THE ECOLOGICAL IMPACT OF ABANDONED MAASAI SETTLEMENTS ON SAVANNA VEGETATION AND ITS HERBIVORES IN THE AMBOSELI ECOSYSTEM.

BY

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Submitted in partial fulfilment of the requirement for the degree of MSc in Biology of Conservation in the University of Nairobi.

I, Andrew N. Muchiru, hereby declare that this thesis in my own original work and has not been presented for a degree at any other university.

Andrew N. Muchiru

We, Dr. Warui Karanja and Dr. David Western hereby declare that this thesis has been submitted for examination with our approval as University Supervisors.

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Dr. David Western

Nairobi, August 1992.

DEDICATION

I dedicate this work to my brother Simon, sister Mary and my mother for their encouragement throughout this exercise.

CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

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ABSTRACT

The open savannas scientist have come to regard as typical have been created by the activities of humans, livestock, fire and wildlife. Many studies of savannas ecosystems have concentrated on the fairly destructive effects of fire, waterholes and woodcutting, deemphasizing the human role. Yet human activity, especially pastoralism is an important part of the savanna ecosystem. In many parts of the world, savannas continues to expand as forest and woodland recede due to human activities including woodcutting for fuel and clearing new land for cultivation.

The impact of abandoned human settlements on the savanna ecosystems is of major importance, but is poorly understood. Construction of a settlement initiates alterations that, in some cases, could last for centuries. In particular, the soils of settlements develop different chemical and physical properties from the soils of undisturbed areas nearby.

During the life of a settlement, cattle, sheep and goats forage on a large area, returning home every night. These animals continually deposit large amounts of nitrogen-loaded faeces and urine over a small area, boosting the availability of nutrients essential for plant growth and production, which are often in inadequate supply in savanna ecosystems. After a settlement has been abandoned, it may act as a source of nutrients far into the future. Essentially, abandoned settlements become eutrophic islands in a dystrophic area.

In Amboseli, ground cover on settlements that had been abandoned for less than 40 years was higher than on the surrounding areas. The settlements that had been abandoned for much longer periods tended ot have a canopy cover dominated by *Acacia tortilis*, which shades out most of the pioneer herbs and grasses that colonize settlement soon after abandonment.

Different herbivores utilized abandoned settlements at successive vegetation stages. Soon after abandonement, some herbivore species spent time resting in the safe open areas of former settlements. Grazers took advantage of the abundant grass that succeeded the pioneer herbs and eventually *A. tortilis* attracted browsers to the abandoned settlements.

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Savanna Ecosystem

The tropical savannas cover some 23 million square kilometers between the equatorial rainforest and mid latitude desert and semi-desert worldwide. They cover 20% of the earth's land surface, 65% of Africa, 60% of Australia, 45% of South America and about 10% of India and South East Asia (Cole 1986). Savannas qualify as one of the world's major biomes (Whittaker 1975), and ungulates make up a large portion of its biomass (Bell 1971). Past studies of the savannas have concentrated on the effects of fire, water holes and wood cutting on savanna ecosystems. These have been regarded as destructive, but just how destructive they are is debatable (Kozlowski 1974; Woodmansee and Wallach 1981).

The savannas include plant communities of diverse floristic composition and varying physiognomy from pure grassland, and low tree and shrub savannas to open deciduous woodland, thicket and scrub (Cole 1986). Savannas are characterized by frequent major changes in range conditions due to fire, water availability, major changes in herbivore numbers and fluctuating grazing pressures. However they are highly resilient, with a strong tendency to recover despite disturbance (Noy-Meir 1982; Walker and Noy-Meir 1982). This is attributed to high reproductive rates of savanna plants under stress conditions, increased growth rates of vegetation at low biomass, spatial heterogeneity which encourages herbivore migration and provides sources of colonization, underground reserves, dormancy mechanisms and the species selection flexibility of the herbivore community exploiting the multispecies plant biomass.

