Areas of fringing emergent vegetation are important for insects such as dragonfly, plus species of wading birds and sitatunga.

The main woodland and forest habitats within KNP are:

Miombo (or Brachystegia) woodland
The predominant vegetation type in KNP. It is characterised by various species of *Brachystegia, Julbernardia, and Isoberlinia*, and is generally not resistant to hot fires. It supports species such as roan antelope (*H.* equines) and sable antelope (*H. niger*), Lichtenstein's hartebeest (*Alcelaphus lichtensteinii*), warthog (*Phacochoerus aethiopicus*), bush pig (*Potamochoerus porcus*), common duiker (*Sylvicapra grimmia*) and yellow baboon (*Papio cynocephalus*).

Mushito wet evergreen forest:
This woodland habitat has been classified on the basis of its overall degree of flooding (Fanshawe, 1969). The more species rich seasonally flooded type, characterised by *Syzygium cordatum, Aporrhiza nitida, Khaya anthotheca, Rauvolfia caffra, Diospyros mespiliformis*, and *Bersama abyssinica*, and the seepage type, which is characterised by *S. cordatum, Maesa lanceolata, A. nitida, Ficus trichopoda*, and *Ilex mitis* have both been recorded in KNP (Byng, 2008). The largest fragment of Mushito provides a roosting area for an annual influx from other countries in Southern and Central Africa of straw-coloured fruitbats (*Eidolon helvum*), estimated in millions. Mushito forest is rare in Zambia, and whilst the KNP component is fragmented, it represents an important local resource.

Mateshe woodland
The woodland type contains tree species common to miombo, with a high percentage of fire sensitive species. It is characterised by a common occurrence of *Brachystegia spiciformis.* Fragments of dry evergreen forest are found on deep organic soils, generally along river corridors. The vegetation type is not widespread in the park, but contains unique assemblages of tree species.

Chipya woodland
The word 'Chipya' derives from the Bemba word 'kupya', which means 'to burn (Smith *et al.* 2000). This woodland type is found generally on deep soils, and is characterised by a relatively open canopy, the absence of fire sensitive tree genera such *Brachystegia, Isoberlinia*, *Julbernardia,* and *Uapaca*, and a presence of fire resistant trees which are not common in miombo (e.g. *Amblygonocarpus andogensis, Albizinia atunesiana, Pericopsis angolensis, Pterocarpus angolensis, Burkea africana, Erythrophleum africanum, Parinari curatellifolia,* and *Combretum* spp. Chipya also has a species poor and distinctive field layer predominantly containing *Pteridium aquilinum*, *Aframomum alboviolaceum, Smilax anceps,* and *Hyparrhenia* spp. It has been suggested that chipya woodlands may occur as a result of the burning of mateshe woodland.

1.1.2 Current management practices and interventions

1.1.2a Hydrology
The main hydrological interventions in KNP have been the digging of furrows within the Wasa dambo complex, which drain seasonal rainwater from roads and other dambos into Lake Wasa I in an attempt to maintain a large area of open water which attracts birds and hippos etc; Lake Wasa I is overlooked by the main tourist lodge. In addition, a stone weir was installed on the Musola River as it passes through the Kapabi swamp, close to Fibwe camp, in an attempt to hold water back in the papyrus swamp, and prevent drying out.

The weir was installed in 1993, and the furrow systems, which drain Musola, Mulaushi and Wasa II roads, and the Kanyamanzi dambo and areas of miombo woodland into Lake Wasa I, were first established in 1999, and are regularly maintained by the removal of silt and vegetation.

Other concerns surrounding hydrology include plans for the establishment of a commercial farm block to the south of KNP, and the possible building of surface dams and groundwater abstraction for irrigation which might accompany this. However, the full scale of the plans is as yet unclear.

1.1.2b Burning
Early burning of grassland and woodland areas has been carried out in KNP since at least 1986. The general procedure has been to carry out burning from May, soon after the end of the wet season, and to complete this by early August, before the load of dry litter has become too high, and daytime temperatures become too hot to control burning. The aim of this practice has been to protect woodland and grassland habitats from late, hot fires.

The first fires have generally been set from May within open grassland areas, which enables only partial burning (although this has largely been delayed during 2007 and 2008 due to persistent standing water following above average rainfall). In June open dambos have been targeted, moving into chipya and wet dambos in July, and into the short field layer in miombo woodland in July and August.

It is generally recognised that patterns of burning in KNP differ from those outside the park. No government or statutory controls exist with regards to the timing of burning, and generally late fires are set in order to clear tall grasses. It is also believed that late burning, prior to the early rains, encourages a flush of fresh leaves in miombo woodland tree species, such as *Brachystegia*, as a food source for edible caterpillars, an important 'cash crop'.

1.1.3 Previous Relevant Research
With Zambia being the centre of the miombo ecoregion, considerable effort has been placed upon understanding this woodland type. Chidumayo (e.g. 1997) has written widely on miombo ecology, and permanent burning plots to investigate long term impacts of burning have been established in the Copperbelt (although results have not been widely

disseminated). Identification guides have been produced for common miombo tree species (Smith and Allen, 2004).

However, within Zambia, biological research, and particularly hydrological research, has been limited. There is still no comprehensive flora of the country, and there has been only limited mapping of natural resources outside the National Parks. The ongoing Land Use Mapping exercise in Kafinda GMA, which is being led by ZAWA (2007), is one of the first such exercises, and regarded as a test case, being carried out in one of Zambia's smaller GMA's.

Since direct management by KTL began in 1990 interest in research has increased. At least four undergraduate university expeditions have visited KNP and KGMA since the late 1980's, and the two most recent expeditions by the University of Glasgow (2006) and the University of Aberdeen (2007) have concentrated on aspects the freshwater and biological resources within KNP.

Honours project from the Glasgow expedition included:

(i) A study of the macroinvertebrate fauna in waterbodies of KNP and KGMA (Morrison 2007), which applied a test of the South African Scoring System (a freshwater biomonitoring methodology which utilises presence and absence of invertebrate groups with varying degrees of sensitivity to pollution). The results showed that more than half of the waterbodies did not reach 'good ecological status'.
(ii) A study of zooplankton assemblages in relation to waterbody chemistry and characteristics (Mackinnon 2007)

The Aberdeen expedition resulted in two honours projects, covering:

(i) A study of the effects of the seasonal straw coloured fruit bat aggregation on mushito forest canopy structure and soil nitrogen status from guanotrophication (Byng 2008). The study identified areas of 'seepage' mushito and seasonally flooded mushito (the dryer of the two types), and highlighted that the second type was slightly more floristically diverse (a third 'estuarine' type, which is the wettest, was not indicated). It also showed that the bats not to have a significant ongoing impact on soil nitrogen and phosphorous status. However, they do have a significant degenerative affect on canopy structure of the forest, and this along with impacts of intermittent large fires, and ongoing controlled yearly burning to the edge of the forest form the major threat to the survival of the mushito.
(ii) A study of the behaviour of sitatunga antelopes in Kapabi swamp (Denerley, 2008). The study gave indications of the animals diet, and suggested that agonistic behaviour between individuals was lower than independent previous studies had reported. This may reflect an abundance of suitable habitat in KNP, and highlights the need to protect areas of papyrus swamp from burning during periods when they are vulnerable to drying (e.g. following subsequent low rainfall years).

A joint Aberdeen and Glasgow University expedition will take place in 2008 and continue freshwater monitoring, and initiate a study of habitat preferences of bats, and their haemo- and ectoparasites.

Other biological and fire related work has been undertaken. A report by Smith *et al.* (2000) details a floristic study that attempted to determine the origins of Chipya woodland, and suggested that it might be a fire-degraded form of evergreen Mateshe woodland. A study by Eriksen (2004) investigated the use of fire in KGMA as a land management tool, and concluded that current practices of late burning do not empower local to people to have full control over their own farming systems.

A study of Dragon and Damselfly fauna, providing an inventory of species in KNP has also been carried out, although as yet this is available only in German (Geschke, S. 2003).

1.1.4 The Need for a Hydrology and Burning Management Plan

The importance of freshwater habitats in Kasanka is well recognised. However, there has been a concern on the part of park management that the water resources, and therefore the wetland habitats, particularly mushito forest and papyrus swamp, may be prone to drying out as a result of short or long term climate change. Given the lack of past hydrological research in the area, it was felt that not enough was known about large scale hydrological flow pathways in the park, or what were the sources of water sustaining various habitats to enable appropriate management plans to be put in place.

In addition, the practise of early burning (i.e. early in the dry season) was seen as the best option to avoid late fires, which may be far hotter and more destructive, from being set either accidentally or illegally (poachers have been known to enter the park, and to burn areas to attract grazing animals to new flushes of vegetation, where they can be snared, or shot). However, a scientific basis was lacking, and experimental work was needed to investigate impacts of burning within different habitat types in the park at different times of year. These impacts were gauged with respect to surface soil moisture, and aspects of vegetation structure and assemblage.

Sitatunga are a secretive species that uses tall vegetation for cover. Due to the current burning regime, suitable habitat cover for sitatunga, away from the main areas of papyrus swamp, is likely to be limited. During the dry season, along areas such as the Kasanka River floodplain, the sitatunga move between the remaining patches of tall grasses.

The formulation of a hydrology and burning management plan was seen as essential to inform an overall management plan for Kasanka. In order to enable Kasanka to be a competitive actor in the developing ecotourism industry in Zambia, its unique wetland biodiversity requires protection through appropriate management

The need for the project was identified during a visit by the Darwin Initiative project leader, Professor Paul Racey, to KNP, at the invitation of and sponsored by the HHT. It became clear during the visit that both the conservation management in the park, particularly the management of wetlands, and the exploitation of natural resources in the surrounding area, lacked scientific underpinning and informed planning.

1.1.5 Approach and Methodologies

Hydrological and hydrochemical sampling was conducted in KNP and KGMA in order to help understand what were the main sources of water contributing to the sustenance of important freshwater habitats, and what the potential threats to hydrological integrity might be. Controlled burning trials were also conducted to determine impacts of timing of burning in various wetland and associated habitat types.

1.1.5a Hydrology and Climate

Rainfall was monitored at a total of thirteen locations across KNP and KGMA (see Figure 1), and hydrological monitoring was employed to characterise water sources and fluxes in KNP from March 2005. Temperature was also recorded hourly, and evaporation from a pan was recorded daily at KRC.

At the outset of the field-sampling programme in 2005, sites within the park and on its boundaries were identified for hydrological monitoring. These represented a variety of shallow lakes, rivers, and seasonally flooded dambo wetlands for which, it was considered year round access should generally be possible (see Figure 1). A number of wells and boreholes were also identified to characterise groundwater reserves.

Four hydrochemical variables were monitored to characterise the various sites. They were: pH, electrical conductivity ($\mu S/cm^3/s^{-1}$) (both measured on site, using Hannah portable probes), alkalinity (μEq/l: measured by titration using a bench top Jenway pH meter at the KRC lab), and oxygen isotope ratios ($\delta^{16}O$: $\delta^{18}O$), which was determined on return to the UK at the Scottish Universities Environmental Reactor Centre (SUERC) in East Kilbride.

Electrical conductivity and alkalinity are useful tracers of the geographical sources of water. Conductivity reflects the concentration of dissolved solutes in water samples, whilst alkalinity indicates the acid buffering capacity provided by geochemical weathering. Low conductivity and alkalinity imply a strong influence of recent rainfall, whilst higher conductivity and high alkalinity is indicative of longer times in contact with catchment soil and geological formations in groundwaters. Measuring oxygen isotope ratios in waters allows further discrimination of water sources. These reflect the residence times in hydrological systems when different sources are compared to values for precipitation. Such tracers are particularly useful in assessing hydrological processes over extensive areas as they act a chemical "fingerprints" of where water has been.

Gauges were established to monitor river levels in several rivers, and basic cross section profiles produced and discharge estimates calculated (volume of water passing a given point in the channel: m^3/s).

In addition tensiometer nests were installed at Wasa Camp (since March 2006), at Kasanka Research Centre (since October 2006), and around Wasa I dambo (since October 2006). Wasa I dambo tensiometers were alongside a sub-set of treatment blocks in each of the miombo, termitaria and seasonally wet grassland habitat types (see below). Research Centre and Wasa Camp tensiometers were located at the upper edge of seasonally wet areas. The tensiometers measure suction within the soil at set depths when water leaves a porous ceramic cup inserted into the soil, at the base of a sealed tube filled with water. This suction is indicated in millibars (Mb) on a dial at the top of the sealed tube.

Dipwells were installed in a transect at Fibwe swamp, adjacent to the Musola River, and in a transect through the mushito forest in Autumn 2005. Tensiometers were also installed alongside dipwells in the forest. Unfortunately neither array yielded useful information. The swamp dipwells quickly became overtopped by floodwater following the onset of 2005 rains, and remained covered. Several dipwells were removed or lost to uncontrolled fire, whilst the tensiometers were irreparably broken by vandalism just a few weeks after installation.

1.1.5b Burning Trials

Controlled burning experiments were also carried out in areas of miombo woodland, termite-dominated grasslands surrounding the three dambos within the Wasa dambos complex (see Figure 1), and in the seasonally flooded areas themselves. The experiments were designed to compare the hydrological and ecological effects of early burning (following the wet season), late burning (preceding the onset of the wet season), and absence of burning in the different habitat types.

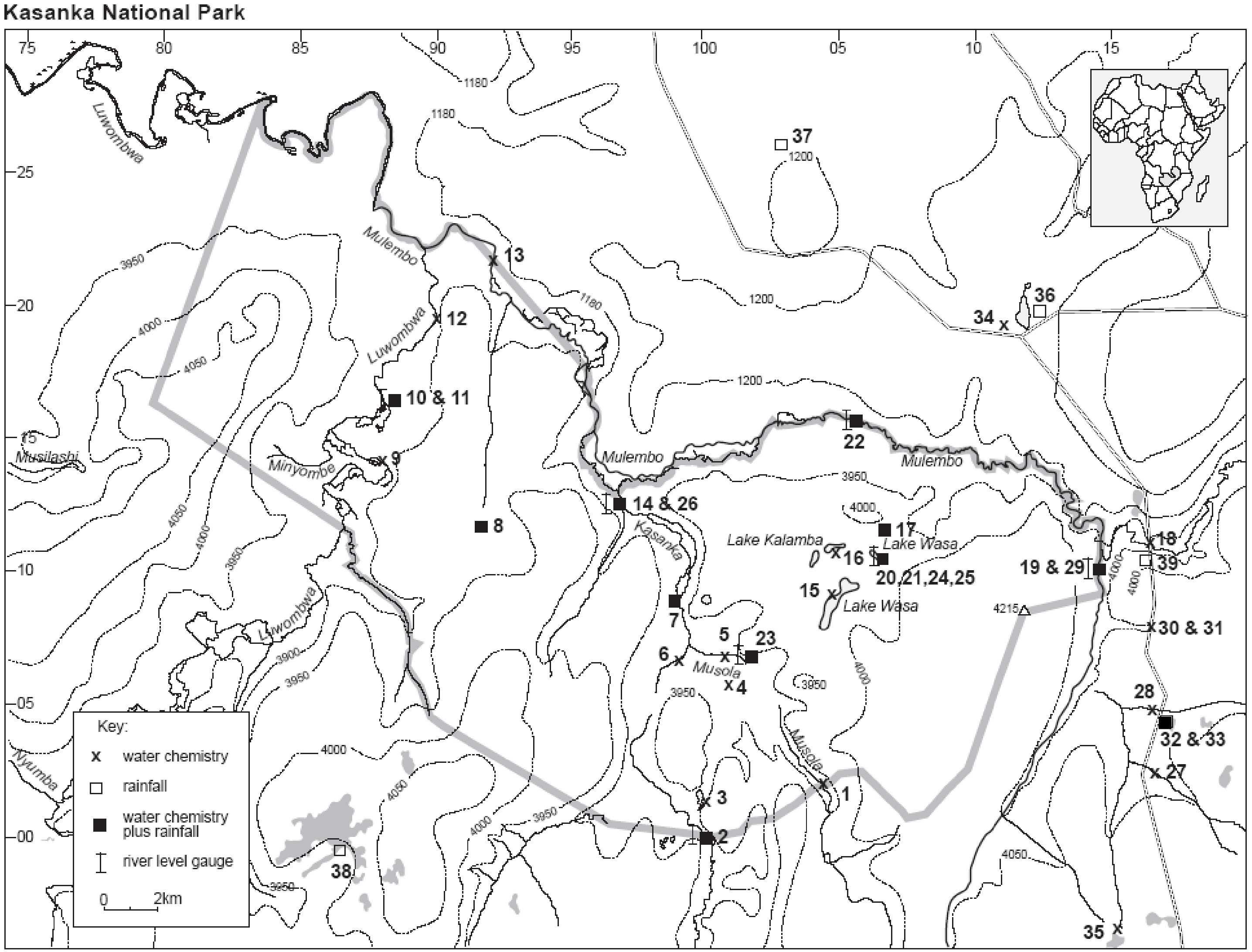
Five replicate blocks (sites) each containing three sets of three burning treatments (No burn, Early burn and Late burn) in each of three habitats (miombo, termitaria grassland and seasonally wet grassland) were established during early 2006 in the complex of enclosed dambos surrounding Wasa Camp. This gave a total of 45 15m x 15m treatment plots. In addition, associated with each of the five blocks, a single control (no burn) plot was also established in permanent wetland areas, but these were not monitored during the course of the study as they became permanently inaccessible due to flooding. The 45 treatment plots were monitored for a number of vegetation and environmental variables including biomass, vegetation height, litter cover and soil moisture. Firebreaks, (10m wide) were established around all plots (except for the additional five in the permanently wet areas), by hand slashing, and maintained into 2007.

Early burn treatments were carried out within a randomly selected plot in each set of three. During June 2006 (the routine early burning in the park was generally delayed due to wet conditions and a relatively late finish to the rains). Late burn treatments were carried out at the end of September 2006. Within one of the blocks, in Wasa I, the grassland plots had very short vegetation, and therefore burns were largely incomplete or not possible. During 2007, the early burn was delayed until late July, due to very wet conditions and persistent flooding, and late burning was carried out in late October. Not all grassland plots could be burned due to continued presence of water during both occasions.

Exclosure cages were deployed in all miombo, termitaria grassland and seasonally wet grassland treatment plots during late June and early July 2006, to allow quantification of above ground net primary productivity and grazing offtake by large grazers in different habitats under different treatments. Monitoring was carried out by taking paired standing crop samples (1m by 20cm) from inside each cage, and from a site adjacent to the cage (generally within 1m). On return to the lab at KRC samples were sorted into live and dead material and each component weighed. These were then dried in a drying tent and reweighed when dry. Live and dead biomass proportions (and ratios of these) were derived. Tables for accumulated biomass production and accumulated offtake by grazers (between September 2006 and May 2007) were derived from a comparison of live biomass values for each set of paired samples.

Surface soil moisture (using a portable Delta-T probe), and vegetation height was also measured at regular intervals in each plot. In June 2006, and June 2007, the plant species present were recorded (along with percentage cover) within three randomly placed 1m x 1m quadrats per plot. Average species richness of the ground flora per m^2 was derived. Bare ground and basal litter percentage cover was assessed and recorded at the same time.

A typical vegetation plot (Lake Kalamba, termitaria late burn plot) is shown in Figure 2, and the layout of 15m x 15m treatment pots in termitaria habitat within Wasa I is shown in Figure 3.



1. Musola inlet
2. Kasanka B Camp
3. Lake Ndolwa
4. Chilengwa na Lese (sink-hole)
5. Musola R. (Kasanka confluence)
6. Kasanaka R. (Musola River confluence)
7. Kasanaka R.(pontoon)
8. Chicufwe (airfield well)
9. Luwombwa R.(Musande Camp)
10. Luwombwa Camp Borehole
11. Luwombwa R.(Main Camp)
12. Luwombwa R. (Yewe Camp)
13. Mulembo R. (Luwombwa confluence)
14. Kasanka R.(Mulemblo confluence)
15. Lake Wasa II
16. Lake Kalamba
17. Mulembo airfield well
18. Mulembo R. inlet
19. Mulaushi Stream (KRC)
20. Lake Wasa I
21. Wasa Camp Borehole
22. Mulembo R. (Chantete Camp)
23. Musola R. (Fibwe Hide Camp)
24. Wasa Camp Kitchen Well
25. Wasa Camp Garden Well
26. Kabwe Camp Well
27. Chitikilo Stream
28. Njelele Stream
29. KRL Well
30. Mpulumba Stream
31. Mpulumba Village Borehole
32. Njelele School Borehole 1
33. Njelele School Borehole 2
34. Chalilo Well
35. Lusenga Stream source
36. Chalilo School
37. Mpelelmbe School
38. Mapepela School
39. Mulembo Check Point

Figure 1 Map of Kasanka National Park (the boundary of which is shown by the solid grey line) showing sample locations within the park and KGMA, and location of Zambia in Southern Africa (© Crown copyright Ordnance Survey. All rights reserved).

Figure 2 Termitaria late burn plot (Lake Kalamba) photographed September 2006, prior to Late Burn treatment.

Figure 3 Aerial view of Wasa I dambo taken in August 2007 (Photo by James Byng) showing replicate termitaria plots (elipses: T1W1 above, T2W1 below). Early burn treatment plots are visible as grey blocks. Approximate locations of corresponding miombo and grassland plots are shown by square boxes.

Chapter Two: Characterisation of Large Scale Hydrology

2.1 Climatic and Hydrological Conditions

Temperatures have been monitored on an hourly basis at Kasanka Research Centre since October 2006. The monthly temperature averages are summarised in Table 1, while daily mean, minimum and maximum temperatures are shown in Appendix A. Temperature values were typical of the region, with minimum mean temperatures in June and July, and maximum temperatures in October and November. Average daytime temperatures between October 2006 and March 2008 ranged from 14 to 33°C. The maximum temperature recorded was 40°C in late November 2006 and 4°C in late August 2007 (see Appendix A).

Table 1 Average monthly temperatures (°C) recorded at Kasanka Research Centre

	2006	2007	2008
January	-	23.0	22.5
February	-	23.0	22.7
March	-	22.4	-
April	-	22.2	-
May	-	21.7	-
June	-	17.9	-
July	-	18.4	-
August	-	20.6	-
September	-	23.6	-
October	26.8	25.0	-
November	24.0	25.0	-
December	23.0	23.0	-

Precipitation has been routinely recorded at Wasa Camp since 1988, giving data for nineteen complete hydrological years (Figure 4). A high degree of variability between years can be seen, with all but four years (1992/93, 2001/02, 2003/04, and 2006/07) having rainfall well below the regional average of 1200mm. The rainfall at Wasa Camp during the 2006/07 wet season was the highest since 1988, at almost 1600mm.

Beginning in 2005, sites across KNP (and a few within KGMA) were instrumented for rainfall recording (see Figure 1 for sampling locations). Not all sites yielded reliable rainfall datasets in each year due to unexpected removal of camp staff.