Increased grazing eventually leads to a decrease in preferred species and an increase in unpalatable species, leading in turn to a reduction in grazing populations and the subsequent recovery of the palatable species. Such in-built fluctuations are to be expected in semi-arid grazing systems (McNaughton 1979; Sandford 1983). The herbaceous stratum is dominant despite the height superiority of the trees and shrub component of the vegetation (Bate 1981). The savannas have been characterized by Johnson and Tothill (1985) as follows.

a) Geographically tropical to sub-tropical;

b) Climatically seasonal and stochastic, with alternating wet and dry periods, and an annual rainfall between 200-1300 mm;

c) Structurally continuous grass-herb layer associated with a discontinuous shrubby or woody overstory;

d) Dynamically highly variable, heterogeneous and labile in time and space; and

e) Functionally a major resource for large grazing and browsing wild and domestic herbivores. Indeed, savannas constitute the majority of the world's grazing lands, (Frost *et al.* 1985), and exceed all other biomes in secondary productivity (Whittaker 1975; Georgiadis 1987).

Recent syntheses of research in savanna (Huntley & Walker 1982; Bourliere 1983; Tothill and Mott 1985) have identified soil water availability, soil nutrient availability, fire and herbivory as the four principal determinants of savanna composition, physiognomy, dynamics and productivity. Fire and herbivores affect vegetation structure and levels of rangeland productivity otherwise intrinsically determined by plant-available moisture and nutrients. Fire is common in tropical grasslands wherever low grazing pressure allows the accumulation of dry plant matter. Fire leads to loss of volatile compounds of nitrogen, carbon and sulphur. It tends to destroy woody seedlings and sensitive species, particularly those lacking seed adaptation, below ground reserves and the capacity to resprout. Temporary protection against fire will, in the absence of compensatory grazing, allow an accumulation of standing biomass of low nutritive value and an increase of fire-sensitive, often unpalatable herbaceous species (Homewood and Rodgers 1991).

The main impacts of herbivores on the environment are defoliation, trampling and nutrient cycling. Selective defoliation may bring about a shift in cover and species composition, in some cases stimulating and in others adversely affecting growth and spread of particular species. Reduced cover and increased bare ground may exacerbate erosion together with physical changes in the soil adverse to plant growth. Trampling in some cases assists tillering and vegetative spread but also leads to soil compaction and adverse structural changes, especially at higher intensities. Herbivores assist nutrient recycling through removal of plant matter and deposition of dung. The latter might be unevenly distributed. McNaughton (1985) comments on the tendency of wildebeest to graze in the medium and tall grassland during the dry season but to ruminate, rest and deposit dung in the shorter grass areas of their dry season habitat. He suggests that this may have implications for nutrient stripping and concentration respectively in the two habitat types.

Large and small mammals plus invertebrate herbivores each have characteristic but to some extent overlapping impacts on range (Sinclair 1975). Small mammals and invertebrates may have significant grazing effects in terms of competition for green biomass at times of low forage availability (Sinclair 1975), and their defoliation effects may be more significant for browse (Belsky 1984) than grass species.

Noy-Meir (1975, 1978 and 1982) has explored different possible patterns of pasture growth combined with different herbivore consumption responses. Plant growth shows an initial increase in response to grazing, up to a maximum productivity. Some systems then show a progressive steady decline with heavier grazing. Others continue at a high level of productivity up to a critical threshold grazing pressure at which there is a dramatic crash to a new much lower level. Noy-Meir suggests that savannas tend to correspond to the former and improved or commercially managed pastures to the latter. The ultimate outcome depends on forage palatability, accessibility and the efficiency of the grazer. Green biomass in dwarf or prostrate forms and underground storage organs of perennials may form an ungrazeable reserve. Thus creeping perennials like *Cynodon* sp and the relatively unpalatable *Eleusine* sp with its high silica content have relatively secure ungrazeable reserves, while erect palatable perennials like *Themeda* sp have little protective reserves. The secondary toxic compounds in *Cynodon* sp young growth also protect against this species being grazed to the point of destruction (Homewood and Rodgers 1991). *Themeda triandra* is stimulated by moderate defoliation and needs dry season burning to ensure its continued survival (Braun 1973; Coughenour *et al.* 1985). Such burning increases palatability and availability and has been used by pastoralist for centuries.