The data collected has shown substantial spatial variability in rainfall across the park and peripheral locations within the Kafinda GMA, and also temporal variability between years (see Table 2). Data from all sites that were gauged from 2005 to 2008 show that rainfall is not uniform across the park, despite its relatively small size and flat topography. All sites gauged during 2005/06 received less than the regional average annual rainfall (1200mm), and all sites received above average rainfall during 2006/07, and 2007/08. The sites with the highest and lowest rainfall levels recorded also varied between years (Table 2).

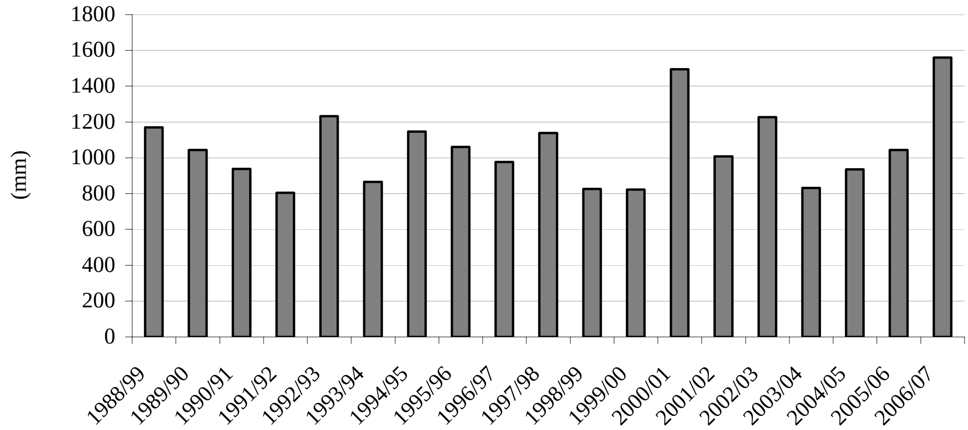


Figure 4 Yearly total rainfall Tables for Wasa camp, KNP, from 1988 to 2007.

Table 2 Yearly rainfall totals (mm) for gauged sites in KNP and KGMA. Tables in bold indicate highest and lowest Tables recorded during each wet season.

Site	**2005/06**	**2006/07**	**2007/08**
Chalilo School	-	1567	-
Chantete Camp	-	1519	**1762**
Chikufwe Airfield	**754**	1426	-
Mulembo Airfield	1062	1591	1302
Fibwe Camp	-	**1884**	1686
Kabwe Camp	-	1539	1515
Kafinda School	-	1609	-
Luwombwa Lodge	930	1567	1460
Mapepela School	-	**1382**	-
Mpelembe School	-	1606	-
Kasanka Research Centre	**1181**	1401	-
Mulembo Checkpoint	-	-	1661
Pontoon Camp	-	1529	1525
Wasa Lodge	1037	1560	**1352**

2.2 Hydrological and Hydrochemical Characteristics

A summarised overview of the major hydrological characteristics of the rivers, lakes and groundwater resources is given in Figures 5 to 10, and in Tables 3 to 9. Detailed results of monitoring are provided in Appendices B, C and D. The Luwombwa River is the largest in KNP, and has the largest catchment. It is therefore almost certain to have the greatest discharge. However, the western side of the park rapidly became inaccessible due to flooding following the onset of rains in 2007, and the river profiling exercise could not be completed. Of the rivers profiled, the Mulembo had the highest discharge and sediment load. Sediment loading (see Appendix B) is important in terms of maintaining floodplain fertility, and acts as a baseline from which to gauge future changes in river catchments (e.g. a rapid increase may indicate soil erosion from newly cleared areas of catchment). Sites that had river level gauges installed initially are indicated in Figure 1.

Although some boreholes were sealed, several sites allowed water levels to be measured, to show overall variability (Figure 11 and Table 10). The general overview is that some sites exhibit extreme variability and are highly responsive to rainfall (although this may be rainfall that infiltrates through the underlying rock), while other areas are far more stable.

In Figures 5 to 9, areas highlighted in green indicates probable zones of mixing between river channels and/or surface or groundwater, based on knowledge of flooding, hydrochemical characteristics, and existing vegetation maps.

2.2.1 River Characteristics

2.2.1a Kasanka River

The consistently high conductivity values suggest that there is a relatively large influence of groundwater input in terms of the dominant runoff source. The variability in alkalinity, but stability in oxygen isotope values shows that seasonal rainfall input is important, but recharge (i.e. water contributing to channel flow) from groundwater is a very important component year round. See Figure 5, Table 3, Appendix D.

Similar hydrochemical patterns are seen in adjacent groundwaters, but at lower values. This suggests that the local geology permits a relatively rapid percolation of new rainwater.

2.2.1b Musola River

The Musola is chemically the most variable river sampled, and as with the Mulembo, alkalinity and conductivity values increase greatly downstream. This increase comes after the river has passed through the Kapabi swamp, indicating that there is a large degree of interaction with the swamp, and substantial groundwater input. Seasonal variability in oxygen isotope values indicates that rainfall is also an important component of channel flow. See Figure 6, Table 4, Appendix D.

2.2.1c Luwombwa River

Consistently low conductivity and alkalinity values indicate that there is probably limited groundwater input into the river channel within the park, and flow is maintained to large degree by surface inputs from the wider catchment, upstream. Similar patterns of variability in groundwater (although to a much greater amplitude) suggest that there is limited exchange between groundwater and the Luwombwa river channel. However, river chemistry is susceptible to flushing from remobilised nutrients following dry periods (e.g. the onset of the 2005/06 wet season). See Figure 7, Table 5, Appendix D.

2.2.1d Mulembo River

The Mulembo river shows hydrochemical variability both along its length, and between seasons. Conductivity and alkalinity both increase downstream, probably due to interaction with the Kasanka main channel, and with surrounding floodplain swamps. However, variability in oxygen isotope data indicates an importance dilution by rainwater during the wet season, and possible enrichment by evaporation, especially at the Fibwe site (the location of the weir) during the dry seasons. See Figure 8, Table 6, Appendix D:

2.2.1e Mulaushi Stream and tributaries

Generally low conductivity and alkalinity values, interspersed with rapid increases during the wet season (especially during the 2005/06 wet season, which followed an extended dry season) characterise the Mulaushi stream and other tributaries flowing into it. This coupled with little similarity between the channel water chemistry and nearby groundwater deposits indicate that these rivers are largely reliant upon rainwater to contribute to their flow. See Figure 9, Table 7, Appendix D.

2.2.2 Lake Characteristics

The chemistry of the lakes in KNP is generally far less variable than for the rivers. While the larger waterbodies (e.g. Lake Ndolwa) appear to have a high groundwater input helping to sustain levels, smaller bodies such as Kalamba and Wasa I appear to be more reliant on rainfall to aid recharge (e.g. see Figure 12). There also appears to be quite a high degree of similarity between Lake Wasa I and Lake Kalamba, suggesting subsurface connectivity and/or common inputs from groundwater. See Figure 10, Table 8, Appendix D.

2.2.3 Groundwater Characteristics

The locations of groundwater sampling sites (wells and boreholes) are indicated in Figure 1, and the main characteristics are summarised in Table 9 and Appendix D. Given the nature of the spacing of the sites (non systematic in their layout, and often distant from each other) they provide an insight into possible interaction between river channels, lakes and other surface waterbodies, with groundwater. The sampling did not allow groundwater flow to be fully characterised: the use of injected chemical tracers and sampling from systematically aligned boreholes would be required for this.

While water levels are quite variable (Figure 11 and Table 10), generally, groundwater chemistry is very stable, and alkalinity values are generally high, suggesting relatively long residence times of water in groundwater aquifers. However, in certain instances residency time appears to be shorter, and groundwater inputs into rivers relatively high, suggesting more permeable localised geological deposits (e.g. Kasanka River at Kabwe Camp, where groundwater levels have fluctuated by more than 10m: Table 10).

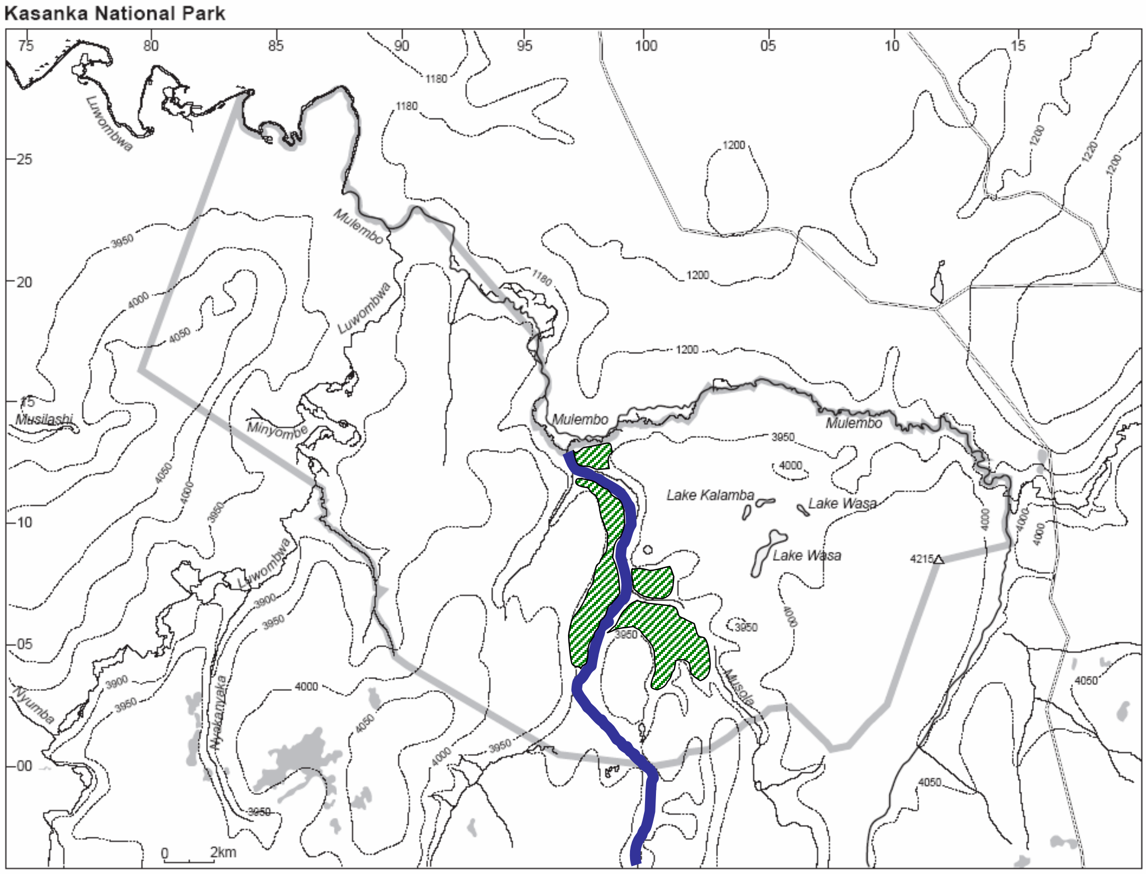


Figure 5 Location of Kasanka River in KNP, indicated in blue. Green hashed areas indicate probable river-floodplain interactions (i.e. movement of water between floodplains and river channel in both directions), and/or groundwater input`(© Crown copyright Ordnance Survey. All rights reserved).

Table 3 Summary of Kasanka River properties between May 2005 and January 2008

Properties	Comments and Interpretation
pH	- Relatively stable between 7 and 8; - Less alkaline following 2005/06 wet season, with recovery into 2006.
Conductivity	- High, relative to other major rivers in KNP, along entire length; - Peak in values following onset of 2005 rainfall from flushing of solutes accumulated during dry season.
Alkalinity	- High, relative to other major rivers in KNP, along entire length; - Rapid seasonal dilution during rainfall period; gradual increase through dry season.
Isotopes	- $\delta^{18}O$ values generally become depleted during wet season, indicating importance of direct rainfall inputs also.
Groundwater	- Similar seasonal hydrochemical patterns observed in adjacent groundwaters.
Surface interaction	- Evidence of channel interaction with surrounding land. Year round to varying degrees.
Other	- Interaction with Mulembo at confluence, indicated by dilution downstream.

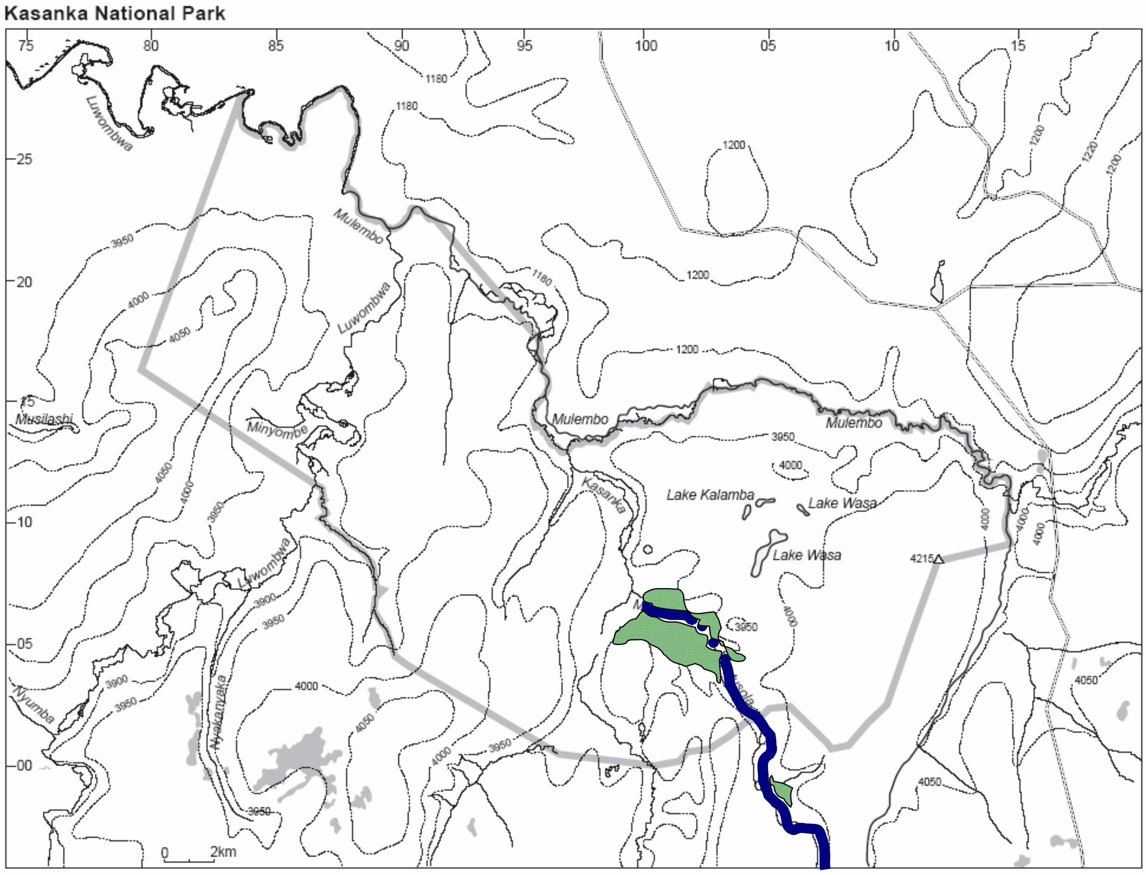


Figure 6 Location of Musola River in KNP, indicated in blue; breaks indicates undefined, multiple channels within *Carex papyrus* swamp. Green hashed areas indicate probable river-floodplain interactions (i.e. movement of water between floodplains and river channel in both directions), and/or groundwater input (© Crown copyright Ordnance Survey. All rights reserved).

Table 4 Summary of Musola River properties between May 2005 and January 2008

Properties	**Comments**
pH	- Variable (between 6 and 7.5); - pH drops at mid sample point (Fibwe) then increases again close to confluence with Kasanka River.
Conductivity	- Relatively low at two upstream sample points. - Increases at downstream sample point close to Kasanka confluence and temporal patterns resemble those for Kasanka River, suggesting mixing between channels.
Alkalinity	- Generally much lower than the Kasanka (more comparable to other large rivers). Site near Kasanka confluence more similar to Kasanka channel, but values are even higher, suggesting groundwater input and/or surface interaction within papyrus swamp in addition to mixing.
Isotopes	- $\delta^{18}O$ values relatively consistently suggesting mixed water source input, but indicating increased rainwater influence into 2007 wet season.
Groundwater	- Evidence of groundwater contributing substantially to flow.
Surface interaction	- Strong evidence of channel interaction with surrounding land, especially within papyrus swamp.
Other	- Strong evidence of mixing with Kasanka river close to confluence.

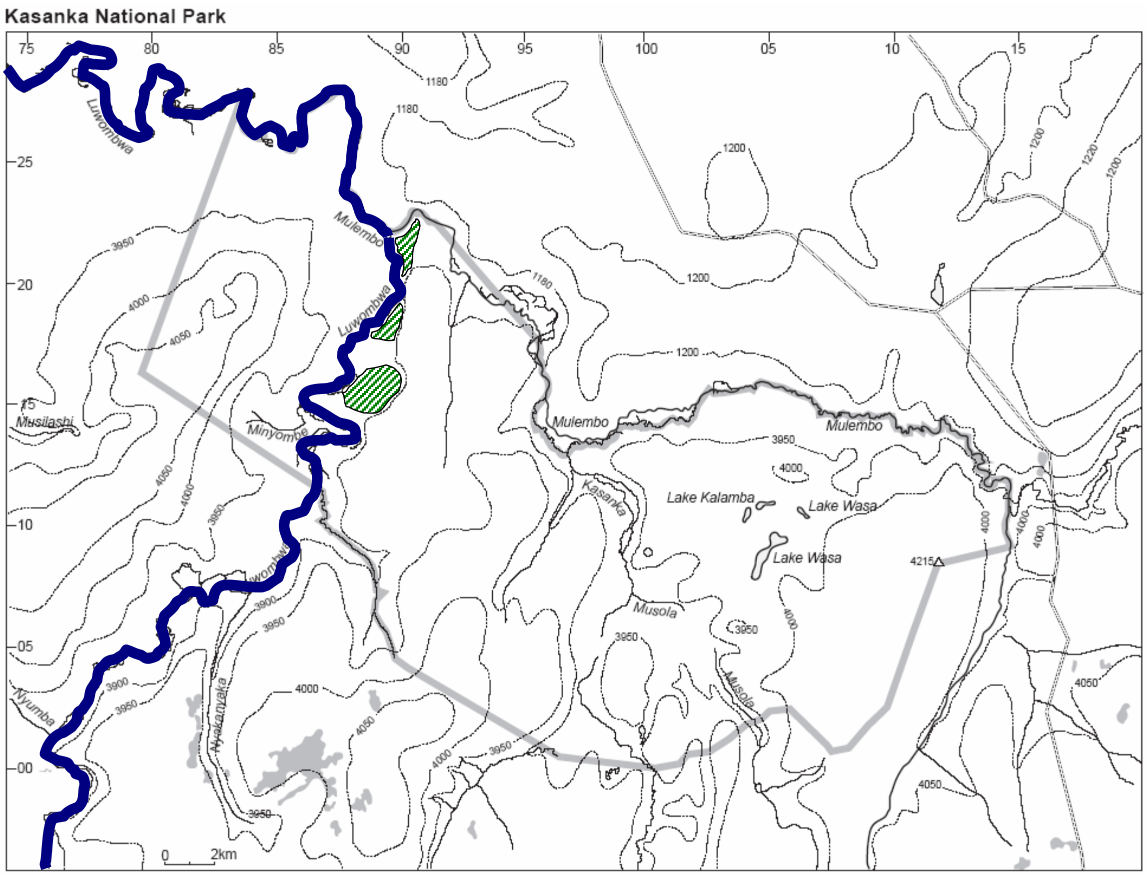


Figure 7 Location of Luwombwa River in KNP, indicated in blue. Red arrows indicate possible localised groundwater input to channel; Green hashed areas indicate probable river-floodplain interactions (i.e. movement of water between floodplains and river channel in both directions), and/or groundwater input (© Crown copyright Ordnance Survey. All rights reserved).

Table 5 Summary of Luwombwa River properties between May 2005 and January 2008

Properties	Comments
pH	- Relatively stable between 7 and 8; - Lower pH following 2005/06 wet season, with recovery into 2006.
Conductivity	- Low along entire length and relative to other rivers in KNP; - Slight, increase following onset of 2005 rainfall. Not sustained
Alkalinity	- Low along entire length and relative to other rivers in KNP;
Isotopes	- Variability in $\delta^{18}O$ values, suggesting predominantly surface water influence during wet season.
Groundwater	- Evidence of only very limited groundwater interaction, limited to seasonal flushing of groundwaters (and pH dependant metals) in wet season.
Surface interaction	- Probably limited to occasional seasonal floodplain inundation.

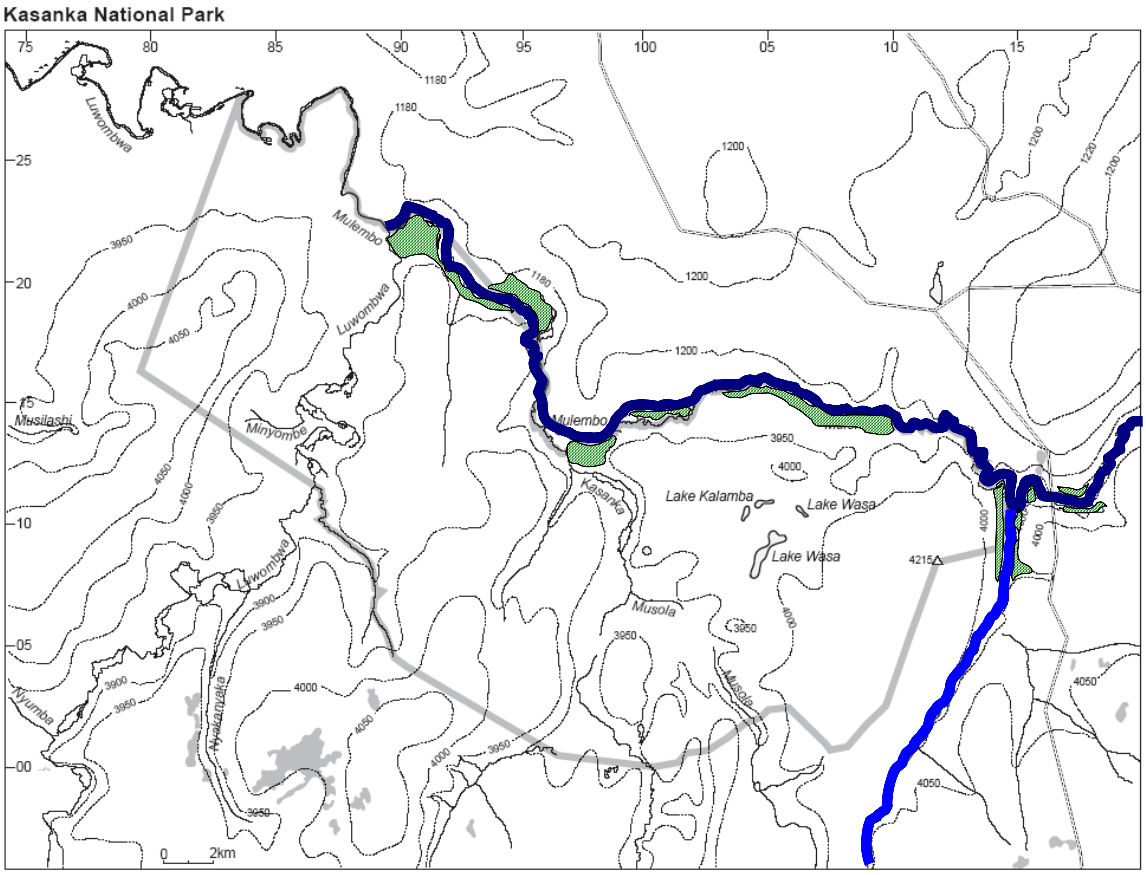


Figure 8 Location of Mulembo River in KNP, indicated in dark blue (and Mulaushi Stream in lighter blue, running north-south). Green hashed areas indicate probable river-floodplain interactions (i.e. movement of water between floodplains and river channel in both directions), and/or groundwater input ((© Crown copyright Ordnance Survey. All rights reserved).