Primary productivity is largely controlled by annual rainfall and soil nutrient availability (Georgiadis 1987; Bell 1982). Soil water and nutrients also affect the relative abundance of trees and grasses (Cole 1982; Tinley 1982) and plant nutritional quality for herbivores Differences in fertility between soils derived from basement or from volcanic rock, known respectively as dystrophic and eutrophic soils, cause systematic differences in primary productivity (Bell 1982). In turn, productivity determines the level of herbivory and the ratio of tree to grass productivity affects the relative abundance of browsers and grazers in a given community (Georgiadis 1987).

Strong interaction exists among the four principal factors, that is soil fertility, fire, herbivory and rainfall. For example, soils tend to be less fertile in high rainfall areas as a result of leaching (Frost *et al.* 1985). Herbivory can increase or decrease grassland productivity (McNaughton 1976, 1985), depending on its timing and intensity with respect to soil moisture and fertility (MacNaughton *et al.* 1986). Browsing mammals can prevent saplings from reaching the height at which they escape fire thereby retarding woodland regeneration (Pellew 1983; Belsky 1984). Conversely, by consuming grass that fuels fire, grazers can decrease fire intensity, and fire-induced sapling mortality (Norton-Griffiths 1979) thereby promoting woodland regeneration. A property of savanna is that local history and the timing, sequence, combination and intensity of biotic and abiotic factors are more important in determining species composition and productivity than are any of those factors operating in isolation (McNaughton 1983)

1.2 Humans Impact on Savannas

Recent evidence suggests that pastoralism has been a factor in the history and ecology of East Africa since 6000 B.C. (Mgomezulu 1981), some 4000 years earlier than previously assumed (Odner 1972; Sutton 1972). Pastoral people are identified in the archaeological records by a combination of one or more types of evidence such as remains of domesticated stock, characteristic pottery and other artifacts including stone bowls and small querns, and location by ecoclimatic zone and soil type (Robertshaw and Collett 1983). Linguistic evidence has contributed a great deal to unravelling the origins of East African peoples including the Maasai (Sutton 1974; Ehret 1974). All East African languages are derived from four distinct groups: Khoisan, Cushitic, Bantu and Nilotic (Greenberg 1963). Among the Nilotic linguistic group are the plains Nilotic who include the Maasai, together with other *Maa*-speaking people like the Samburu.

Historically, pastoralist may be partly responsible for inducing and maintaining the grasslands which characterize the East African savanna (Jensen 1983a). In the study of the savannas it is important to consider human ecology. Human impact, especially through pastoralism, has played a large part in the structure and dynamics of the savanna ecosystem. Bell (1971) suggests that the highest concentration of wild ungulates are found in areas of past and present pastoral activity, while Cole (1986) concedes that a large portion of the biomass in the savanna is livestock, which plays a large role ecologically. The most common pastoralist livestock species in tropical African rangeland are cattle, sheep and goat, with camel restricted to more arid areas and small numbers of donkeys being found throughout pastoralist areas. Cattle are estimated to make up 70% of all tropical livestock units with sheep and goat contributing 17%, camel 8% and equines 5% (Homewood and Rodgers 1991).

Cattle are coarse bulk grazers, able to crop a grass sward down to 3cm. They prefer leaf but will take stem. In the dry season they can browse selectively on a variety of herbaceous and woody species, rarely above 1.5m. in height, but avoid thorny or leathery xerophytes. Sheep are basically grazers, capable of cropping short turf below 2cm. They will take soft forbs and coarser grass. Goats are largely browsers, taking some greener grass leaves. They can exercise considerable selection due to mobile lips and tongue and can nibble around thorns. Climbing and standing on their hind legs, they can browse to an effective height of 1.5 m. Donkeys are coarse grazers cropping closely but not selectively and taking a diet high in stem (Honeywood and Rodgers 1991).

Savannas in many parts of the world are expanding as forests and woodlands recede due to human activities, including cultivation and cutting wood for fuel and building. Past studies have concentrated on the direct impact of human, livestock and water holes on the savanna vegetation. The effects of settlement on woody vegetation have been looked at by Jensen (1983b). The author quantified wood use in settlement building and fuel wood consumption by pastoralist Maasai. Wood use in building was measured by sampling the weight of wood used in huts, perimeter fencing and small corrals at occupied sites. Mean number of huts, perimeter length and total corral length were measured. This information was used in calculating the weight of the wood used in building an average settlement. The wood used in settlement repair was roughly estimated, while fuelwood use was measured on per hut basis at occupied settlements. Tree species were noted while weighing the fuelwood.

In another paper, Jensen (1983a) studied the effect of settlement on shrub vegetation. Shrubs surrounding a settlement are trampled, browsed heavily by goats or cut for use in building huts, thorn enclosures and beds. A ring of shrub denudation develops around an occupied settlement but the degree of denudation decreases as a function of the distance from the site. Large settlement sites and those which have been occupied for long periods of time have more extensive areas of shrub denudation (Jensen 1983a). The author compared occupied to abandoned settlements in terms of shrub density, species richness and species composition. Other comparisons were done on extant settlements, which were either occupied or unoccupied but not abandoned, and abandoned settlements, which were either burned or not. Jensen found the presence or absence of burning to have greater effect on shrub density and recovery onsite than age of the abandoned site. Burned sites were nearly devoid of shrubs. The mean density of shrubs on unburned sites was much higher than on the burned sites. While offsite mean shrub density around occupied sites was found to be lower than around abandoned sites, offsite shrub density around abandoned sites was found to increase as a function of age. Species richness was also lower offsite around occupied sites than around those abandoned.

In their research on the vegetation of Turkana district Ellis and Dick (1985) found no evidence of extensive environmental degradation caused by traditional practice. Ngisonyoka (a section of Turkana people) will only use small *A. tortilis* (12-15 cm. diameter at breast height-dbh) for settlement construction while conserving those exceeding 20m. canopy diameter for shade. Herders harvest seed pods from mature *A. tortilis* for goats and young camels (Ellis and Dick 1985). Ngisonyoka livestock are corraled nightly for 10-12 hours for protection from predators. This results in accumulation of large amount of dung and urine on a small area (Corral). The authors observed that abandoned corrals often supported a large number of *A. tortilis* seedlings and relatively few outside the corrals. *A. tortilis* germination is increased by passage of seeds through the gastro-intestinal tract of ruminants because of scarification and reduction in seed parasitism (Lamprey *et al.* 1974). Ellis and Dick (1985), hypothesized that the concentration of nutrients from faeces and urine in corrals might further enhance seedling establishment. The ultimate fate of the seedlings appear to depend on the location of the abandoned corral. On upland areas, these trees seldom, if ever, exceed 12-15 cm. dbh. Truly large *A. tortilis* with a canopy diameter exceeding 20m. occur in association with drainage channels (Ellis and Dick 1985).

Nutrient concentration through dung accumulation has a visible effect on vegetation growth both in abandoned and around current Maasai settlements (Stelfox 1986). Stelfox found high levels of nitrogen, phosphorous, sulphite, calcium salts and organic material in and around settlement sites compared with control sites 250 m. from settlements. Grasses immediately around the site were higher in crude protein (CP) and lower in crude fibre (CF), and the higher quality grass *Cynodon* predominates, as is common on disturbed fertile soils. By contrast, the control sites were all *Pennisetum-Themeda* grassland. The author points out that the frequent relocation of settlements encourages redistribution of nutrients concentrated in dung and urine throughout the range.

Tolsma *et al* (1987), studying nutrient levels in soil and vegetation around artificial waterpoints in Eastern Botswana, suggest that cattle strip the savanna off specific nutrients to the point of generating phosphate deficiency both in vegetation and ultimately in their own diet. The deposition of phosphate and other nutrients over a small radius round waterpoints results in toxic concentrations that would only allow a few toxic resistant herbs to grow. The heavily trampled area precludes the growth of anything other than trampling-resistant woody species.

Georgiadis (1987) looked at the response of savanna vegetation and soil to herbivore use intensity (HUI) along a gradient from water troughs. The soil samples were tested for nitrogen, carbon, pH, electrical conductivity and exchangeable cations. Highly significant differences were found between gradients for all soil variables except C/N ratio, which differed marginally between gradients. At the lowest level of herbivore use intensity soils at some sites had on average lower pH, higher sand content, higher bulk density and infiltration rate and lower electrical conductivity, compared to soil at the other sites. Overall, none of the soil could be considered infertile, since levels of exchangeable cations were moderate. Green biomass varied with distance in different ways between and within HUI gradients.