Table 6 Summary of Mulembo River properties between May 2005 and January 2008

Properties	Comments
pH	- Greatest variability of all major rivers sampled (between 6 and 8.5); downstream sample site (before confluence with Luwombwa) most variable; - More acidic conditions following 2005/06 wet season, with recovery into 2006. Same response in 2006/07 wet season, but less pronounced.
Conductivity	- Low at first two sample locations. Higher (up to three times) at downstream (Luwombwa confluence) sample point. - General increase in values, followed by dilution into wet season.
Alkalinity	- Relatively high, indicating groundwater input (or interaction with surface water/soils). Temporal and spatial variability comparable to conductivity.
Isotopes	- $\delta^{18}O$ values variable, suggesting groundwater influence. Increase in rainwater component apparent in 2006/07.
Groundwater	- Evidence of variable inputs relative to season and level of rainfall.
Surface interaction	- Possibly some limited interaction upstream (though floodplain inundation in wet season). Much greater interaction apparent near Luwombwa confluence.
Other	- Similar temporal hydrochemical characteristics exhibited by Mulaushi stream, suggesting some channel mixing, and/or shared groundwater.

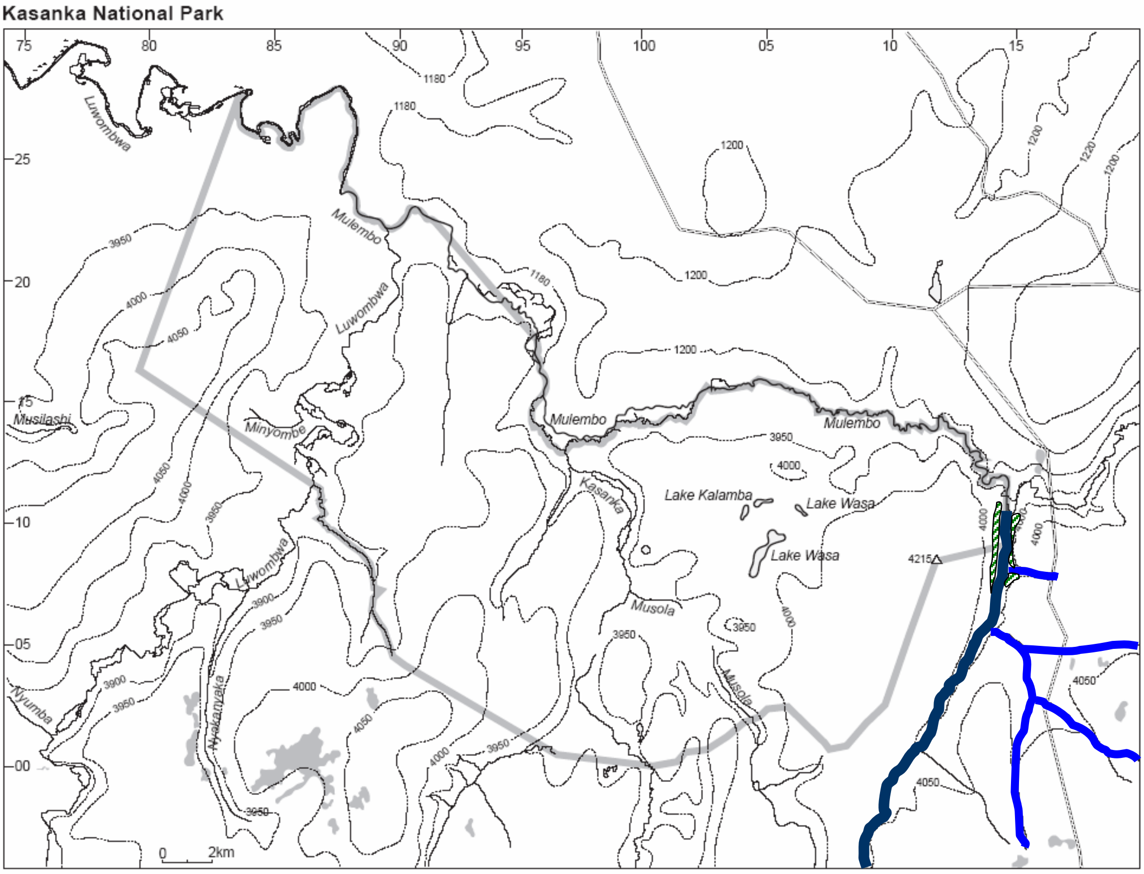


Table 9 Location of Mulaushi Stream and tributaries in KNP, indicated in blue. Green hashed areas indicate probable river-floodplain interactions (i.e. movement of water between floodplains and river channel in both directions), and/or groundwater input ((© Crown copyright Ordnance Survey. All rights reserved).

Table 7 Summary of Mulaushi Stream and tributary properties between May 2005 and January 2008

Properties	Comments
pH	- Very variable, between 5.4 and 8.7. - Strong seasonal influence (especially from rainfall).
Conductivity	- Variable, but generally low relative to larger rivers
Alkalinity	- Generally low. - Highest in Mulaushi stream during set season, probably due to influence of main Mulembo channel.
Groundwater	- Hydrochemical characteristics quite distinct form nearby groundwater samples, suggesting that these smaller streams are predominantly rain fed.
Surface interaction	- Limited to localised wet season flooding
Other	Flow is very seasonal, and response to rainfall rapid, further indicating than majority of flow is derived from rainfall.

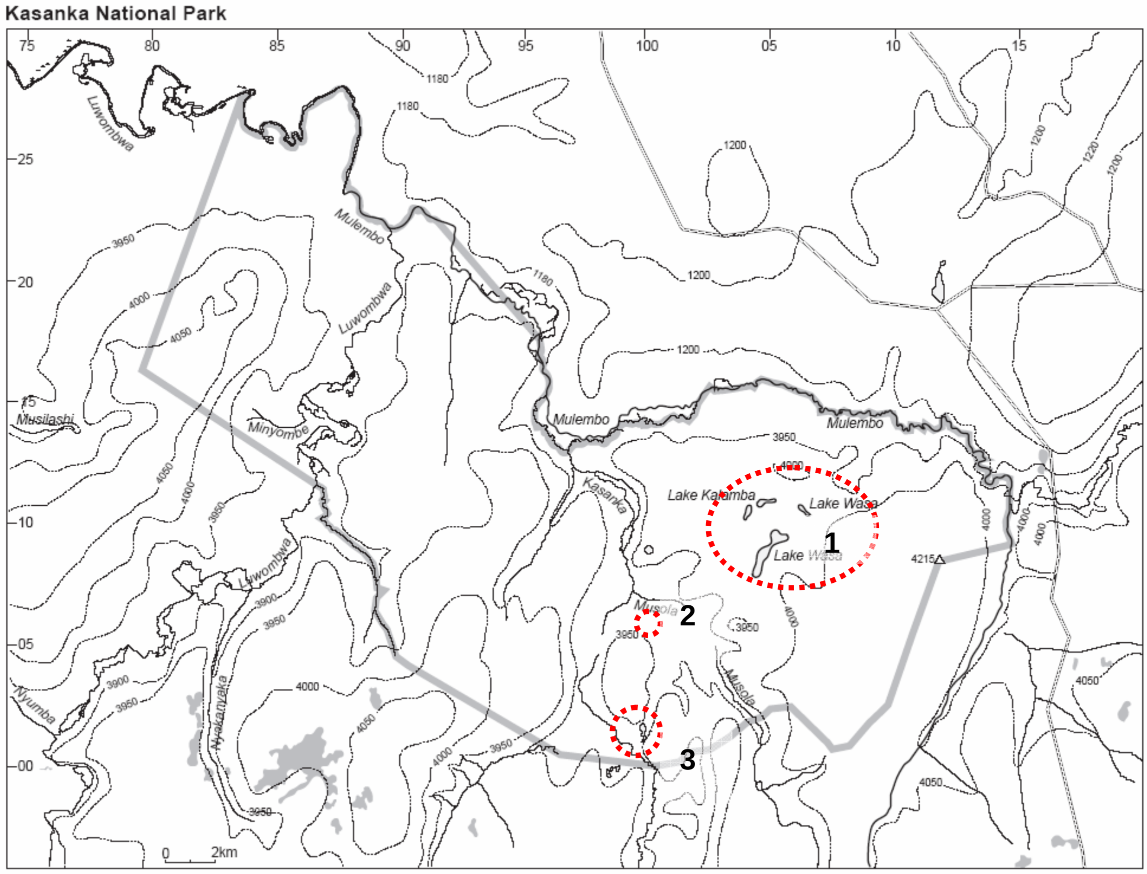


Figure 10 Location of Lakes sampled (circled in red). 1 = Kalamba, Wasa I and Wasa II complex, 2 = Chilengwa na lese, 3 = Lake Ndolwa (© Crown copyright Ordnance Survey. All rights reserved).

Table 8 Summary of Lake properties between May 2005 and January 2008

Properties	**Comments**
pH	- More stable between years and less variable overall, than rivers. - Chilengwa na lese most acidic; Ndolwa most alkaline. - Kalamba, Wasa I and Wasa II generally circumneutral.
Conductivity	- Relatively low overall; - Greatest variability in smaller waterbodies between years, suggesting large influence of water flushing catchment surface. - Peak in values following onset of 2005 rainfall.
Alkalinity	- Generally highest in Ndolwa and Chilengwa na lese, suggesting a high groundwater component. - Wasa II highly variable, suggesting a sustained groundwater input, supplemented by rainfall recharge (and a flushing of nutrients and or groundwater into the open water following rainfall) - Lowest, and most similar in Kalamba and Wasa I. - Probable localised geological differences.
Isotopes	- $\delta^{18}O$ values generally higher than for rivers, but variable, suggesting mixed groundwater and rainwater influence. - Strong influence of evaporation (shown by enrichment) during dry season. - Kalamba and Wasa I show very similar characteristics for a large proportion of the time.

Table 8 (continued)

Properties	Comments
Groundwater	- Similar seasonal hydrochemical patterns observed in adjacent groundwaters, suggesting a strong influence of groundwater in sustaining lakes, especially during dry season.
Surface interaction	- Only localised flooding and interaction with surface soils - Probably a good degree of sub-surface connectivity between Kalamba and Wasa I.
Other	- Good evidence of larger lakes (e.g. Ndolwa) being buffered from large hydrochemical changes. - Evidence of smaller lakes (e.g. Kalamba) shrinking during dry periods, and being very reliant on rainfall for recharge. - Kalamba and Wasa I show the greatest similarity, indicating common hydrological inputs, or a high level of sub-surface connectivity.

Table 9 Summary of groundwater properties between May 2005 and January 2008

Properties	Comments
pH	- Generally very stable - Kabwe camp well relatively variable, suggesting surface water inputs or rapid recharge.
Conductivity	- Borehole values generally high, and open well values lower and more variable - Some response seen in most sites to 2004/05 rain, and remobilisation of nutrients, showing that rain-fed recharge does occur.
Alkalinity	- Similar characteristics to conductivity between sites, indicating that open wells recharge from rain, and the lag time is much less than for deeper boreholes.
Isotopes	- $\delta^{18}O$ values consistently low in all sites, suggesting any infiltration of rainwater into groundwater aquifers is relatively slow.
Other	- Some sites such as Kabwe camp well are hydrochemically variable, suggesting that there might be two way lateral movement between the groundwater and river water (Kasanka), and/or a relatively rapid rainwater infiltration (probably localised permeable geology)

Table 10 Mean, maximum and minimum groundwater depths below ground level (cm), November 2005 to February 2008

Site	Mean	*n*	*SD*	Max.	Min.
Chikufwe Airfield (Well)	-550	*24*	222	-148	-806
Mulembo Airfield (Well)	-826	*24*	428	-92	-1270
Wasa Lodge Kitchen (Well)	-313	*25*	221	-57	-785
Wasa Lodge Garden (Well)	-158	*25*	132	30	-380
Kabwe Camp (Well)	-693	*20*	388	-21	-1085
Njelele School 1 (Borehole)	-628	*8*	182	-361	-879
Kasanka Research Centre (Well)	-710	*4*	313	-241	-888

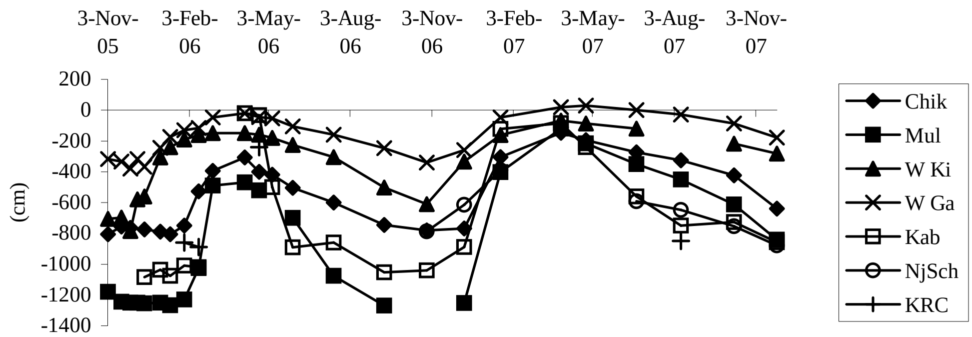


Figure 11 Groundwater depth (cm) relative to surface datums for wells. Chik = Chikufwe airfield; Mul = Mulembo airfield; W Ki = Wasa camp, Kitchen well; W Ga = Wasa camp, Garden well; Kab = Kabwe camp; NjSch = Njelele School Borehole 1; KRC = Kasanka Research Centre.

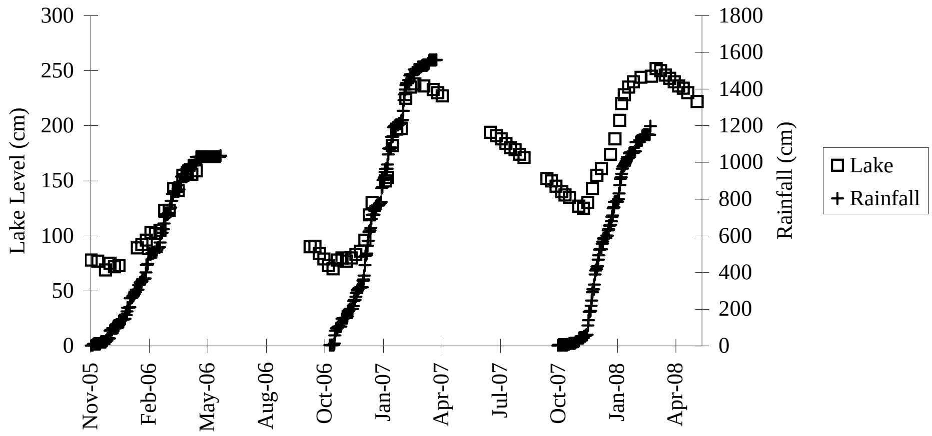


Figure 12 Lake Wasa 1 water level (cm) (relative to datum) and cumulative precipitation at Wasa Camp (November 2005 to May 2008).

Chapter Three: Experimental Plot Characteristics, and Effects of Burning

3.1 Soil and Vegetation Characteristics in Target Habitats

3.1.1 Floristics

The 85 plant species recorded (and which could be identified) within each combined set of treatment plots in each habitat are listed in Appendix E (e.g. Table E1, column one, represents all species recorded in the Lake Kalamba miombo woodland, in the control, early burn and late burn plots combined for both 2006 and 2007). The plots had only been subjected to one set of fire treatments by the time the 2007 samples were taken, and species complement would not be expected to change so quickly (although relative abundances might). Therefore, Table E1 provides a starting point from which to monitor future change. It will be more useful to assess long term impacts of relative treatments in future years by re-surveying all plots, and comparing to the original and 2006 datasets per plot. Table E1 only represents those species that could successfully be identified following visits to the Zambian National Herbarium in Kitwe, although this was a majority of the samples taken.

Table E2 (Appendix E) lists the canopy species recorded within each of the respective miombo habitat treatment blocks.

Average species richness per habitat type for ground layer species is greatest (almost three times so) amongst miombo sites, but the variability is also greatest in miombo. Average species richness is equivalent in termitaria and grassland, but slightly more variable in termitaria (Table 11a). Species richness of canopy trees is also variable, with species richness being highest in the Wasa I miombo plots, and lowest in one of the Wasa II plots (Table 11b).

Table 11 Number of species identified and recorded per habitat type. (a) Ground layer species (including tree saplings <20cm) per habitat type for all sites combined, June 2006 and June 2007; (b) Canopy tree species sampled and identified per miombo habitat site. K = Kalamba; W1 = Wasa 1, W2 = Wasa 2.

(a)

Habitat	Mean	Max	Min
Miombo	27	32	24
Termitaria	10	15	6
Grassland	10	14	7

(b)

Site	Mean	Max	Min
K1	7	9	4
1 W1	12	13	8
2 W1	12	13	11
1 W2	8	10	5
2 W2	4	4	3

3.1.2 Soil Moisture

Soil matric potential (whereby a more negative reading in millibars indicates dryer soils) was measured at depths of 30cm, 60cm and 90cm below ground in dambo edge sites at Wasa Camp and Kasanka Research Centre between March 2006 and December 2007 (Appendix F, Tables F1 and F2). It was also measured in association with treatment plots in Wasa I (Appendix F, Table F3). Within Wasa I grassland habitat tended to have the greatest variability over depth, with soil tending to be damper at a depth of 30cm and dryer at a depth of 90cm, but was the wettest habitat type overall. Termitaria and miombo were more similar in terms of moisture level, and both dried out relatively quickly following the end of the 2006/07 rains (Table 12). However, the rate of drying in miombo was much faster, indicating that the miombo habitat is probably water limited for large periods of the year (See Appendix F, Table F3).

Surface soil moisture was also recorded in each individual treatment plot (see Appendix F, Table F4), but will be discussed further in section 3.1.3, in relation to effects from burning treatments imposed.

Table 12 Summary of tensiometer matric potential readings (Mb) for grassland, termitaria and miombo habitats in Wasa I (October 2006 to October 2007).

Habitat	Depth (cm)	Mean (Mb)	*Sd*	Maximum (Wet)	Minimum (Dry)
Grassland	30	-9	15.0	0	-63
	60	-11	19.3	0	-72
	90	-19	26.9	0	-76
Termitaria	30	-25	22.9	-0.5	-66
	60	-29	27.7	0	-78
	90	-34	29.2	0	-74
Miombo	30	-30	29.1	0	-100
	60	-38	29.6	-3	-79
	90	-36	30.0	0	-74

3.1.3 Effects of burning on vegetation characteristics and Grazer Utilisation

A number of vegetation structural and biomass related variables were monitored within the treatment plots. For all variables the data were analysed to look for any significant different differences amongst treatments, habitats, date and their interactions. Tests for accumulated biomass and grazer offtake did not have a time component, as the data was accumulated from several sampling sessions (Appendix G). One termitaria late burn plot dataset (T1W2) was excluded from the analysis as it was accidentally burned early in the season. All grassland early burn and late burn plot data was excluded from tests after the early burn period for 2007 as water levels were still too high to burn during that year. However, Figures 13 to 15 show all data, to give an impression of patterns in the vegetation where they had different treatments in the preceding year.

For the purposes of informing management with regards to the timing of burning, the main effect of **Treatment** is of most interest, along with interactions between treatment and habitat, as this indicates whether early burning, and/or late burning, and/or no burning have significant impact on vegetation characteristics (e.g. reducing or increasing biomass). However, significant differences between habitats, dates, and their interactions also need some consideration (e.g. do soils in certain habitat types become water limited more rapidly during the dry season, and will this make the habitat more susceptible to damage by late fires?). The results of the statistical tests are shown in Appendix G (Tables G1 to G6), and plots for the variables that differed significantly in relation to burning treatment are presented in Figures 13 to 15.

Soil Moisture varied significantly between all habitat types, with miombo being driest, termitaria being intermediate and grassland being wettest. There was no treatment effect. There was also a significant time effect, with all sites drying out significantly during the dry season. There was a significant habitat*time effect with seasonally wet grassland remaining significantly wetter than either miombo or termitaria into the dry season during both 2006 and 2007.

Litter cover did not vary between habitat type, in relation to treatment, or between years.

Bare ground varied between habitat type, with percentage bare ground significantly lower in miombo than in either termitaria or grassland. There was no treatment effect.

Vegetation height:
- was significantly higher overall in termitaria;
- was significantly reduced by both early burn and late burn treatments in comparison to no burn control (i.e. any burning significantly reduces cover);
- significantly declined in all cases between April (late wet), August (post early burn), and October 2006 (post late burn).
- both early burn and late burn significantly reduced vegetation height in termitaria, but not in miombo or grassland.

Standing crop, live biomass, **dead biomass** and **live to dead ratio** was significantly different between all habitats, with the highest values for termitaria and the lowest for miombo.

Live biomass and **dead biomass** only were significantly influenced; early burn significantly reduced both in the early season.

Between **April, September** and **December 2006**, across all habitat types, total **standing crop** significantly decreased, whilst **live biomass** and **dead biomass both** significantly decreased and then increased again (indicating rapid response to early wet season rain coupled with senescence: For the dead biomass component to increase during this period, some senescence must already have occurred by December).

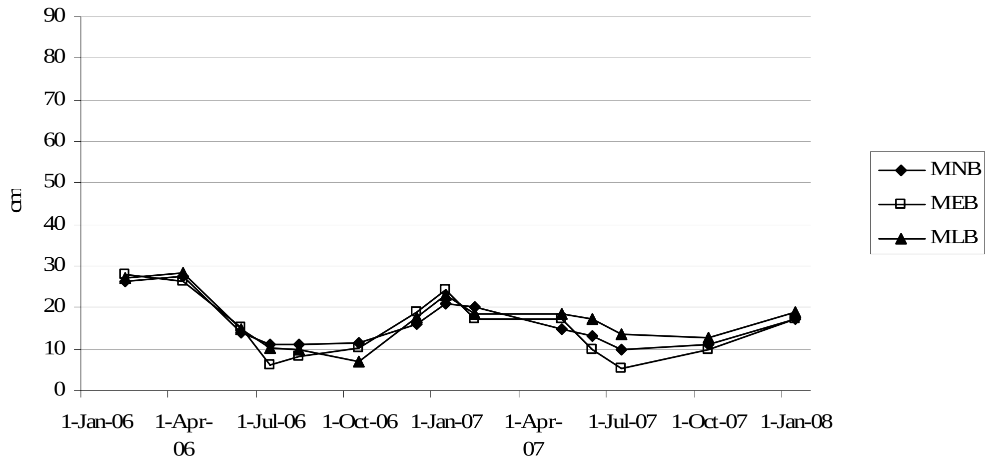
Dead biomass was significantly reduced with both early and late burn treatments in termitaria, and by early burn alone in grassland (i.e. habitat treatment interaction)

There were no significant differences between habitat types, or in relation to treatment for **accumulated biomass** calculated for the period September 2006 to May 2007 (a period encompassing the wet season response, following the implementation of both early burn and late burn treatments in 2006). However, when calculated between September 2006 and December 2006, **accumulated biomass** was significantly lower in miombo than in the other habitats. This indicates that miombo ground flora might respond more slowly to early rainfall than either termitaria or grassland habitats.

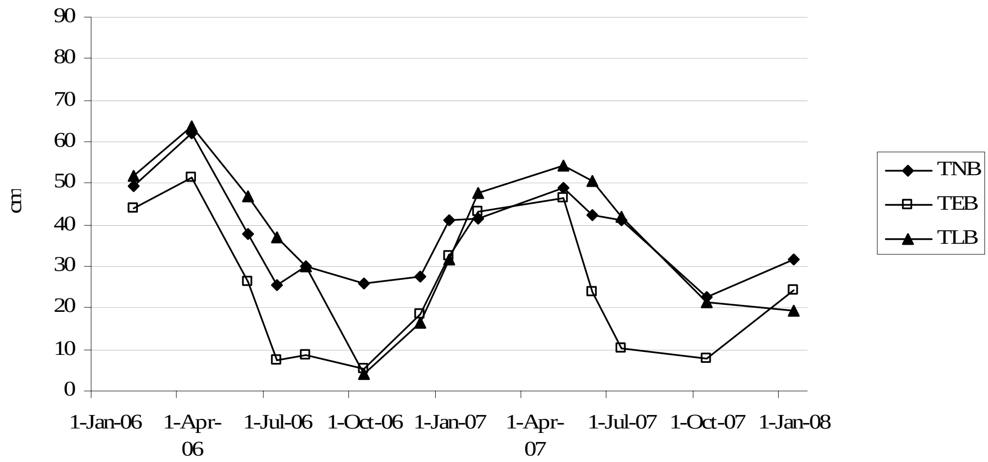
Accumulated offtake did not differ significantly in relation to Habitat type or treatment.

- **Any treatment effects which were observed as a result of early or late burning did not persist into the second year (i.e. effects of treatments carried out during the 2006 dry season were not detected following the onset of rains during the 2006/07 wet season).**

(a)



(b)



(c)

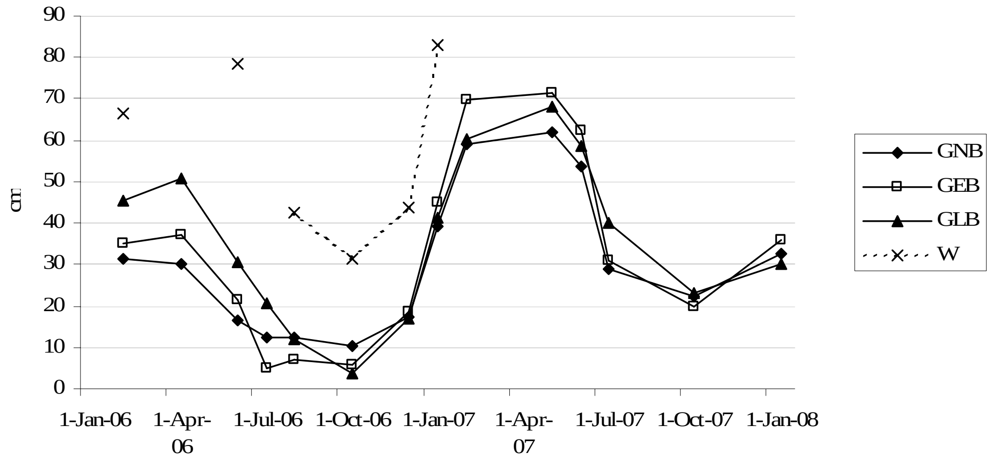


Figure 13 Mean vegetation height (cm) across treatment plots. (a) Grassland; (b) Termitaria; (c) Grassland (W = Permanent wetland plots). NB = No burn; EB = Early burn; LB = Late burn.

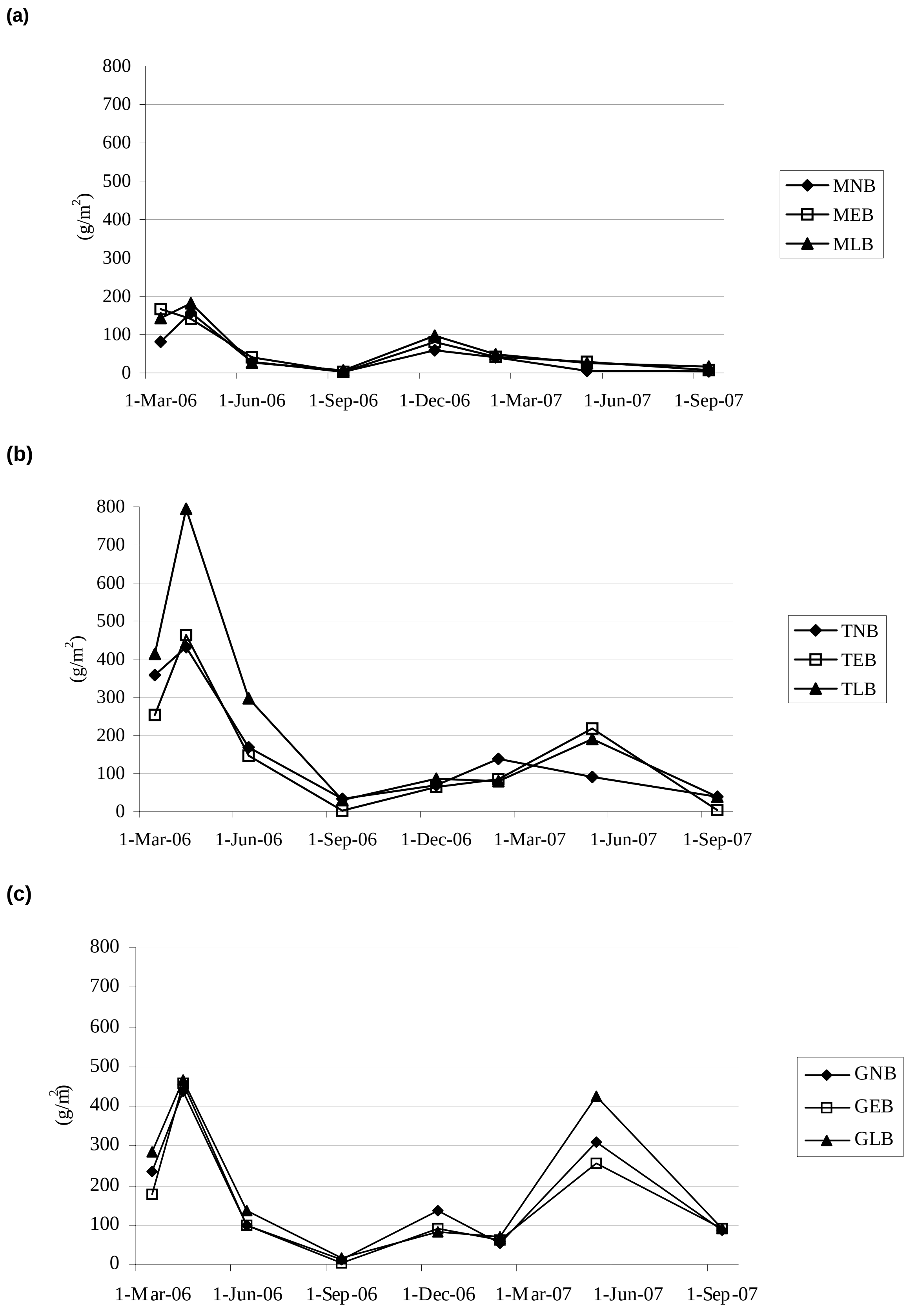
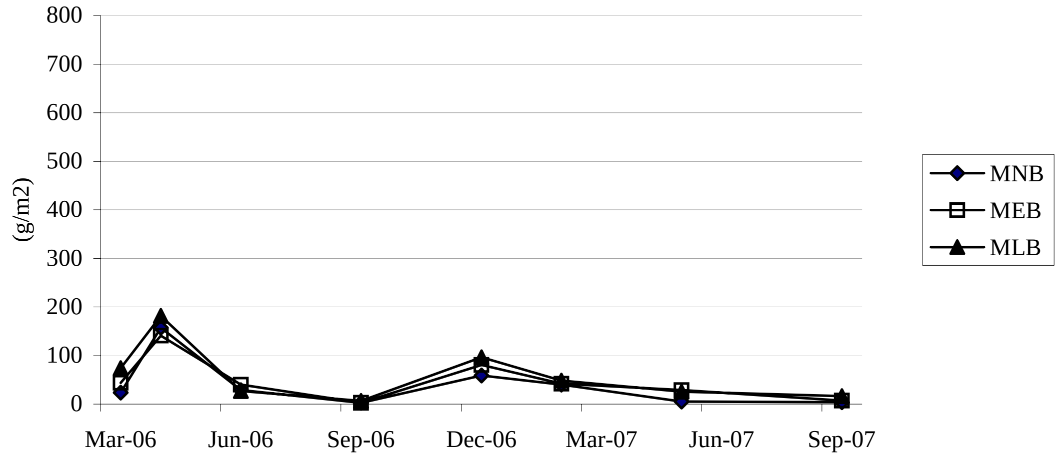
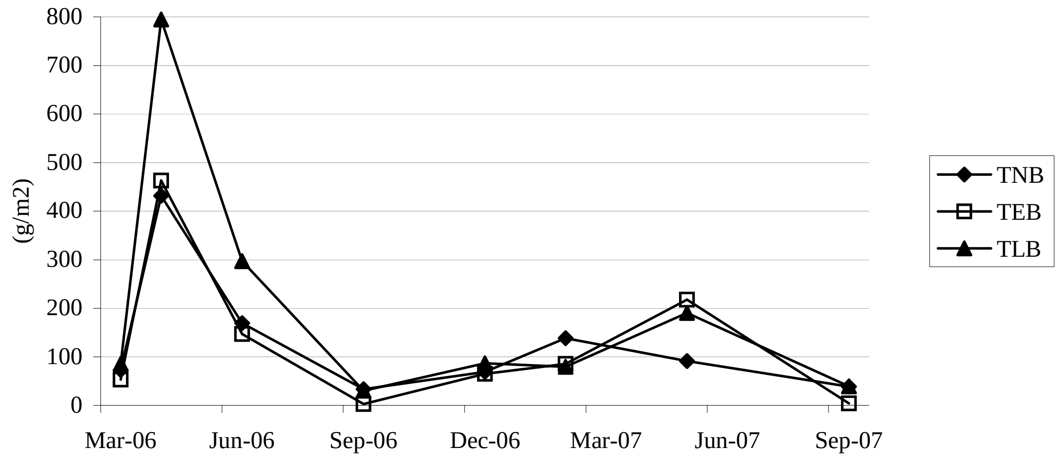


Figure 14 Mean live biomass (g/m^2) across treatment plots. (a) Grassland; (b) Termitaria; (c) Grassland. NB = No burn; EB = Early burn; LB = Late burn.

(a)



(b)



(c)

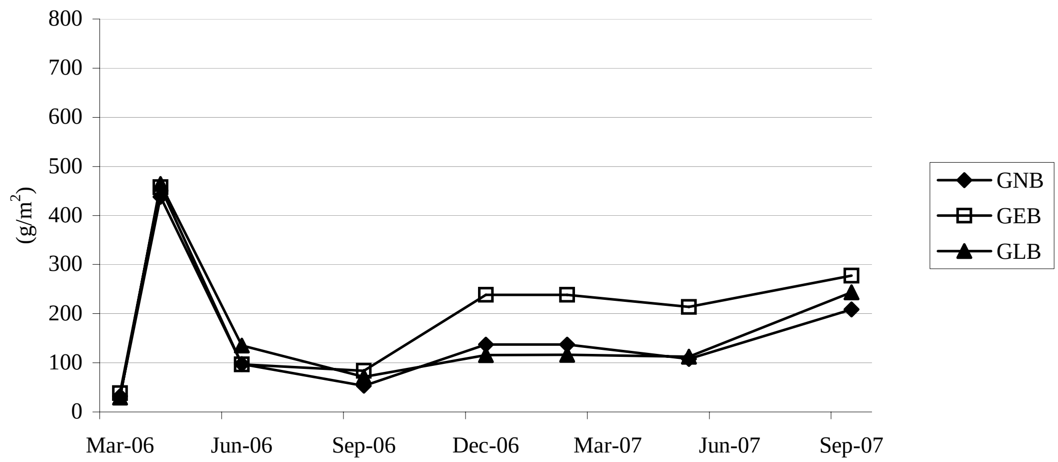


Figure 15 Mean dead biomass (necromass) (g/m^2) across treatment plots. (a) Grassland; (b) Termitaria; (c) Grassland. NB = No burn; EB = Early burn; LB = Late burn.

Evidence of vegetation becoming more structurally complex over time in relation to burning regime can be seen in Figure 16. Figure 16a shows a section of chipya woodland at KRC which has not been burned for at least 4 years, to a nearby area of chipya (just outside of KRC) which was early burned in 2007 (Figure 16b). Note the predominance of *Hypharrenia* spp. in the more recently burned plot (16b) and the greater abundance of low-lying shrubs, and less *Hypharrenia* spp. in the unburned section (16a).

(a)

(b)

Figure 16 (a) Chipya understorey KRC not burned for at least 4 years; **(b)** Chipya understorey near KRC burned early in previous dry season (2007).

3.2 Hydrology and Burning Interaction

The scope of the study did not make it possible to carry out detailed studies of interaction between burning and key hydrological and biogeochemical responses (e.g. relative rates of chemical transport through soils following early or late burning). Such studies would be very worthwhile. For example, providing appropriate buffer zones could mitigate effects of increased nutrient loading into water. However, this would require intensive instrumentation and facilities for broad-spectrum water nutrient and anion analysis.

Investigations using a surface soil moisture probe gave some evidence of deeper soil water being drawn to the surface by hotter, late fires in all habitat types. However, the effect was limited, and our continued use of the moisture probe showed that there was no significant ongoing effect.

Chapter Four: Recommendations for Management

4.1 Current Water and Fire Interventions in KNP and their Implications

The current general approaches to hydrology and fire management are discussed in Chapter 1, but are reiterated here to give focus to management recommendations in the light of the results outlined in Chapters 2 and 3.

The main hydrological interventions in KNP are:

- Digging of furrows within the Wasa dambo complex.

- Installation of a stone weir on the musola stream close to Fibwe camp.

Early burning of grassland and woodland areas has been carried out in KNP since at least 1986. The aim has been to protect woodland and grassland habitats from late, hot fires, with the general sequence being:

- **May:** Open grassland areas to enable only partial burning.
- **June:** Open dambos.
- **July:** Chipya and wet dambos.
- **July and August:** Miombo with short field layer

4.2 Hydrological Findings and Implications for Management

Despite the small size of KNP, plus its relatively flat topography and uniform geology, the hydrological inputs into the freshwater systems are varied and complex.

- All of the wetland habitats are vulnerable to drying as a result of reduced or changing rainfall patterns. This would pose the greatest threat to the integrity of the major wetland habitats of KNP.

- The Kasanka and Musola rivers, which are important in sustaining water levels in the largest areas of papyrus swamp, have high levels of groundwater input and extensive surface interaction, and therefore need protection.

- All dambos and dambo lakes, but especially smaller ones such Kalamba are seasonal wetlands, and recharge from precipitation is important. They will shrink during dry periods, but this is a natural phenomenon.

4.2.1 Threats to Hydrological Functioning

The hydrological monitoring has allowed an overview of the large scale hydrological processes operating in KNP and KGMA at the river basin scale, and have shown that these processes are strongly driven by the climate (i.e. rainfall).

In reality the main threats to freshwater wetland ecosystems in KNP come from outside the park. However, uncontrolled fire encroaching into fragile but key habitats (e.g. Papyrus swamp and Mushito forest), could also be a threat, especially when rainfall levels have been low for several subsequent years and soil-water and groundwater reserves are diminished.

4.2.1a Current Management Practices in KNP

The presence of man-made furrows is very localised to the Lake Wasa I and II area, and is unlikely to have negative impacts on the overall hydrological balances of KNP.

- There is concern that following heavy rainfall, the furrows might be depositing sediment into Lake Wasa I at an increased rate, and possibly speeding up succession from open water to swamp.

- There is no evidence that nutrient enrichment is occurring in the lake as a whole as a result of the furrows.

The weir in the Kapabi swamp at Fibwe camp is likely to be beneficial during very dry periods (e.g. prior to the 2005/06 wet season), by extending flooded areas and protecting swamp habitat adjacent to the Musola River.

- There is no evidence that the presence of the weir unduly affects downstream hydrochemistry.

- Large areas of peat in the floodplain (generally more than 300m from the river channel) were burned out in 2005 by a peat fire, showing that the influence of the weir is localised under extreme dry conditions.

- During above average rainfall years the weir is overtopped by floodwater for up to several weeks, highlighting the importance of the structure during low rainfall years only.

- Larger dams downstream on the Musola or Kasanka Rivers would not be beneficial. Continually deep water would threaten the nature of the swamp, and might lead to an expansion of 'seepage' and 'estuarine' mushito (see section 1.1.3), which has lower species diversity and is less preferential as roosts for fruitbats.

4.2.1b Impacts from the KGMA

The main potential threats to the integrity of the hydrology and important wetland habitats in KNP relate to possible activities outside of the park. However, at the time of writing, the details relating to the possible establishment of a farming block beyond the southern boundary of KNP are still unclear.

- **Damming** of the Luwombwa River upstream of the park could have several impacts if it is ever carried out on the main channel. These could include:
  - (i) A reduction of nutrient input into floodplain areas adjoining the river via sediment deposition and water recharge (i.e. floodwater in the floodplain percolating into underlying geology).
  - (ii) A damping off of natural flood pulses during the wet season that can keep riverbeds clear of excessive sediments and provide suitable habitat for invertebrate and fish species.
  - (iii) A loss of backwater habitats (distributaries) which act as refugia for spawning fish.

- **Damming** of the Kasanka and Musola Rivers could decrease water levels in the wider area of the papyrus swamps during wet periods and make them more susceptible to fire in the dry season.

- **Intensive farming** using artificial fertilisers may cause nitrate and phosphate pollution from overland flow, and potentially long term through infiltration into the groundwater.

- **Abstraction** of groundwater and surface water on a commercial scale for irrigation of crops could limit input of water into key freshwater habitats in KNP.

4.3 Burning Findings and Implications for Management

4.3.1 Impacts of The Timing of Burning

The early burning approach that has been followed to date is unlikely to have been detrimental to soil properties or vegetation structure, or to have compromised localised water conservation, except in those instances where it has been allowed to encroach on fire sensitive habitats such as papyrus swamp, following prolonged dry periods.

- The strongest effects on standing crop and biomass production were in relation to habitat type, and not as a result of treatment.
    - The study was carried out during a particularly wet period, and this may not hold true during drier periods.
- In miombo woodland, early burning was associated with a greater (though not quite statistically significant) net primary production during the subsequent growth season, than in unburned or late burn miombo. This was not evident in termitaria or grassland habitat.
    - Again, this might not be the case under drier conditions.
- Extensive early burning removes a large proportion of above ground (dead) biomass for a large period of the year (for up six months). Therefore, physical habitat (e.g. shade, cover and nesting material) for grazers, birds, insects and other animals will potentially be lost.
- In particularly dry periods this problem will be exacerbated as vegetation will senesce earlier and more rapidly, and will therefore burn earlier.
- There appears to be no significant stimulation of early biomass growth (at the onset of rains as a result of early burning, except for miombo habitat (which has low overall biomass for grazers).
- Early burning is a useful option to reduce late, destructive fires, but care should be taken to preserve a mosaic of unburned areas of vegetation, by introducing strategic firebreaks.
- Late burning will remove more biomass overall (though for a shorter period), but is potentially much more damaging to fire sensitive species.

4.3.2 Soil Moisture

- A majority of the soils in miombo, termitaria, and even some dambo habitats are mineral dominated, and appear to be far more sensitive to rainfall than to burning treatment.
- Miombo habitat becomes water limited very rapidly following the end of the wet season. Therefore, focussing on burning early will prevent hot fires that may damage saplings and small trees.

4.3.3 Grazer Preference

- Under the recent climatic conditions experienced during this study, changes in current burning practices may not benefit large grazers in terms of food availability. However, the current burning regime may restrict physical habitat for important species such as sitatunga.

- Biomass accumulation (a surrogate for net primary production), and offtake by grazers were not significantly affected by the timing of treatment (burning).

- In very wet periods it is likely to be the physical habitat that is most important in determining species distribution, with flooded grassland (and termitaria) effectively excluding puku and other non-wetland species. At the same time, flooding would have to be sustained, and suitable habitat expanded in order for sitatunga populations to expand.

4.4 Continued and Further Monitoring

If staffing levels permit, the following activities would be highly beneficial in establishing long-term datasets for KNP, and would allow an assessment of future change under altered climatic conditions, or in relation to potential activities in the KGMA.

4.4.1 Hydrology

- Regular **monitoring** and **quantification** of sediment loading and flow rates into Lake Wasa via the furrows over the course of at least two consecutive wet seasons would help determine if excessive (i.e. above and beyond natural surface runoff) sediment is being deposited in the lake. Ideally, sediment cores would also be obtained from the lake to investigate whether sediment loading from the wider catchment has increased in recent years.