When the Maasai move into an area, they first locate a suitable settlement site. Physical, biological and social factors determine the suitability of a site for a settlement. The settlements avoid hillslopes with a gradient exceeding 0.08 and the long sections of hills. Amboseli Maasai most often selected areas of canopy cover not greater than 10%, to reduce the risk of being attacked by predators and other large animals. Settlements are never located in area with no canopy cover, as wood is needed for settlement building and fuel wood (Western and Dunne 1979). A trade off results between the danger of high tree density and the inconvenience of wood collection which low tree density represents. Availability of water and good pasture are among the first priorities that the Maasai have to consider while selecting a settlement site. This is because the Maasai are severely constrained by water during the dry season. Good pasture should cater for the needs of the stock and also enable them to return to the settlement for protection against nocturnal predators.

A trade off between frequency of water intake and grazing intake is the most important compromise required of a settlement location. Where both requirements spatially coincide no compromise is necessary and location is as close to the resources as possible. Where grazing is better further away from the water, a trade-off maximizing the level of forage intake with water intake is necessary. Settlement location then approximates a point midway between water and the pastures, such that it is half a days walk to water and half a days walk directly to the pasture (Western 1973).

Local abundance of grazing will lead to a local concentration of settlements. In this situation settlements tend to be of a larger size, a strategy more economical and less destructive of local resources such as wood used in settlements and browse for livestock. Large settlements will require less wood for building a thorn fence to protect the livestock from nocturnal predators, than would several small settlements. The area occupied by the settlements is reduced, leaving a larger area for livestock. Conversely, uniform distribution of forage over a large area lead to uniformly distributed settlements of smaller size, a strategy leading to a more uniform distribution of stock and efficient use of available forage.

There are three aspects of Maasai ecology that could conceivably lead to woodland deterioration: cutting, burning and trampling by livestock. The construction of a settlement has an impact on the savannas which may last for centuries. Wood cutting, both for building material and fuel, decreases woody vegetation cover around the settlement. This creates an open plain in the bushland or woodland, which increases the grazing area for the grazers which move in after the abandonment of the settlement. Grasses and herbs surrounding the settlement may recover quickly from grazing and trampling after the abandonment, while shrubs and trees may take a longer time. The more significant impact of the settlement is on the site. Cattle, sheep and goats forage over a large area around the settlement and spend up to twelve hours in the settlement each night, depositing large amounts of faeces and urine during the occupation of the settlement (Western and Dunne 1979).

A settlement will not be occupied continuously. Most families will move a minimum of four times a year (Jensen 1983b). The Maasai will abandon a settlement completely after several episodes of occupation because of dung accumulation, which eventually impedes the infiltration of urine into the ground, causing discomfort to both human and livestock. Deterioration of huts and fences are other factors contributing to the abandonment of a settlement site. Occasionally they will come back and burn the site. Burning reportedly reduces tick, flea and fly outbreaks. This is important even though the site is abandoned, because Maasai often will build a new settlement near an abandoned one (Jensen 1983a).

Nutrients essential for plant growth and production are inadequate in many parts of the savanna. The deposits of livestock urine and faeces therefore become an important source of nutrients in the grassland adjacent and on the settlements. Long after the settlement has been abandoned, it acts as a nutrient source which may last for decades. Essentially these old settlements become eutrophic islands in a dystrophic area. These old settlement sites have influenced the diversity, patchiness and productivity of the savannas. Thus, the impact of the settlement is an important factor in changing the savanna flora and fauna that needs to be understood particularly in management and development decisions.

The area covered in this study lies to the north of Amboseli National Park as described in detail in the study area section (Chapter 2.2). In early 70s the human-livestock complex here contributed 50% of the total biomass (Western 1973). The influence of man (and his stock) is the most significant biotic factor in the community. The Maasai moved into southern Maasailand and presumably Amboseli, around the 15th or 16th century (Jacobs 1965). In so doing they displaced an earlier group of pastoralist whom they called Oloogalala (people of the hard teeth). How far their mode of pastoralism differed from that of Maasai is not known, but it is clear that the arrival of Maasai did not introduce a new element into the ecosystem. Pastoralism was already a component of it and probably had been for millennia (Western 1973).