- Establishment of replicate early burn, late burn and control plots adjacent to the furrow network, followed up by sampling of hydrochemistry of water in the furrows in the early wet season to determine any effects on **nutrient loading**.

- Monitoring of **pH** and **conductivity** in river and lake sites early and late in each wet season (i.e at least twice) to determine any **deviation** from the 'baseline' established by this study.

4.4.2 Burning Plots

- Maintain experimental plot burning sequence and firebreaks between and around plots.

- **Photograph** each plot, at least yearly, but preferably twice yearly (one mid dry season, and once mid wet season).

The following would be of great value, and could be carried out by able volunteer or student placements, or through links established with the University of Zambia (UNZA) during 2007:

- Monitoring of biomass variables (including Net Primary Production and Offtake), vegetation height, and surface soil moisture. At the very least in response to extreme low rainfall wet seasons.

4.5 Management Recommendations

4.5.1 Hydrology

4.5.1a In KNP

- The weir at Fibwe Camp should be maintained to help protect fragile and important papyrus swamp from burning during dry years.

- No dams any larger than the current installation at Fibwe Camp should be installed on either of the Musola or Kasanka Rivers as these may be detrimental to the ecology of the floodplains and/or their hydrochemistry.

- The furrow system which feeds into Lake Wasa I should not be extended any further until an assessment of sediment loading via furrow flow, over at least two wet seasons is carried out.

    - In the meantime, it would be beneficial to clear only 50% of vegetation from the furrow system in each year during the wet season so that what remains acts as a sediment trap.

    - If possible, and a fire risk is not posed, sections of dead vegetation should be left in the furrows during the dry season to enable traping of sediment transported by early rains.

Lake Wasa I is a seasonally flooded dambo and the main aim of interventions such as the furrow system is to maintain water levels in the lake as the main tourist lodge overlooks it. However, all such dambo wetlands are prone to drying periodically given variable rainfall levels and over time through sedimentation and vegetation encroachment (succession), and the flora and fauna present are adapted to the system. The provisions made by the furrows may therefore prove futile in the long term, and more radical mechanical removal of vegetation and accumulated sediment may be the only option to maintain an open water body. Whether such management interventions are appropriate in a National Park is, however, questionable.

4.5.1b in the KGMA

- Protection of forest cover in the wider KGMA should be a priority, and KTL should actively seek to use any statutory legal instruments to help enforce this via ZAWA and the Forestry Department.

    - The completion of the KGMA Land Use Plan (KGMA-LUP) will aid the identification of legally protected areas.

- Priority should also be given to the protection of the headwaters of the Kasanka and Musola Rivers, which are the most critical to the unique character of KNP, under the KGMA-LUP.

    - Efforts should also be made by park management to lobby for legal protection of the entire headwaters of the Kasanka and Musola Rivers (currently, outside of KNP, only small portions within the KGMA are protected).

4.5.2 Burning

Early burning is the best approach for managing large areas of floodplain and seasonal dambos which may otherwise be prone to late uncontrolled fires. But, care should be taken to preserve a mosaic of unburned areas of vegetation.

- The practice of early burning should be continued in all habitats where it is viewed as essential to protect from late, destructive fires.

    - Given the fact that the character of the wetland systems in KNP are primarily climate driven, the specific extent and timing of burning needs to be assessed by trained staff on a yearly basis. The production of ‘burning maps’ or a detailed list of areas to be burned, and at what precise time of year is not possible.

- The burning regime that has been followed until present (see Section 4.1) should largely be followed.

- It would be sensible to continue with the practice of early burning in areas such as seasonally inundated dambo grasslands where some seasonal flooding occurs, but is not sustained (e.g. Wasa II). The high biomass produced as a result of flooding dries more quickly if flooding is not maintained, and could lead to hot late fires if not dealt with early.

- However, where burning is essential in **miombo** woodland, **early** burning should be prioritised:

    - In *dry* years this will prevent damage to seedlings, and will retain more biomass as physical habitat as miombo soils rapidly become water limited (much quicker than adjoining termitaria habitat) and vegetation quickly senesces.

    - In *wet* years, this will have the advantage of stimulating early production of biomass to provide grazing opportunity where other suitable grassland habitat is still inundated by floodwater.

- Where discrete 'islands' of vegetation exist (e.g. a patch of dryer termitaria surrounded by seasonally flooded grassland, or a patch of woodland), slashing and strategic burning should be used to protect such islands by introducing strategic fire breaks (e.g. slashing termitaria and avoid burning dambo edge grassland, using existing roads as firebreaks, or by slashing tall termitaria vegetation around islands of miombo grassland to prevent fire entering).

- It is not possible to deduce or infer any long term effects on species composition or soil nutrient pools and soil moisture given the short term nature of this study and the extreme wet conditions which prevailed, but future monitoring to assess change in these variables as a result of the treatments imposed should be a priority.

4.5.3 Hydrology and Burning Interactions

- Substantial (e.g. 50m or more) strips of vegetation along river banks adjoining floodplains (**this includes all rivers in the park at various points**) should be left unburned (by establishing strategic firebreaks), or be burned as early as possible to preserve a high degree of complexity to the above ground structure of the vegetation. This will be hugely beneficial to:
    (i) Help prevent loss of nutrients as ash by surface flow during early rains.
    (ii) Encourage trapping and retention of mineral and organic particles from the river channel during flooding (i.e. vegetation does not respond immediately to rainfall: this has been shown by 'spikes' in conductivity in water samples at the onset of each wet season, where solutes, including nutrients are not taken up). Therefore areas completely cleared of biomass by late burning will have no means of trapping sediments.

- Overhanging vegetation by rivers and lakes, and vegetation which will be emergent in seasonally flooded areas (but which is vulnerable to burning in the dry season) should be protected from burning to limit evaporative losses.

4.5.4 Sensitive Habitats

The two habitats which are key to the character and tourism potential of KNP, yet are most vulnerable to disturbance by burning in dry years are the **Papyrus swamp** and the **Mushito forest.**

- Consideration should be made to consolidating scout presence within these areas, and intensifying this presence during the dry season in order to protect the areas from illegal or uncontrolled burning during this vulnerable time.

Papyrus swamp: needs protection from burning following below average rainfall years (and especially where there are several consecutive such years).

- This could be achieved by slashing and burning firebreaks 100 to 200m from the swamp edge, coupled very early burning of the remaining vegetation.

Mushito forest: The main anthropogenic threat comes from uncontrolled burning:

- Burning should be avoided in the forest itself to preserve the unique microclimate and prevent peat deposits from drying and becoming susceptible to burning.

- Firebreaks should be implemented around the edge of seasonally flooded forest most distant from the papyrus swamp (i.e. the driest area of forest) to protect from fire encroaching from adjacent grassland and deep peat fires from setting. These should be established 100 to 200m from the forest edge, and initially be coupled with slashing or mowing of the remaining vegetation between the firebreak and the forest.

- Burning at the immediate forest edge should be avoided to aid successful recruitment and growth of Mushito tree species.

- There is evidence that the annual influx of fruitbats is affecting the structure and microclimate of the mushito, possibly making it more susceptible to fire encroachment. Therefore, burning for management must not be allowed to exacerbate the effect of the bats, as this might ultimately lead to their loss from KNP.

4.6 General Observations and Recommendations

General recommendations can be made as to the nature of hydrology in the park, of potential impacts of burning, and what measures might be taken to safeguard vulnerable habitats. However, in the case of burning there needs to be a direct control on activities by management, so that random burning by park staff in general does not occur. The following should therefore be considered:

- Creation of a burning log at the end of each wet season, which reflects a response to the prevailing conditions that year (e.g. floodwaters might remain high in dambos, delaying the start of expected early burning). This should be maintained centrally in the main office, and those involved in burning activities made aware of it. Each burning activity should be recorded in the log on a daily basis.

- A definitive list of staff trained and licensed to carry out burning should be updated each year.

- Increased education is needed amongst staff in general regarding the objectives of burning in the park. The objectives of burning in a village (e.g. to keep an area neat or to keep snakes away etc.) differ form the objectives of burning in the park (where the desire is to reduce potentially dangerous loads of inflammable material, but to also maintain some biomass as grazing, and cover for animals).

- Experimental plots need to be maintained, and burning sequences within the plots followed if long term impacts of burning are to be deduced. Slashing of firebreaks to ensure that plots are not ‘accidentally’ burned needs to be a primary and integral part of the burning plan, and implemented before general burning commences each year. If simple plans are put in place to protect the plots they will provide a valuable long term research resource for KNP.

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APPENDIX A

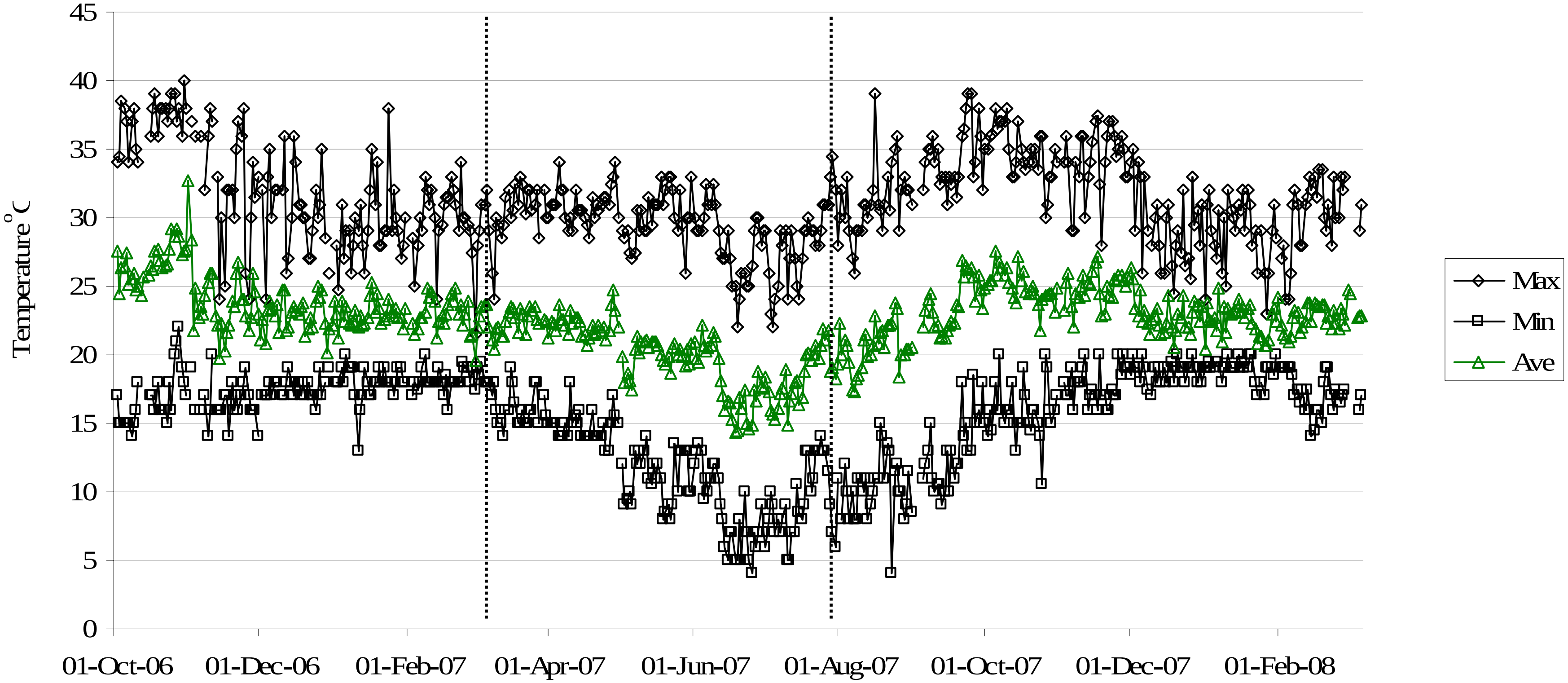


Figure A1 Daily mean, minimum and maximum temperatures, October 2006 – January 2006; dashed lines indicate approximate seasons (April – July = dry, becoming cool; August – November = dry, becoming hot; December – March = Wet and hot.

APPENDIX B

Table B1 River and Stream physical characteristics and discharge summaries, for sub-maximum flow conditions, and estimations of potential discharge values under bank-full flow conditions. †Potential discharge is based on velocity measurements recorded during river profiling. Therefore, where these are lower than bank-full conditions, potential discharge Tables presented are likely to be below maximum.

River	River Profiles							Bank-full measurements			
	Date Sampled	Width (m)	Mean Depth (m)	Mean Velocity (m/s)	Discharge (m^3/s)	Sediment Conc. (mg/litre)	Sediment Discharge (t/day)	Width (m)	Mean Depth (m)	Potential Discharge (m^3/s)†	Potential Sediment Discharge (t/day)†
Chitikilo Stream	08-Dec-07	2.00	0.49	0.14	0.14	0.4	0.0025	3.80	0.61	0.32	0.005
Kasanka											
- Inlet (Boston Bwalya Camp)	12-Dec-07	8.00	0.99	0.41	3.29	0.6	0.0855	11.85	1.73	8.48	0.22
Mulembo											
- Inlet	8-Dec-07	7.00	0.39	0.48	1.31	0.9	0.0510	33	2.5	39.35	1.53
- Chantete Camp	8-Dec-07	8.80	0.42	0.71	2.59	0.9	0.1005	16	2.82	31.93	1.24
Mulaushi Stream (Kasanka Research Centre)	15-Dec-07	5.65	0.48	0.22	0.60	0.4	0.0105	11	1.49	3.59	0.06
Musola											
- Inlet	12-Dec-07	6.70	0.49	0.71	2.35	0.2	0.0205	9.90	1.56	11.0	0.095
- Kasanka confluence	12-Dec-07	8.00	0.63	0.42	2.11	0.4	0.0365	13.70	1.74	10.01	0.175

APPENDIX C

Table C1(a) Summary statistics for hydrological years running October to September (except where indicated) for (a) pH, (b) Conductivity (µS/cm^3/s^{-1}), (c) Alkalinity (µEq/l), and (d) δ^{16}O: δ ^{18}O ratios of major rivers, lakes and groundwater resources within Kasanka National Park. *n* = number of samples upon which average is based (no entry indicates single sample or no sample for given period); *SD* = Standard deviation; - = no sample for specified period;

(a) pH Summary Statistics. †2004/05 = September 2005 only; †† = November 2007 only.

Site Number and Name	2004/05†	2005/06					2006/07					2007/08††
		Mean	*n*	SD	Min	Max	Mean	*n*	SD	Min	Max	
(i) Rivers												
27 Chitikilo Stream	-	6.22	*11*	0.35	5.88	7.05	6.40	*7*	0.48	5.83	7.08	7.07
Kasanka												
2 - Inlet (Boston Bwalya Camp)	7.95	7.84	*16*	0.50	6.57	8.9	7.84	*5*	0.12	7.70	8.00	7.56
7 - Pontoon	7.57	7.15	*16*	0.36	6.3	7.6	7.29	*6*	0.19	7.10	7.61	7.39
14 - Mulembo confluence	7.8	7.31	*15*	0.40	6.3	7.77	7.31	*6*	0.28	7.04	7.76	7.47
35 Lusenga Stream (source spring)	-	5.82	*4*	0.32	5.38	6.14	-					-
Luwombwa												
9 - Musande Camp	7.7	7.13	*16*	0.47	6.12	7.66	7.28	*6*	0.26	6.94	7.72	6.79
11 - Luwombwa Camp	7.61	7.27	*16*	0.40	6.05	7.6	7.31	*6*	0.20	7.04	7.55	7.17
12 - Yewe Camp	7.85	7.28	*16*	0.47	6.13	7.93	7.14	*5*	0.19	6.94	7.38	7.33
30 Mpulumba Stream	-	6.15	*5*	0.26	5.9	6.55	7.36					7.21
Mulembo												
18 - Inlet	7.4	7.06	*17*	0.30	6.41	7.41	7.32	*7*	0.26	6.90	7.60	7.34
22 - Chantete Camp	7.45	7.13	*17*	0.40	6.26	8	7.18	*6*	0.22	6.90	7.54	7.27
13 - Luwombwa confluence	8.27	7.60	*15*	0.66	6.14	8.41	7.61	*5*	0.32	7.23	8.06	7.74
19 Mulaushi Stream (Kasanka Research Centre)	7.22	6.93	*15*	0.59	6.14	8.75	6.93	*6*	0.20	6.69	7.17	7.94

Table C1(a) (continued)

Musola												
1 - Inlet	7.39	7.18	*16*	0.35	6.4	7.66	7.38	*6*	0.19	7.12	7.60	7.31
23 - Fibwe Hide	6.58	6.61	*16*	0.23	6.12	6.99	6.70	*6*	0.32	6.44	7.26	7.32
5 - Kasanka confluence	7.49	7.24	*15*	0.32	6.38	7.6	7.25	*4*	0.23	7.00	7.48	7.36
28 - Njelele Stream	-	6.18	*10*	0.40	5.82	7.1	6.32	*7*	0.49	5.89	7.07	6.92
(ii) Lakes												
4 - Chilengwa na Lese (sink hole)	6.83	6.75	*13*	0.37	6.18	6.93	7.12	*4*	0.34	6.82	7.44	8.19
16 - Kalamba	6.32	6.53	*16*	0.30	6	7.15	6.68	*6*	0.44	6.14	7.18	6.95
3 - Ndolwa	6.81	7.02	*16*	0.32	6.34	7.94	6.96	*4*	0.15	6.83	7.17	7.18
20 - Wasa 1	7.1	6.85	*17*	0.44	6.18	7.71	7.10	*6*	0.68	6.46	8.36	7.14
15 - Wasa II	5.99	6.76	*16*	0.33	5.84	7.17	6.75	*6*	0.17	6.60	7.07	7.25
(iii) Groundwaters												
34 - Boston's Village (Well)	-	7.36					5.07	*2*	0	5.07	5.07	-
8 - Chicufwe Airfield (Well)	5.72	5.79	*16*	0.59	5.21	7.34	5.89	*6*	0.71	5.06	6.81	5.88
17 - Mulembo Airfield (Well)	5.42	5.94	*17*	0.31	5.35	6.35	6.24	*6*	0.50	5.74	7.11	6.78
26 - Kabwe Camp (Well)	-	6.65	*11*	0.37	5.7	7.05	6.77	*6*	0.35	6.33	7.29	7.34
29 - Kasanka Research Centre (Well)	-	6.18	*5*	0.28	5.76	6.54	6.49	*2*	0.03	6.47	6.51	-
10 - Luwombwa Lodge (Borehole)	7.38	7.31	*16*	0.30	6.51	7.9	7.45	*6*	0.36	7.08	8.09	7.58
32 - Njelele School 1 (Borehole)	-	5.40					5.62	*6*	0.93	5.18	7.52	6.64
33 - Njelele School 2 (Borehole)	-	7.20					6.66	*7*	0.61	6.05	7.64	6.82
31 - Mpulumba Village (Borehole)	-	6.62					6.98	*3*	0.77	6.48	7.87	-
21 - Wasa Lodge (Borehole)	6.89	6.50	*17*	0.21	5.9	6.93	6.79	*6*	0.60	6.22	7.92	7.48
25 - Wasa Lodge Garden (Well)	-	6.37	*16*	0.22	5.86	6.77	6.59	*6*	0.61	6.23	7.83	7.38
24 - Wasa Lodge Kitchen (Well)	-	6.46	*16*	0.25	5.91	6.93	6.51	*6*	0.45	6.09	7.38	7.37

Table C1(b) Conductivity summary statistics. †2004/05 = September 2005 only; †† = November 2007 only.

Site Number and Name	2004/05†					2005/06					2006/07					2007/08††
	Mean	*n*	SD	Min	Max	Mean	*n*	SD	Min	Max	Mean	*n*	SD	Min	Max	
(i) Rivers																
27 Chitikilo Stream	-					40	*10*	29	9	94	33	*9*	9	25	48	13
Kasanka																
2 - Inlet (Boston Bwalya Camp)	230	*2*	23	246	214	194	*15*	110	18	413	190	*6*	67	93	259	266
6 - Musola Confluence	22					-										
7 - Pontoon	210	*2*	35	185	235	206	*15*	96	11	365	210	*8*	61	147	310	277
14 - Mulembo confluence	204	*2*	42	174	233	179	*14*	118	15	437	194	*8*	85	46	309	136
35 Lusenga Stream source	-					33	*4*		21	42	-					-
Luwombwa																
9 - Musande Camp	53	*2*	4	56	51	59	*15*	36	6	141	60	*8*	10	48	74	77
11 - Luwombwa Camp	55	*2*	0	55	55	56	*15*	39	10	163	61	*8*	8	49	70	74
12 - Yewe Camp	48	*2*	9	41	54	64	*15*	45	11	156	68	*6*	21	48	102	73
30 Mpulumba Stream	-					42	*4*	18	25	63	70	*3*	9	62	80	16
Mulembo																
18 - Inlet	39	*2*	10	32	46	50	*16*	25	13	97	58	*9*	19	34	86	40
22 - Chantete Camp	49	*2*	0	49	48	50	*16*	23	15	96	62	*8*	17	41	89	48
13 - Luwombwa confluence	138	*2*	32	160	115	108	*14*	67	3	206	122	*6*	37	88	183	139
19 Mulaushi Stream (Kasanka Research Centre)	31	*2*	6	27	35	72	*14*	35	12	121	44	*8*	22	23	87	17
Musola																
1 - Inlet	54	*2*	6	50	59	66	*16*	36	14	174	84	*8*	22	64	131	91
23 - Fibwe Hide	62	*2*	2	61	64	83	*15*	66	16	243	73	*8*	22	48	101	32
5 - Kasanka confluence	228	*2*	11	236	220	232	*14*	151	21	535	180	*5*	129	11	375	149
28 Njelele Stream	-					36	*9*	31	9	109	34	*9*	9	21	47	24

Table C1(b) (continued)

(ii) Lakes																
4 - Chilengwa na Lese (sink hole)	99	*2*	1	98	100	129	*12*	80	9	164	139	*5*	61	69	224	190
16 - Kalamba	75	*2*	23	91	59	123	*15*	137	9	419	93	*8*	45	45	172	123
3 - Ndolwa	154	*2*	11	146	162	167	*15*	125	15	500	191	*5*	28	152	216	193
20 - Wasa 1	76	*2*	8	70	82	135	*16*	69	6	275	109	*8*	39	69	170	72
15 - Wasa II	95	*2*	65	49	141	129	*15*	77	12	248	127	*8*	75	32	210	196
(iii) Groundwaters																
34 - Boston's Village (Well)	-					38					22	*2*	0	21	22	-
8 - Chicufwe Airfield (Well)	35	*2*	16	23	46	69	*15*	71	6	222	51	*7*	76	17	223	11
17 - Mulembo Airfield (Well)	33	*2*	8	27	38	67	*16*	55	10	216	66	*8*	49	33	149	66
26 - Kabwe Camp (Well)	-					183	*10*	162	8	454	108	*8*	65	44	210	19
29 - Kasanka Research Centre (Well)	-					178	*5*	162	30	436	228	*2*	8	222	234	-
10 - Luwombwa Lodge (Borehole)	271	*2*	77	216	325	334	*15*	236	5	881	327	*8*	19	258	353	306
32 - Njelele School 1 (Borehole)	-					30					47	*8*	17	29	77	11
33 - Njelele School 2 (Borehole)	-					112					121	*9*	72	35	257	44
31 - Mpulumba Village (Borehole)	-					451					492	*5*	38	455	539	-
21 - Wasa Lodge (Borehole)	173	*2*	55	134	212	186	*16*	124	8	482	174	*8*	19	152	211	86
25 - Wasa Lodge Garden (Well)	-					106	*15*	68	8	231	102	*8*	28	63	144	45
24 - Wasa Lodge Kitchen (Well)	-					190	*15*	111	7	418	219	*7*	25	176	244	44

Table C1(c) Alkalinity summary statistics. †2004/05 = May and September 2005 only; †† = November 2007 only.