Although much work has been done on ecological impact of settlement on the savanna, a few other issues need to be addressed. Wood use has been quantified, but it is important to establish the effect of the wood harvest on the savanna and its implications for the wildlife and livestock. Taking a settlement as a disturbed area in an otherwise mature community, what happens after it has been abandoned and left undisturbed is ecologically important. The dung deposit decomposes gradually over time, eventually changing the physical and chemical characteristics of the soil. This creates conditions conducive for a plant community different from the original one. The site may go through several secondary successional stages before attaining a new climax community. The successional communities have diverse implications that are ecologically important especially to the herbivore community. This study attempts to elucidate the ecological impact of Maasai settlements in Amboseli in regard to these issues.

1.3 Objectives

The central hypothesis of this study is that Maasai settlement increases the diversity of bushed savannas under the traditional pattern of pastoral nomadism. The hypothesis assumes that settlement site activity increases diversity in the bushed savanna by increasing its patchiness and once abandoned providing a rich eutrophic site able to support a unique plant community. A subsidiary hypothesis is that the settlement sites act as nutrient source which create islands of locally high primary and secondary production in the savanna after they are abandoned. These hypothesis were tested through the following objectives:

1) To establish the impact of Maasai settlements on the ecology of a savanna ecosystem;

2) To determine the impact of abandoned settlements on the distribution and composition of the large herbivore community;

3) To assess the contribution of abandoned settlements in the savanna ecosystem in terms of species richness, diversity and cover.

CHAPTER 2

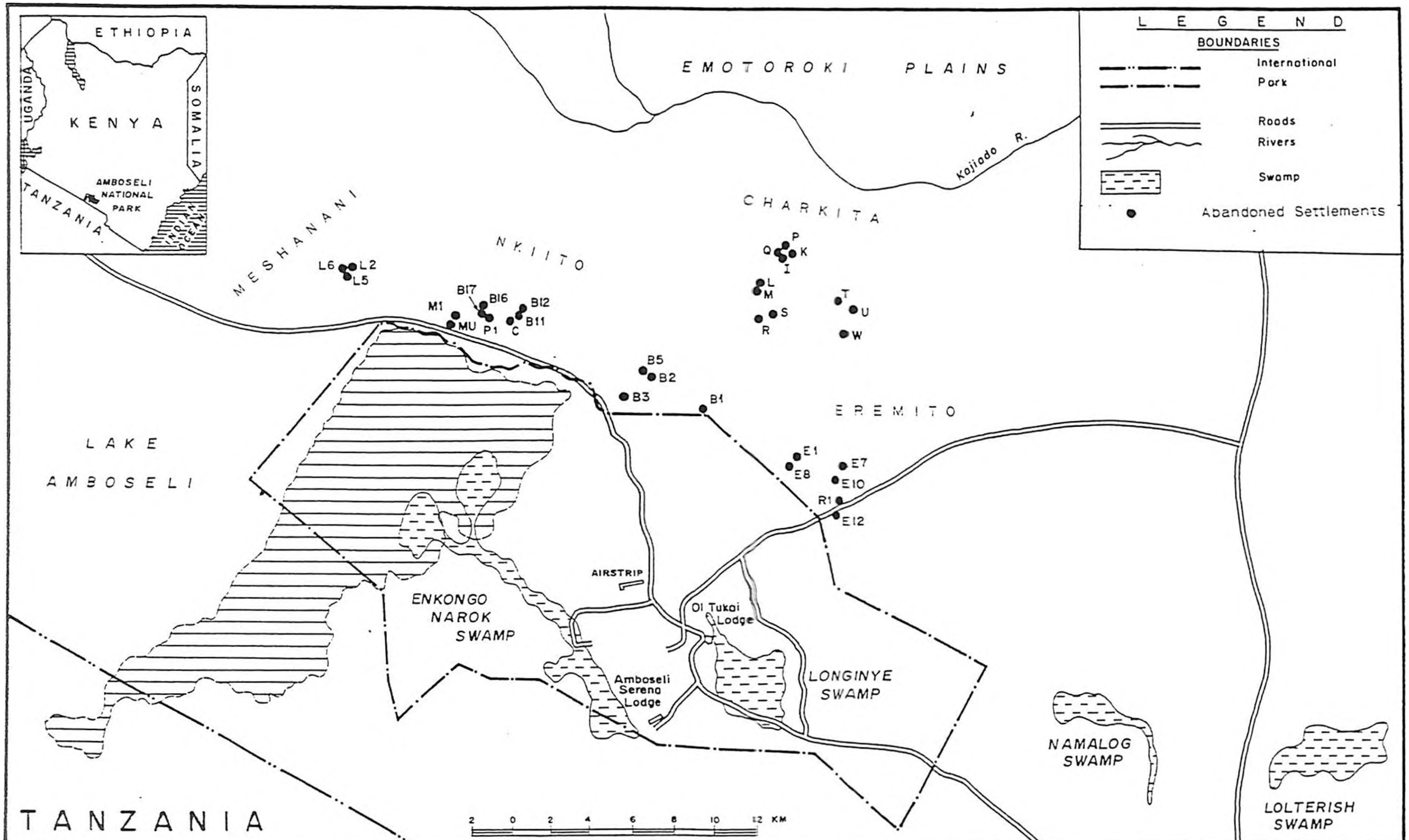
AREA

2.1 Amboseli Ecosystem

The Amboseli ecosystem covers nearly 3000Km^2 of eastern Kajiado district in Southern Kenya. It lies at the northern base of Mt. Kilimanjaro, bounded in the east by the Chyulu hills. The Meshanani Ridge, a Precambrian formation, lies in the northern side of the basin extending to the flood plains of Lengesim, Selengei and Kiboko rivers (Williams 1972). The Meshanani Ridge varies in height from 15 to 70 m above the Amboseli basin and its southern hillslopes vary in length from 680 to 3000m (Western and Dunne 1979). These authors describe the area as bushed grassland, after Pratt *et al.* (1966), with tree cover dominated by *Acacia mellifera*, *A. nubica*, *Commiphora* species, *Cordia gharaf* and *Maerua tripholia*. Grass cover is dominated by *Aristida*, *Chloris* and *Eragrostis* species.

The ecosystem is in a semi-arid savanna environment in which water availability is highly seasonal, a feature which has an important bearing on the structure and efficiency of the large mammal community. Western (1973) has grouped the large mammal community into water-dependent and water-independent species. The water-dependent species move back into the dry season concentration area, Amboseli basin, during the dry season. The water-independent will move into the basin when it is extremely dry (Western 1975).

The area has a hot and dry climate with daily maximum temperatures varying between 26°C to 44°C and minimum temperatures between 6°C to 24°C. There are two wet seasons a year, October-December and March-May. Average annual rainfall is about 350mm but inter-annual variation is high. The central area is defined by a Pleistocene lake basin, bordered to the north by the Meshanani ridge (Figure 1). According to the soil survey map compiled by Touber (1983), this area has soil developed on gneiss, mixed with volcanic ash, well drained, deep, dark reddish brown, friable to firm and sandy clay to clay (ferric luvisols).


LEGEND
BOUNDARIES
International
Park
Roads
Rivers
Swamp
Abandoned Settlements
ETHIOPIA
UGANDA
KENYA
SOMALIA
AMBOSELI NATIONAL PARK
TANZANIA
INDIAN OCEAN
EMOTOROKI PLAINS
Kajiado R.
CHARKITA
MESHANANI
NKIITO
L6
L2
L5
B17
B16
B12
M1
MU
P1
C
B11
P
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K
I
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M
S
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T
U
W
B5
B2
B3
B1
EREMITO
E1
E8
E7
E10
R1
E12
LAKE AMBOSELI
AIRSTRIP
ENKONGO NAROK SWAMP
Ol Tukai Lodge
Amboseli Serena Lodge
LONGINYE SWAMP
NAMALOG SWAMP
LOLTERISH SWAMP
TANZANIA
2 0 2 4 6 8 10 12 KM

Figure 1. Map of the study area showing the location of the abandoned settlements in relation to Amboseli National Park

Amboseli has several permanent swamps which are fed by underground springs from Mt. Kilimanjaro. These are Longinye, Enkongo Narok, Namelog and Kimana swamps. These swamps have made Amboseli the home for large populations of various species of wild animals. Also, the pastoralist Maasai have for a long time taken the advantage of the availability of water in these swamps. During the wet season the availability of water around the area was increased by the seasonal lake Amboseli and rain water collecting in water holes. The seasonal water bodies allows the Maasai to extend the grazing area further away from the Amboseli basin.