Site Number and Name	2004/05					2005/06					2006/07					2007/08
	Mean	*n*	SD	Min	Max	Mean	*n*	SD	Min	Max	Mean	*n*	SD	Min	Max	
(i) Rivers																
27 Chitikilo Stream	-					459	*5*	458	126	1264	251	*9*	86	165	444	-
Kasanka																
2 - Inlet (Boston Bwalya Camp)	2528	*2*	396	2248	2808	2346	*8*	890	1004	3760	2419	*6*	1164	963	4093	3655
6 - Musola Confluence	2350					-										
7 - Pontoon	2701	*2*	362	2445	2957	2810	*8*	913	1548	4197	2434	*8*	1052	1272	4542	3730
14 - Mulembo confluence	2738	*2*	378	2471	3006	2907	*7*	791	1485	3974	2286	*8*	1229	371	4492	3456
35 Lusenga Stream (source spring)	-					478	*2*	255	298	659	-					-
Luwombwa																
9 - Musande Camp	512	*2*	58	471	552	578	*8*	181	276	779	534	*8*	137	427	828	802
11 - Luwombwa Camp	515	*2*	83	456	574	559	*8*	155	285	726	544	*8*	192	218	852	760
12 - Yewe Camp	558	*2*	43	527	589	602	*8*	220	281	993	570	*6*	175	398	829	599
30 Mpulumba Stream	-					1137	*2*	398	856	1419	572	*3*	74	501	649	-
Mulembo																
18 - Inlet	572	*2*	208	424	719	625	*8*	272	225	1005	437	*8*	125	278	669	820
22 - Chantete Camp	569	*2*	184	439	699	581	*8*	199	249	864	522	*8*	227	331	1023	723
13 - Luwombwa confluence	1467	*2*	504	1110	1823	1745	*8*	936	737	3506	1292	*6*	646	732	2495	1268
19 Mulaushi Stream (Kasanka Research Centre)	365	*2*	51	329	400	564	*7*	464	216	1460	389	*8*	279	33	985	678
Musola																
1 - Inlet	642	*2*	21	628	657	805	*8*	140	649	1095	795	*8*	190	594	1164	1025
23 - Fibwe Hide	629	*2*	6	624	633	806	*8*	114	625	1017	747	*8*	291	452	1263	1432
5 - Kasanka confluence	2470	*2*	281	2271	2668	2947	*7*	1135	1192	4365	2886	*5*	1687	1884	5844	3354
28 - Njelele Stream	-					288	*5*	67	174	335	278	*9*	96	187	485	-

Table C1(c) (continued)

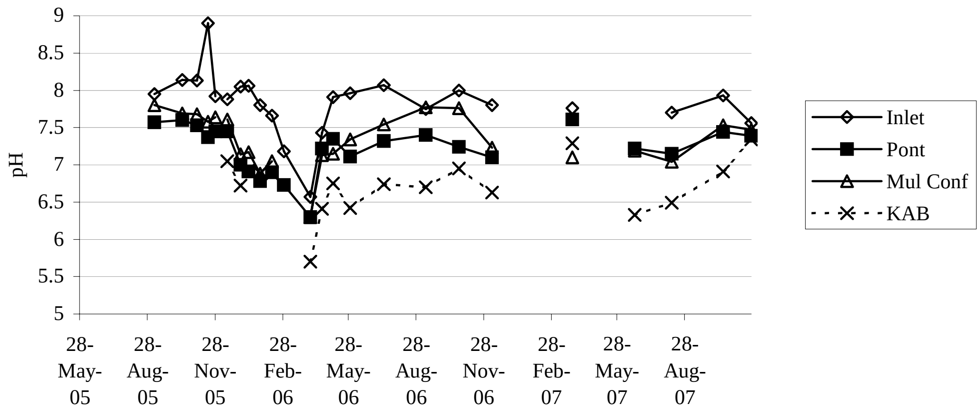
(ii) Lakes																
4 - Chilengwa na Lese (sink hole)	1236	*2*	329	1004	1469	1484	*7*	970	721	3592	1803	*5*	848	636	2753	3943
16 - Kalamba	567	*2*	131	475	660	783	*8*	300	292	1236	839	*8*	426	406	1410	1537
3 - Ndolwa	1610	*2*	2	1608	1611	2102	*8*	344	1655	2644	2202	*5*	369	1844	2678	3155
20 - Wasa 1	861	*2*	151	754	968	1238	*8*	328	752	1681	1061	*8*	470	663	1890	1058
15 - Wasa II	832	*2*	563	434	1230	2031	*8*	677	804	3011	1243	*8*	963	168	2915	2586
(iii) Groundwaters																
34 - Boston's Village (Well)	-					176					99	*2*	6	95	103	-
8 - Chicufwe Airfield (Well)	243	*2*	144	141	345	464	*8*	570	126	1807	569	*7*	1010	70	2831	240
17 - Mulembo Airfield (Well)	291	*2*	52	254	327	437	*8*	155	281	774	602	*8*	592	237	1629	561
26 - Kabwe Camp (Well)	-					1440	*6*	715	403	2220	1101	*8*	900	334	2448	-
29 - Kasanka Research Centre (Well)	-					2004	*2*	354	1754	2254	2157	*2*	225	1998	2317	-
10 - Luwombwa Lodge (Borehole)	2831	*2*	117	2748	2913	3339	*8*	735	2427	4162	3328	*7*	370	3016	4114	3823
32 - Njelele School 1 (Borehole)	-					289					269	*8*	131	164	551	-
33 - Njelele School 2 (Borehole)	-					280					950	*9*	777	395	2867	-
31 - Mpulumba Village (Borehole)	-					5401					4091	*5*	1122	2340	5323	-
21 - Wasa Lodge (Borehole)	1565	*2*	37	1539	1591	1860	*8*	339	1486	2291	1786	*8*	486	817	2440	2136
25 - Wasa Lodge Garden (Well)	-					1084	*8*	255	801	1466	977	*8*	375	571	1543	-
24 - Wasa Lodge Kitchen (Well)	-					2026	*8*	630	1150	3267	2087	*7*	323	1676	2634	-

Table C1(d) $\delta^{18}O$: $\delta^{16}O$ ratio summary statistics. †2004/05 = May and September 2005 only; †† = To April 2007 only

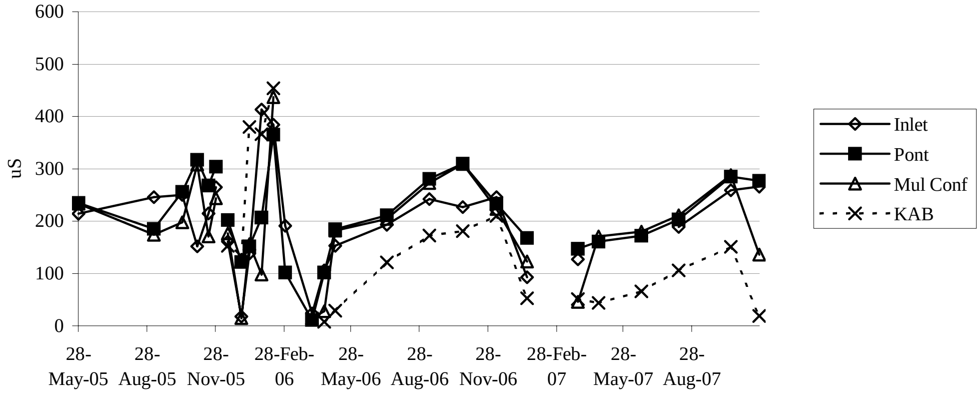
Site Number and Name	2004/05†					2005/06					2006/07††				
	Mean	***n***	**SD**	**Min**	**Max**	**Mean**	***n***	**SD**	**Min**	**Max**	**Mean**	***n***	**SD**	**Min**	**Max**
(i) Rivers															
Kasanka															
2 - Inlet (Boston Bwalya Camp)	-6.2	*2*	0.04	-6.2	-6.2	-5.5	*10*	1.15	-7.9	-4.4	-7.0	*4*	0.91	-8.3	-6.3
7 - Pontoon	-5.7		-			-5.1	*9*	0.66	-5.8	-4.2	-6.5	*5*	1.05	-8.3	-5.7
14 - Mulembo confluence	-6.0	*2*	0.41	-6.3	-5.7	-4.4	*9*	0.68	-5.7	-3.2	-6.2	*5*	1.20	-8.3	-5.3
Luwombwa															
9 - Musande Camp	-5.5	*2*	0.22	-5.7	-5.4	-4.1	*10*	1.49	-7.4	-2.7	-6.0	*4*	0.77	-6.8	-5.1
11 - Luwombwa Camp	-5.3	*2*	0.39	-5.6	-5.0	-4.4	*9*	1.53	-7.4	-2.1	-5.9	*4*	0.90	-6.9	-4.9
12 - Yewe Camp	-5.4	*2*	0.73	-5.9	-4.9	-4.6	*10*	1.34	-7.4	-2.8	-6.4	*3*	1.89	-8.5	-4.9
Mulembo															
18 - Inlet	-5.2	*2*	1.78	-6.5	-3.9	-5.0	*10*	1.24	-8.2	-3.9	-6.3	*4*	0.82	-7.1	-5.5
22 - Chantete Camp	-4.5	*2*	0.99	-5.2	-3.8	-5.1	*8*	1.47	-8.3	-3.4	-6.6	*5*	1.32	-8.6	-5.4
13 - Luwombwa confluence	-5.8	*2*	0.60	-6.2	-5.4	-4.2	*9*	0.84	-5.8	-3.1	-5.4	*2*	0.28	-5.6	-5.2
19 Malaushi stream (Kasanka Research Centre)	-4.0	*2*	1.63	-5.2	-2.9	-3.7	*9*	2.67	-7.6	1.0	-5.3	*4*	2.65	-8.3	-1.9
Musola															
1 - Inlet	-6.4	*2*	0.06	-6.4	-6.3	-5.5	*9*	1.11	-7.6	-4.4	-6.8	*5*	0.89	-8.4	-6.2
23 - Fibwe Hide	-5.2	*2*	0.66	-5.6	-4.7	-4.9	*10*	1.12	-7.6	-3.7	-6.1	*4*	1.88	-8.4	-4.0
5 - Kasanka confluence	-5.7	*2*	0.14	-5.8	-5.6	-5.2	*9*	1.07	-6.9	-3.6	-7.8	*1*			
(ii) Lakes															
4 - Chilengwa na Lese (sink hole)	2.9	*2*	4.46	-0.3	6.0	-2.0	*5*	2.92	-6.0	1.1					
16 - Kalamba	0.3	*2*	2.09	-1.2	1.7	0.7	*9*	4.49	-8.3	6.7	-3.3	*4*	3.77	1.1	0.3
3 - Ndolwa	-1.6	*2*	1.32	-2.5	-0.7	0.1	*9*	3.13	-4.0	4.8	-3.6	*3*	1.75	-5.5	-2.1
20 - Wasa 1	3.1	*2*	2.18	1.5	4.6	0.7	*10*	2.97	-5.7	4.6	-1.9	*5*	4.49	-7.5	3.8
15 - Wasa II	1.8	*2*	3.29	-0.5	4.1	0.3	*9*	4.70	-8.1	5.3	-2.8	*4*	4.51	-8.6	1.9
(iii) Groundwaters															
8 - Chickfufwe airfield (Well)	-5.9	*2*	0.10	-6.0	-5.8	-5.6	*9*	0.81	-6.5	-4.5	-7.0	*5*	1.18	-8.4	-5.7
17 - Mulembo airfield (Well)	-4.9					-6.0	*10*	0.87	-6.6	-4.2	-7.5	*5*	1.23	-9.5	-6.4
10 - Luwomba Lodge (Borehole)	-6.5	*2*	0.09	-6.6	-6.4	-5.5	*9*	0.97	-6.6	-4.1	-6.9	*4*	0.93	-8.3	-6.4
21 - Wasa Lodge (Borehole)	-5.0		-			-6.1	*10*	0.80	-7.3	-5.0	-6.8	*5*	0.38	-7.5	-6.5
25 - Wasa Lodge Garden (Well)	-		-			-2.5	*8*	2.02	-6.4	-0.4	-4.0	*5*	2.39	-8.1	-2.5
24 - Wasa Lodge Kitchen (Well)	-		-			-5.4	*9*	0.95	-6.8	-3.4	-6.5	*4*	1.14	-7.6	-5.4

APPENDIX D

(a)



(b)



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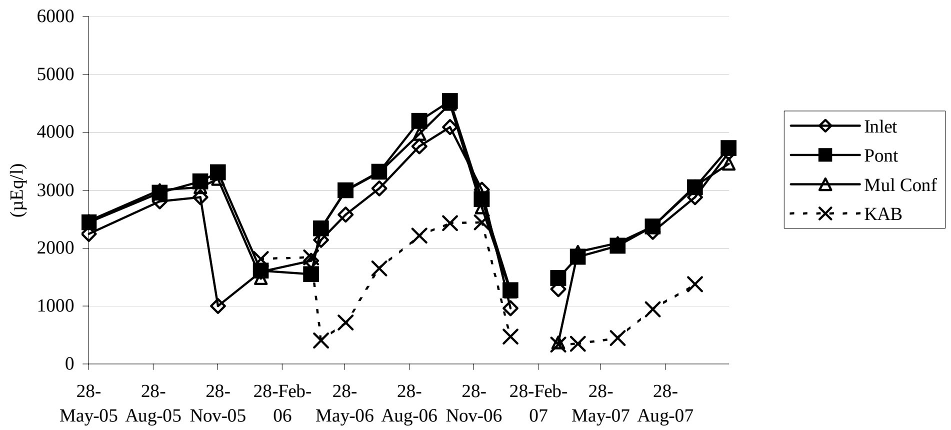


Figure D1 Kasanka River water chemistry values. (a) pH, (b) conductivity (µS/cm^3/s), (c) Alkalinity (µEq/l). Inlet = Kasanka B Camp (southern boundary of park); Pont = Pontoon crossing; Mul Conf = confluence with Mulembo River; KAB = Kabwe Camp well.

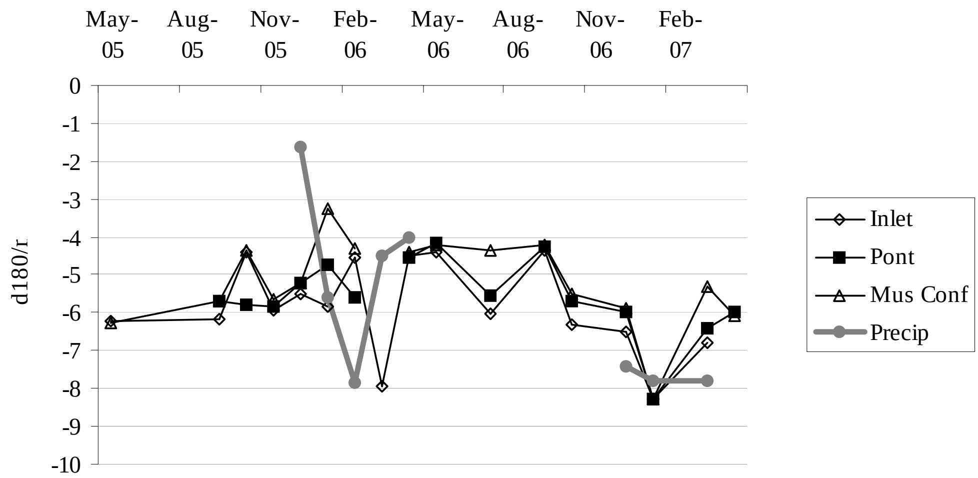
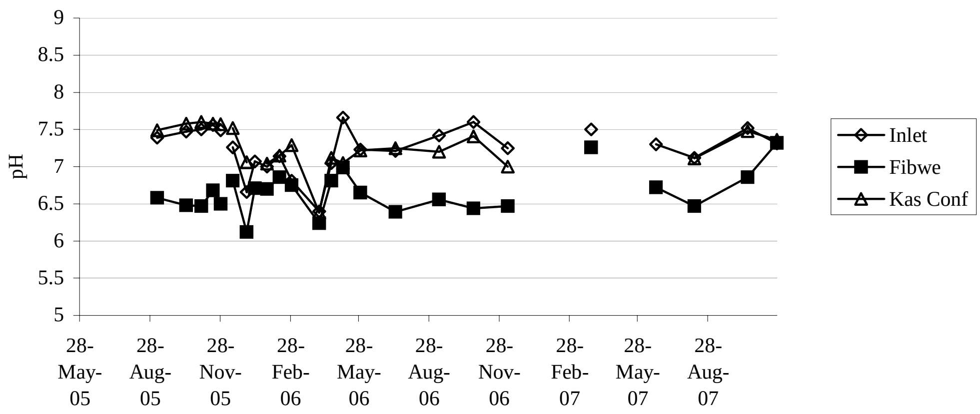
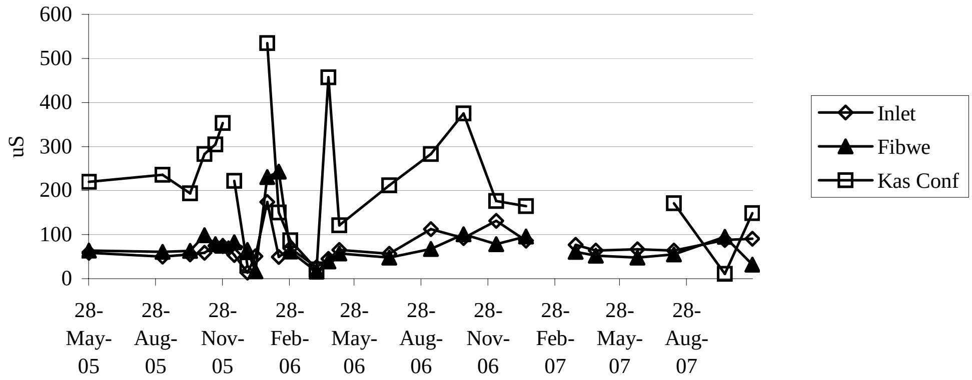


Figure D2 Kasanka River δ^{18}O/ml values. Inlet = Kasanka B Camp (southern boundary of park); Pont = Pontoon crossing; Mul Conf = confluence with Mulembo River; KAB = Kabwe Camp well.

(a)



(b)



(c)

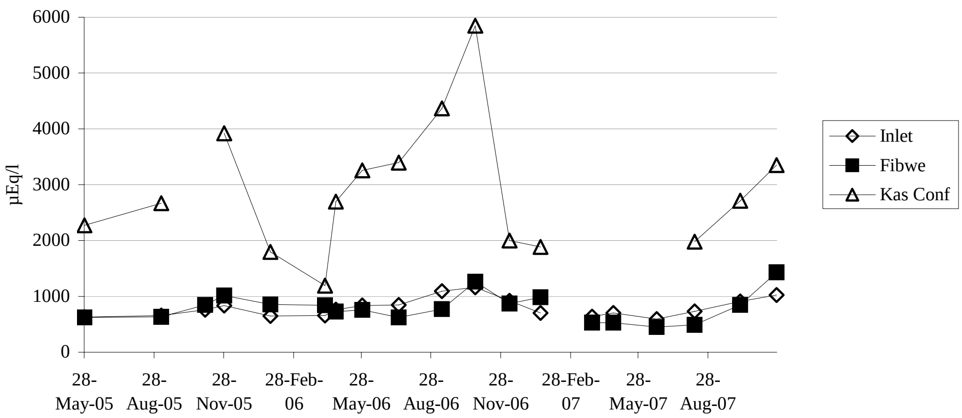


Figure D3 Musola River water chemistry values. (a) pH, (b) conductivity (µS/cm^3/s), (c) Alkalinity (µEq/l). Inlet = river at Southern boundary of park; Fibwe = Fibwe hide camp, at weir; Kas Conf = confluence with Kasanka River.

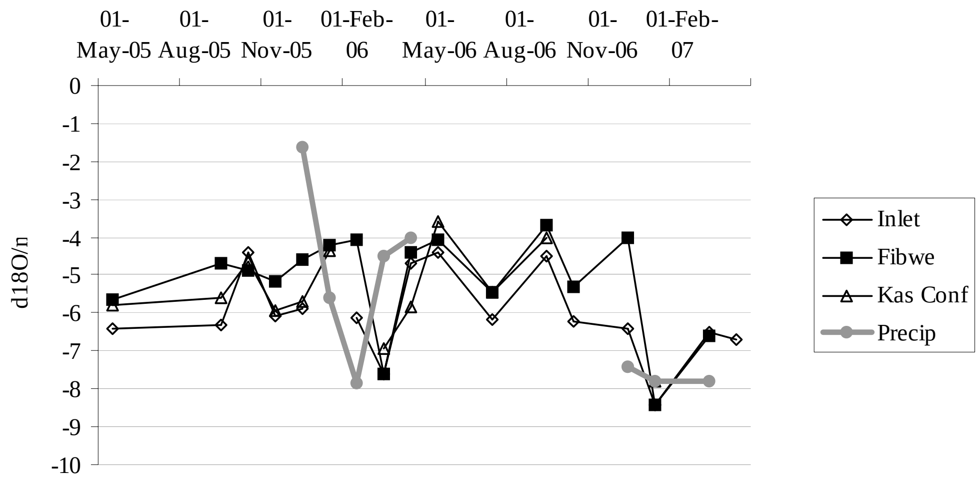
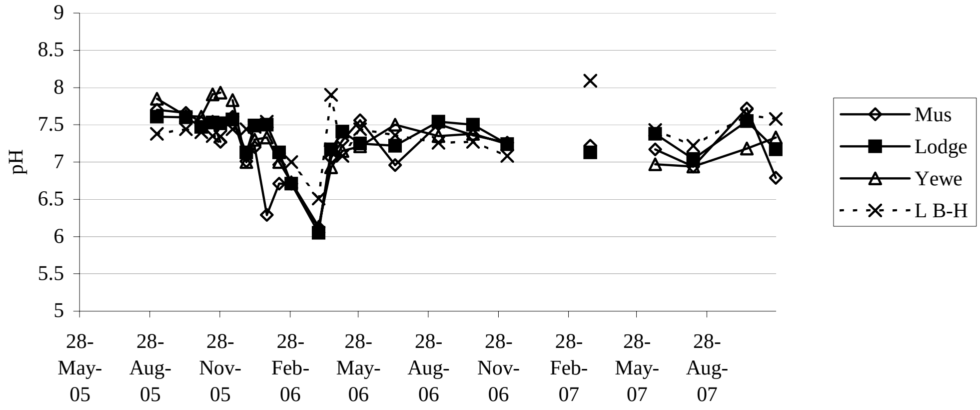
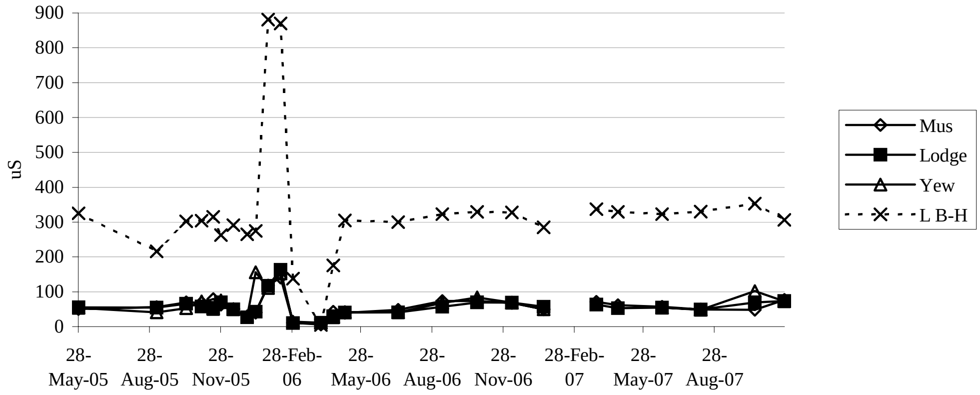


Figure D4 Musola River $\delta^{18}O$/ml values. Inlet = river at Southern boundary of park; Fibwe = Fibwe hide camp, at weir; Kas Conf = confluence with Kasanka River.

(a)



(b)



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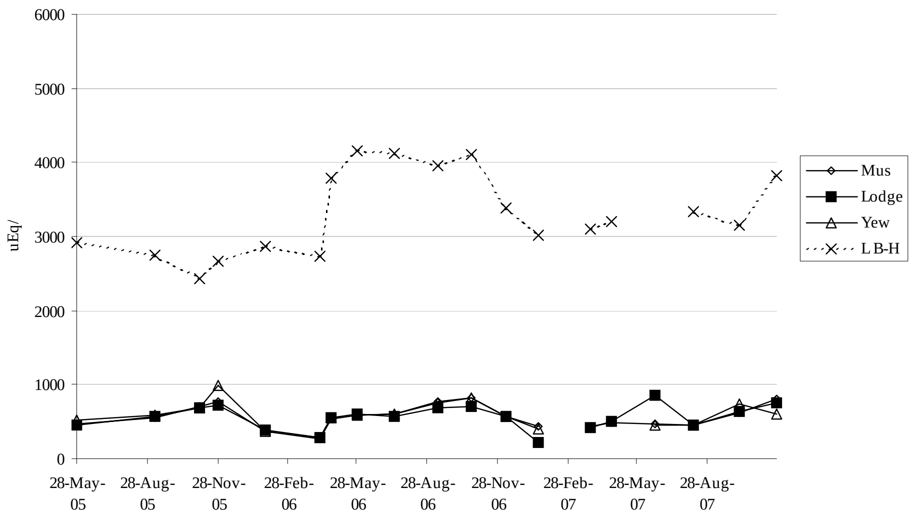


Figure D5 Luwombwa River water chemistry values. (a) pH, (b) conductivity (µS/cm^3/s), (c) Alkalinity (µEq/l). Mus = Musande Camp; Lodge = Luwombwa Lodge; Yew = Yewe Camp (near confluence with Mulembo River); L B-H = Luwombwa Camp Borehole.

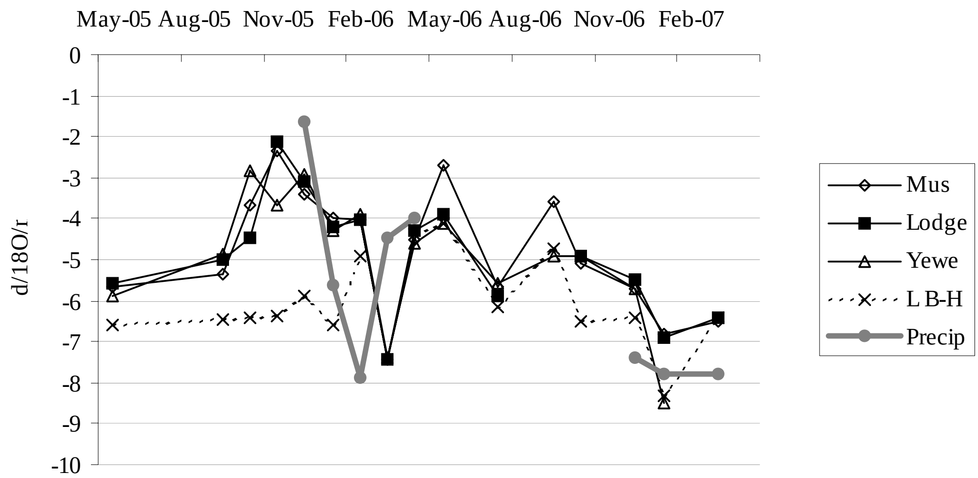
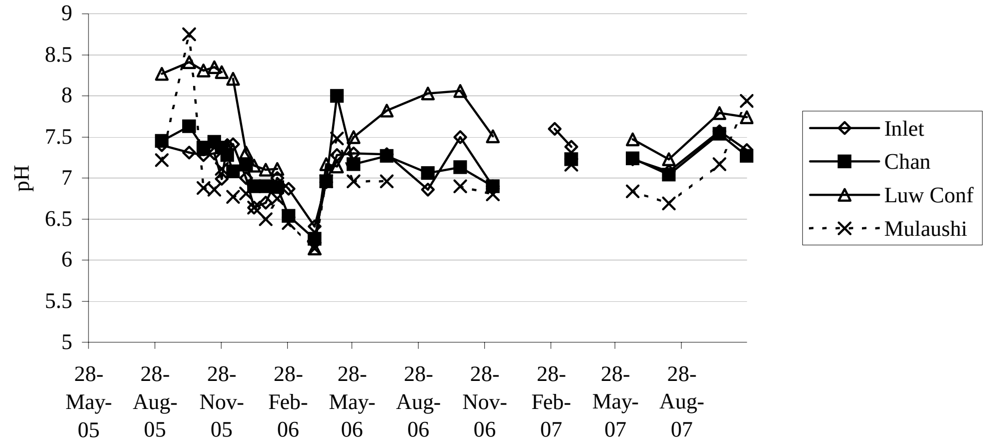
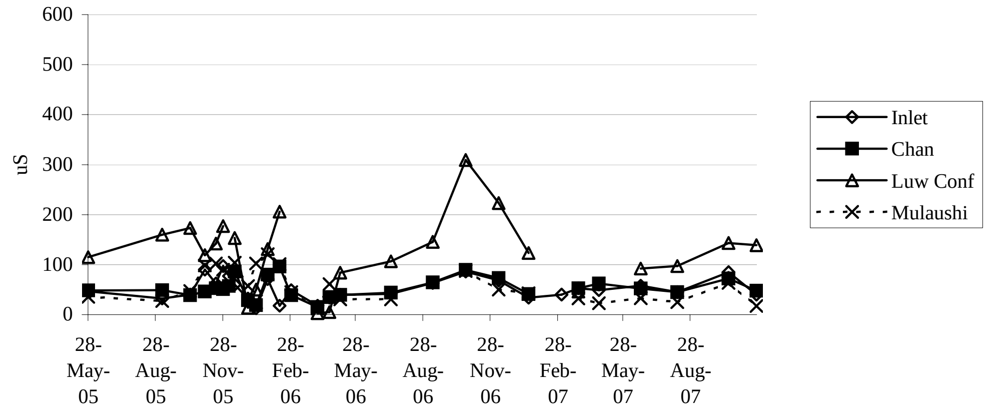


Figure D6 Luwombwa River $\delta^{18}O$/ml values. Mus = Musande Camp; Lodge = Luwombwa Lodge; Yew = Yewe Camp (near confluence with Mulembo River); L B-H = Luwombwa Camp Borehole.

(a)



(b)



(c)

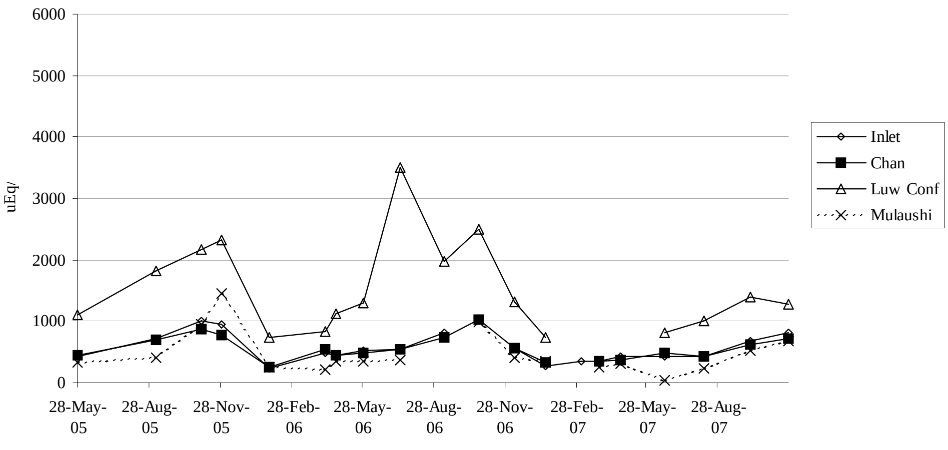


Figure D7 Mulembo River water chemistry values. (a) pH, (b) conductivity (μS/cm^3/s), (c) Alkalinity (μEq/l). Inlet = Main road bridge at Mulaushi village; Chan = Chantete Camp; Luw Conf = Luwombwa River confluence; Mulaushi = Mulaushi Stream at Kasanka Research Centre (near confluence with Mulembo River).

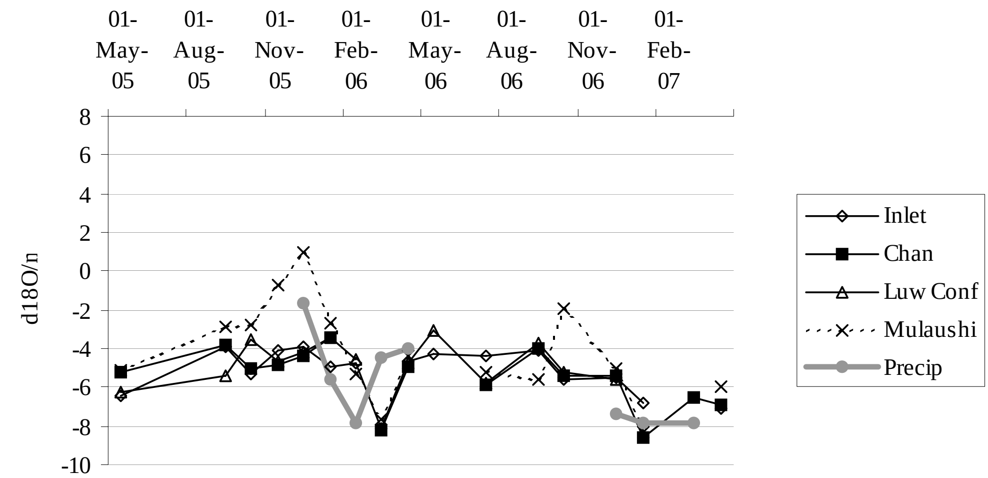
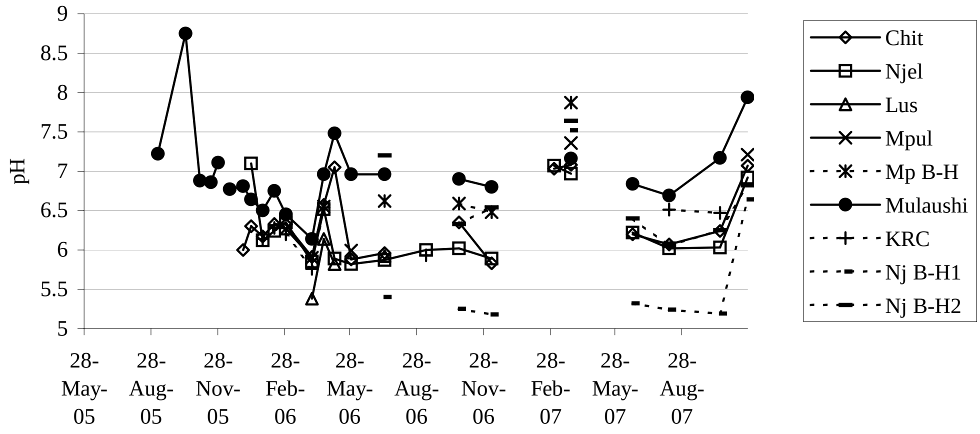
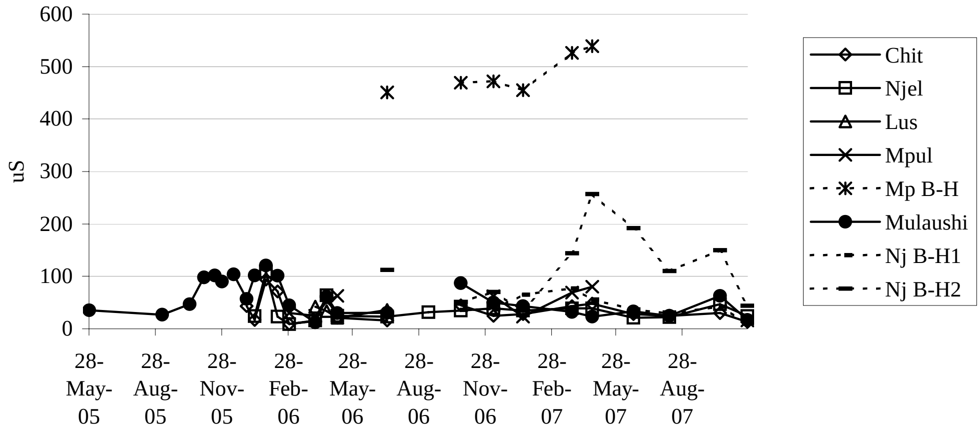


Figure D8 Mulembo River $\delta^{18}O$/ml values. Inlet = Main road bridge at Mulaushi village; Chan = Chantete Camp; Luw Conf = Luwombwa River confluence; Mulaushi = Mulaushi Stream at Kasanka Research Centre (near confluence with Mulembo River).

(a)



(b)



(c)

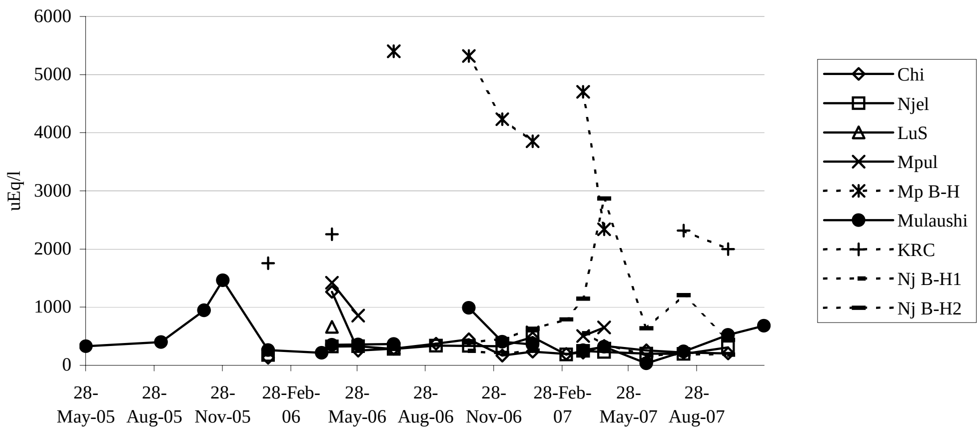
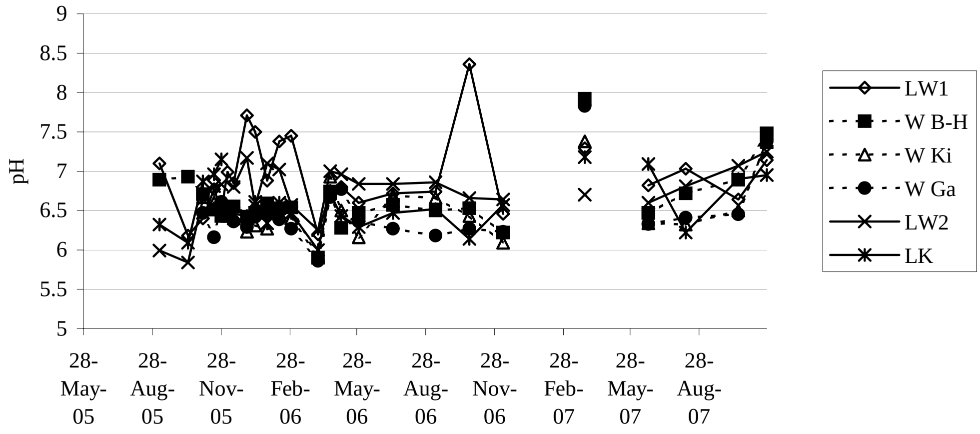
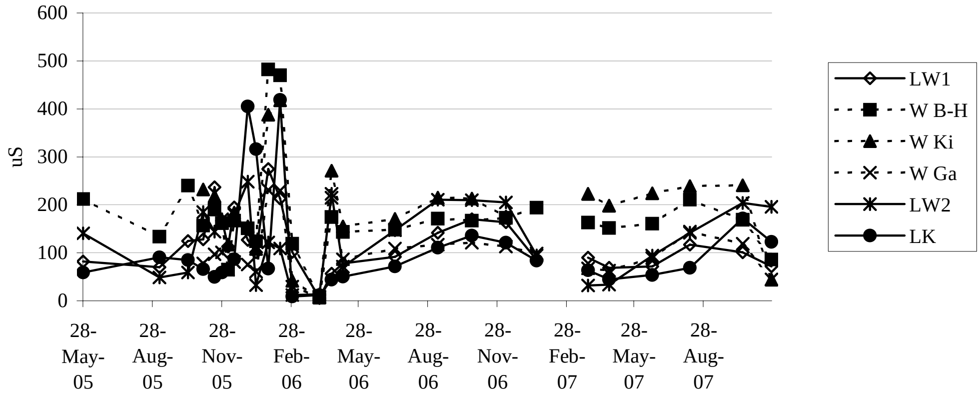


Figure D9 Water chemistry values for tributaries (and nearby groundwaters) of Mulaushi stream (in Kafinda GMA). (a) pH, (b) conductivity (μS/cm^3/s), and (c) Alkalinity (μEq/l). Chit = Chitikilo Stream; Njel = Njelele Stream; Lus = Lusenga Stream (source of); Mpul = Mpulumba Stream; Mp B-H = Mpulumba Village Borehole; Mulaushi = Mulaushi Stream at Kasanka Research Centre; KRC = Kasanka Research Centre Well (Excluded for conductivity due to bat guanatrophication); Nj B-H1 = Njelele School Borehole 1; Nj B-H2 = Njelele School Borehole 2

(a)



(b)



(c)

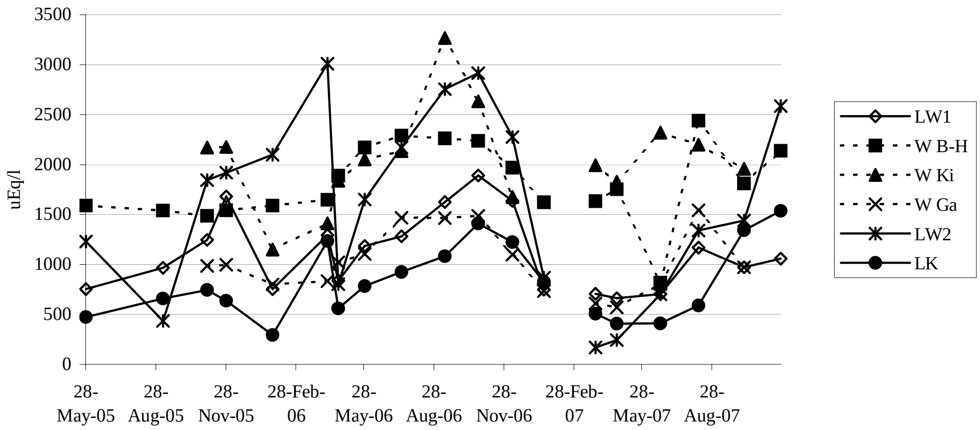


Figure D10 Water chemistry values for enclosed dambo complex (lakes and groundwaters) surrounding Wasa Camp. (a) pH, (b) conductivity (μS/cm^3/s), (c) Alkalinity (μEq/l). LW1 = Lake Wasa 1; W B-H = Wasa Borehole; W Ga = Wasa Camp, Garden Well; W Ki = Wasa Camp Kitchen Well; LW2 = Lake Wasa 2; LK = Lake Kalamba.

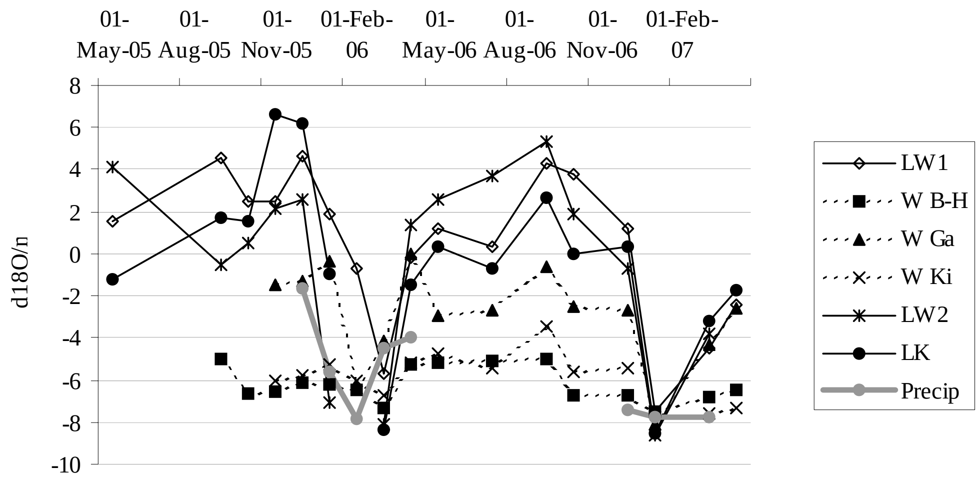


Figure D11 δ¹⁸O/ml values for enclosed dambo complex (lakes and groundwaters) surrounding Wasa Camp. LW1 = Lake Wasa 1; W B-H = Wasa Borehole; W Ga = Wasa Camp, Garden Well; W Ki = Wasa Camp Kitchen Well; LW2 = Lake Wasa 2; LK = Lake Kalamba.

APPENDIX E

Table E1 Species recorded in June 2006 and June 2007 within habitat blocks per site. M = Miombo, T = Termitaria, G = Grassland. K = Lake Kalamba, W1 = Wasa 1, W2 = Wasa 2.

	M1K1	M1W1	M2W1	M1W2	M2W2	T1K1	T1W1	T2W1	T1W2	T2W2	G1K1	G1W1	G2W1	G1W2	G2W2
Achyranthes aspera var. argentea	+		+												
Adenodolichos punctatus	+		+	+			+								
Aeollanthus engleri				+											
Andropogon spp								+	+						
Anisophyllea pomifera			+												
Antherotoma nandinii	+		+	+											
Asparagus spp			+												
Baphia massaiensis			+												
Barleria spp					+										
Becium grandiflorum	+	+	+	+	+			+	+	+					
Bidens schempezi			+	+					+						
Biophytum kassneri	+		+		+										
Blephelis spp			+												
Bothmania ingiliana (S)		+													
Brachiaria brizantha	+		+	+	+				+	+					
Brachiaria serrata		+													
Brachystegia boheme (S)		+	+	+											
Brachystegia longifolia (S)		+			+										
Brachystegia stipulata (S)				+											
Buchnera foliosa									+				+		
Bulbostylis spp	+	+	+	+	+				+	+		+	+	+	+
Centauria praecox							+								
Chironia palustris		+	+	+											
Commelina zambesiaca	+	+							+						
Costus spectabilis		+													
Crinum macowanii										+				+	+
Cryptosepalum maraviense	+	+	+	+											
Cyanotis longifolia		+	+	+											
Cycnium tubulosum										+	+	+	+		+
Cynodon dactylon												+			
Cyperus alternifolius											+				
Cyperus denudatus												+	+	+	+
Desmodium salicifolium	+		+	+	+										
Dicranum spp		+													
Digitaria nitens	+	+	+	+	+										
Echinochloa stagnina											+		+	+	+
Eleocharis spp											+	+	+		
Eragrostis arenicola				+	+			+							
Eragrostis aspera						+									
Eragrostis atrovirens				+				+	+	+					
Eragrostis spp	+				+	+		+	+	+	+	+	+	+	+
Eriocaulon buchanani											+			+	+
Erythrocephalum zambezianum	+				+										
Floscopa glomerata										+				+	+

Table E1 continued

	M1K1	M1W1	M2W1	M1W2	M2W2	T1K1	T1W1	T2W1	T1W2	T2W2	G1K1	G1W1	G2W1	G1W2	G2W2
Garcinia livingstonei (S)		+	+												
Gnidia chrysantha			+				+	+	+	+					
Hibiscus canabinus		+		+		+	+	+	+						
Hypharrenia hirta	+	+	+	+	+	+	+	+	+	+	+		+	+	+
Hypoxis spp		+	+		+										
Isoberlinia angolensis (S)	+	+		+	+										
Julbernadia paniculata (S)	+	+	+	+	+										
Juncus spp											+		+		
Lannea discolor (S)	+														
Leptactina benguelensis		+		+	+										
Melinis nerviglumis			+			+	+	+			+				
Murdannia simplex											+				
Nymphoides indica subsp. occidentalis											+	+	+		+
Parinari curatellifolia (S)		+	+												
Phyllanthus spp		+													
Pseudolachnostylis maprouneifolia (S)		+	+		+										
Rhynchosia heterophylla	+	+	+	+	+										
Scirpus spp										+					
Scleria adpresso-hirta									+	+					
Scleria bulbifera	+														
Scleria glabra										+					
Setaria pumilla	+				+	+		+	+	+	+				
Siphonochilus kirkii		+			+										
Smilax spp			+												
Spermacoce dibrachiata	+	+	+	+	+					+					
Stathmostelma fornicatum															+
Striga forbesii	+				+										
Strychnos cocculoides (S)				+											
Syzigium cordatum (S)	+	+	+		+										
Syzygium guineense (S)	+		+												
Thunbergia huillensis	+			+	+										
Thunbergia kirkiana				+											
Uapaca ntida (S)		+													
Utricularia stellaris											+				
Vernonia periottoti								+							
Vernonia petersii				+											
Vitex doniana (S)		+	+												
Xyris spp											+		+		

Table E2 Tree species recorded in June 2006 and June 2007 within miombo treatment blocks per site. K = Lake Kalamba, W1 = Wasa 1, W2 = Wasa 2.

	K	1 W1	2 W1	1 W2	2 W2
Afzelia quanzensis		+			
Albizya antunesiana				+	
Anisophyllea boehmii			+		
Anona senegariensis				+	
Brachystegia boehmii	+				
Brachystegia longifolia	+	+	+	+	
Brachystigia stipulata	+	+	+	+	+
Combretun molle				+	
Combretum spp.		+			
Diplorhynchus condylocarpon	+	+	+	+	+
Garcinia spp.	+	+	+		+
Isoberlinia angolensis	+	+	+	+	+
Julbernadia paniculata	+	+	+		
Lannear discolor			+		
Mapurounea africana		+			
Monotes spp.		+	+		
Parinari Curateliforia		+	+		
Pavelta schumannia				+	
Pericopsis angolensis	+	+	+		+
Pseudolachnostylis maprouneifolia		+	+	+	
Rothmannia englerana		+	+		
Strychnos spinosa					+
Swartzia madagascariensis		+			
Syzygium guineense	+	+	+	+	
Uapaca spp			+		
Uapaca bengwelensis			+		
Uapaca guineensis			+		
Uapaca Kirkiana	+	+	+		
Uapaca nitida	+	+	+	+	
Uapaca Sansibarica		+	+	+	
Vitex doniana				+	

APPENDIX F

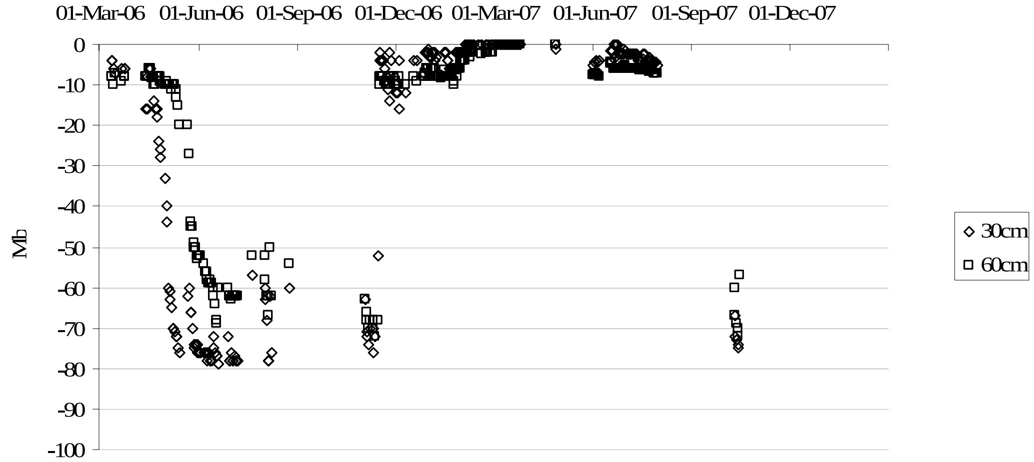


Figure F1 Soil matric potential (Millibars) for soils at depths of 30cm and 60cm below surface level at Wasa Camp.

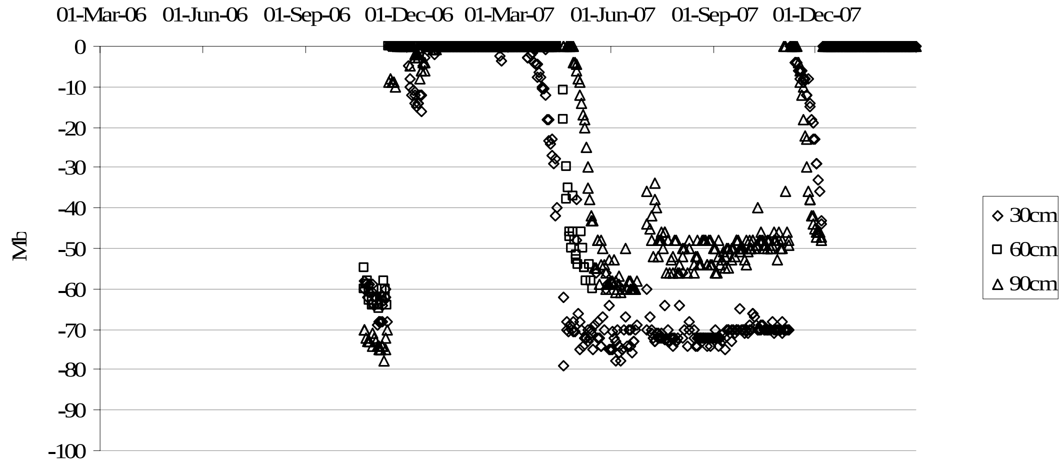
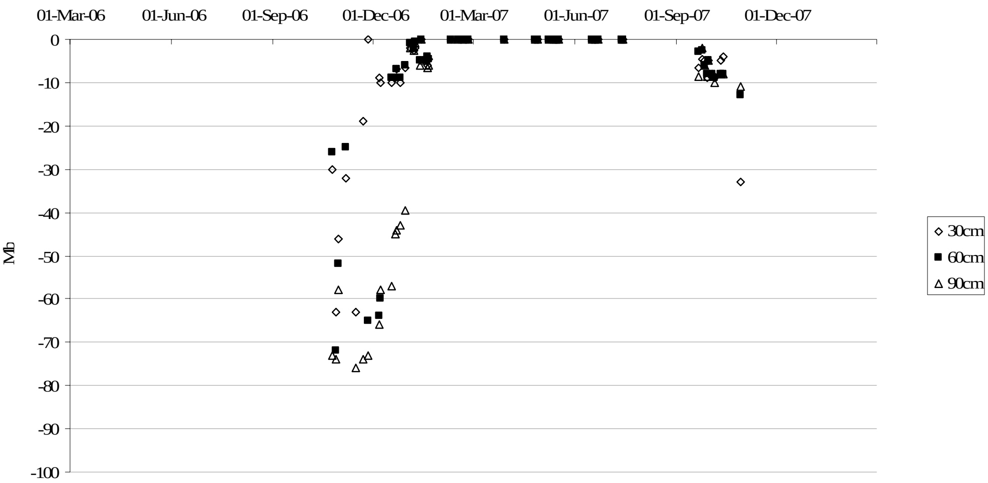
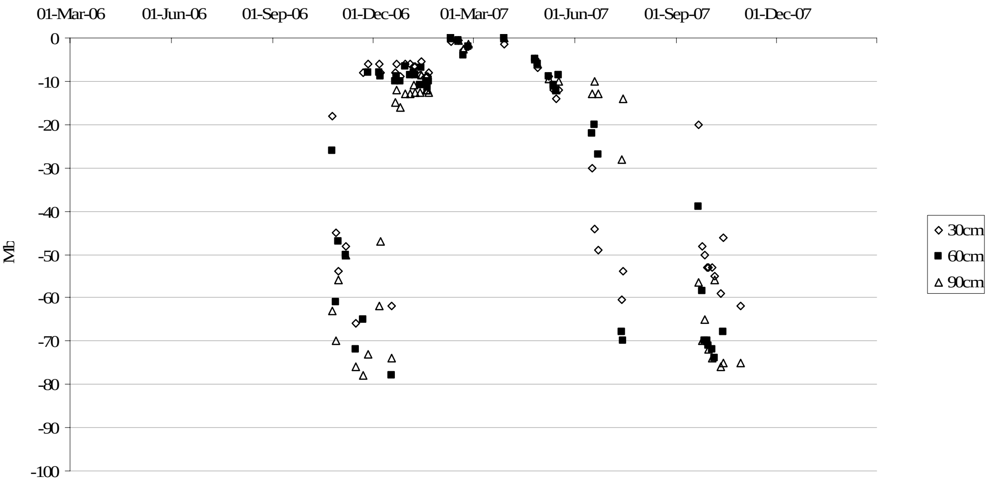


Figure F2 Soil matric potential (Millibars) for soils at depths of 30cm, 60cm and 90cm below surface level at Kasanka Research Centre.

(a)



(b)



(c)

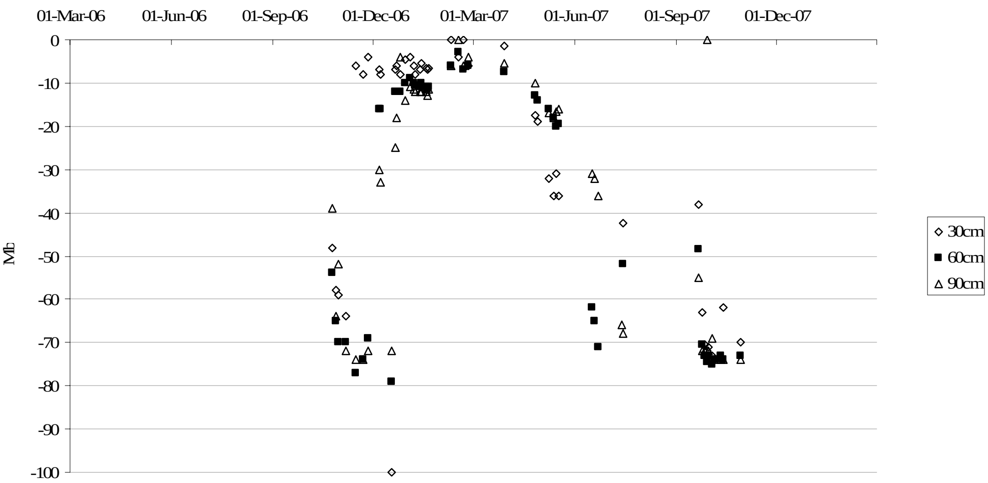
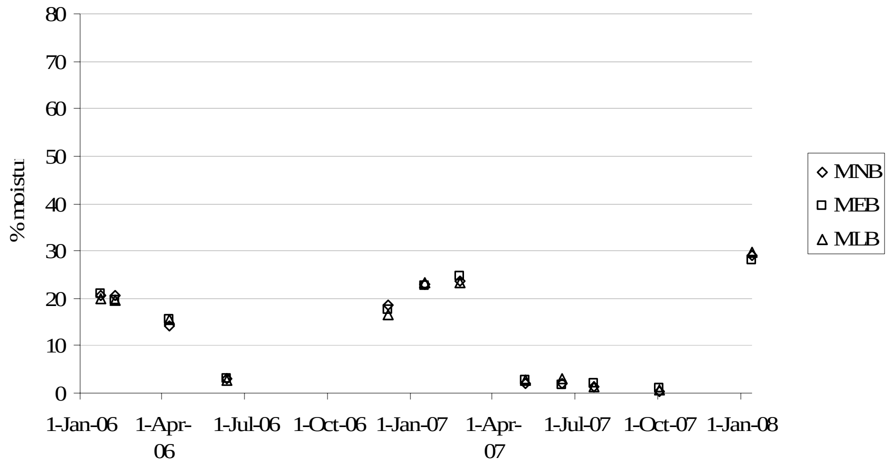
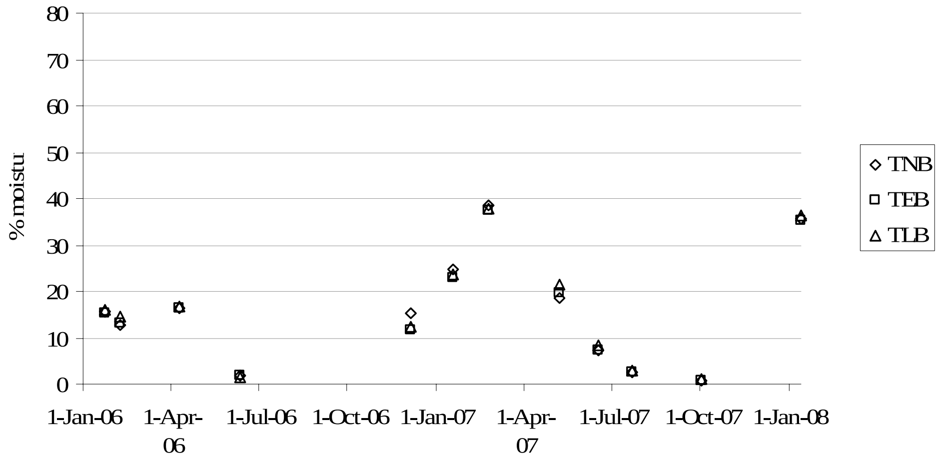


Figure F3 Soil matric potential (Millibars) for soils at depths of 30cm, 60cm and 90cm below surface level in Wasa 1 dambo. **(a)** Grassland; **(b)** Termitaria grassland; **(c)** Miombo woodland.

(a)



(b)



(c)

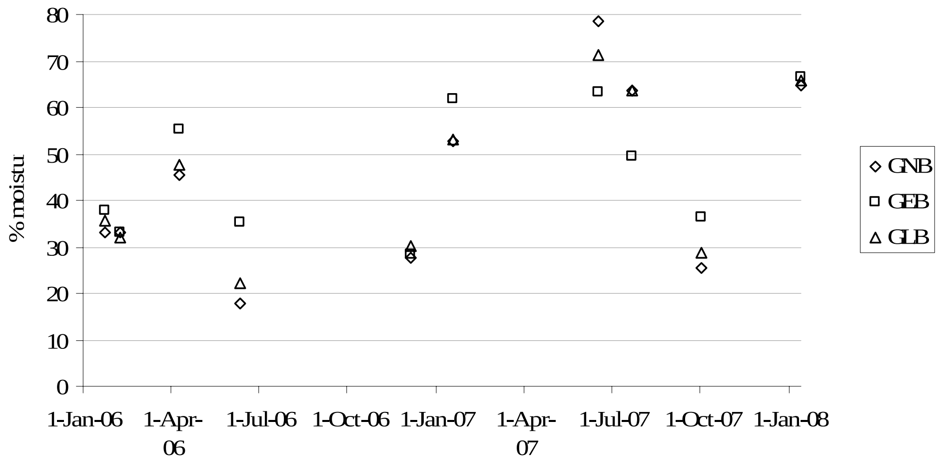


Figure F4 Soil moisture (%) across treatment plots. (a) Grassland; (b) Termitaria; (c) Grassland. NB = No burn; EB = Early burn; LB = Late burn.

APPENDIX G

Table G1 ANOVA results of percentage soil moisture per habitat type and treatment (blocked by site), with factor interactions. *** = *p*< 0.001; ns = non significant.

Factor	Soil Moisture
Habitat	*** (f = 561; df = 2)
Treatment	Ns
Date (year)	*** (f = 116; df = 4)
Habitat*Treatment	Ns
Habitat*Date	*** (f = 1442; df = 7)
Treatment*Date	Ns
Habitat*Treatment*Date	Ns

Table G2 ANOVA results of percentage bare ground and litter cover (both log transformed) per habitat type and treatment June 2006 and June 2007 (blocked by site), with factor interactions. *** = *p*< 0.001; ns = non significant.

Factor	Log Bare Ground	log Litter
Habitat	*** (f = 14; df = 2)	ns
Treatment	ns	ns
Date (year)	ns	ns
Habitat*Treatment	ns	ns
Habitat*Date	ns	ns
Treatment*Date	ns	ns
Habitat*Treatment*Date	ns	ns

Table G3 ANOVA results of vegetation height (cm) per habitat type and treatment (blocked by site), with factor interactions. * = *p*<0.05; *** = *p*< 0.001; ns = non significant.

Factor	Vegetation Height
Habitat	*** (f = 8.1; df = 2)
Treatment	*** (f = 8.9; df = 2)
Date no.	*** (f = 129; df = 2)
Habitat*Treatment	* (f = 2.7; df = 4)
Habitat*Date	* (f = 2.8; df = 4)
Treatment*Date no.	*** (f = 10.9; df = 4)
Habitat*Treatment*Date no.	ns

Table G4 ANOVA results of biomass variables per habitat type and treatment (blocked by site), with factor interactions. * = $p<0.05$; ** = $p<0.01$; *** = $p< 0.001$; ns = non significant.

Factor	**Standing Crop**	**Live Biomass**	**Dead Biomass (Necromass)**	**log Live:Dead ratio**
Habitat	*** (f = 10.4; df = 2)	*** (f = 12.1; df = 2)	*** (f = 14.9; df = 2)	* (f = 4.1; df = 2)
Treatment	ns	* (f = 4.6; df = 2)	** (f = 5.7; df = 2)	ns
Date no.	*** (f = 32.4; df = 2)	*** (f = 178; df = 2)	* (f = 3.9; df = 2)	*** (f = 30.1; df = 2)
Habitat*Treatment	ns	ns	* (f = 2.9; df = 4)	ns
Habitat*Date	* (f = 3; df = 4)	** (f = 3.7; df = 4)	ns	ns
Treatment*Date	ns	* (f = 3.16; df = 4)	*** (f = 7; df = 4)	ns
Habitat*Treatment*Date	ns	ns	ns	ns

Table G5 ANOVA results of treatment carry-over effects of burning treatments in the previous year (2006) for biomass variables measured in May in the subsequent year (2007) per habitat type and treatment (blocked by site), with factor interactions. *** = $p< 0.001$; ns = non significant.

Factor	**Standing Crop**	**log Live Biomass**	**Dead Biomass (Necromass)**	**log Live:Dead ratio**
Habitat	*** (f = 22.3; df = 2)	*** (f = 12.7; df = 2)	*** (f = 22.1; df = 2)	*** (f = 11.3; df = 2)
Treatment	ns	ns	ns	ns
Habitat*Treatment	ns	ns	ns	ns

Table G6 ANOVA results of accumulated log live biomass and accumulated offtake of live biomass per habitat type and treatment (blocked by site), between September 2006 and May 2007, with factor interactions. *** = $p< 0.001$; ns = non significant.

Factor	**log Live Biomass Accumulation**	**Offtake**
Habitat	*** (f = 12.4; df = 2)	Ns
Treatment	ns	Ns
Habitat*Treatment	ns	Ns