Over the last two decades Amboseli's ecology has changed drastically. Most of Amboseli was dense woodland with a canopy dominated by *A. xanthopholea* and *A. tortilis*. However, this has been reduced to heavily grazed plains with large numbers of wildebeest and zebras and scores of other grazing species. The elephants contributed substantially to the opening up of the woodland. Although Amboseli always had many elephants, their population increased suddenly in the seventies due to compression of their range as a result of poaching. The elephants that used to migrate as far as Sultan Hamud and areas near Namanga became sedentary in Amboseli. The elephants destroyed most of the young trees, which they could break easily. The mature trees were debarked to the extent that they could not survive either.

The loss of vegetation dramatically affected the diversity of the Amboseli ecosystem. Many species of birds have disappeared from the park and primate numbers have fallen. Such species as lesser kudu (*Tragelaphus imberbis*), bushbuck (*T. scriptus*), giraffe (*Girafa camelopardalis*) and gerenuk (*Litocranius walleri*) moved out of the Amboseli basin into the more bushed area.

2.2 Study Area

The study area extends from Meshanani ridge through Nkiito to Eremito covering a stretch of about 40km. It lies adjacent to the northern boundary of Amboseli National Park. The area extends 10Km further north to Charkita (Figure 1). This area was chosen because it has a high density of abandoned settlements and a good aerial photographic record. Western and Dunne (1979) report that settlements in this area were used for an average of 3.7 years. Meshanani and Nkiito areas coincide with that studied by Western and Dunne (1979) and Jensen (1983a). Western and Dunne examined the environmental aspects of settlement site decision among pastoral Maasai, while Jensen looked at the effect of settlement on shrub vegetation.

The Eremito area is more of an open grassland in comparison to Meshanani, Nkiito and Charkita, with *Commiphora* species and *Acacia nubica* as dominant in tree cover. *A. thomaxii* is also found in substantial amounts in Charkita. *Sporobolus nervosa* dominates grass cover in Eremito and *Sericocomopsis pallida* predominates in the herb layer. In Charkita *Heliotropium albohispidum* and *H. steudneri* are the dominant herbs. Despite differences in these four areas (Meshanani, Nkiito Charkita and Eremito) *Blepharis linariifolia* is evenly distributed in all of them. Wild herbivores are sparsely distributed throughout the area with the exception of eland (*Taurotragus oryx*) and giraffe (*Giraffa camelopardalis*). Both of these species mostly preferred Charkita. They avoid the more open Eremito area. Elephants (*Loxodonta africana*) were observed mainly in Nkiito, but there were some sightings in Eremito. According to current research in Amboseli, elephants have stopped moving out of the Amboseli basin since the height of poaching (Western and Lindsay 1984). Herbivore distribution can be attributed to the swamps, Longinye and Enkongo Narok, which also have greatly influenced the location and distribution of settlements in the study area for a long time. In this area settlements are on average 8.3km away from the swamps (Western 1973).

2.3 Study Sites

Thirty two abandoned settlement sites were selected along the Meshanani Ridge through Nkiito to Eremito extending north to Charkita (Figure 1). Part of Charkita is an open savanna and the rest is bushed grassland. These settlement sites were selected from among many to have representative sites of different ages. Thus the thirty two sites ranged in age from those recently abandoned to those covered by grass, trees and shrubs.

Of five settlements covered by dung two were in bushed savanna and three in open grassland. The six settlements in the next successional stage were partly or completely covered by *C. plectostachyus*, some were in the open savanna and others in the bushed savanna. Sites in the next category ranged from settlements with a substantial amount of *Cynodon plectostachyus* and scattered shrubs to those with well established shrubs and trees, including some *A. tortilis*. In the final category settlements were dominated by *A. tortilis* canopy.

CHAPTER 3

METHODS

3.1 Introduction.

In studying the impact of abandoned settlements on savanna ecology several data sets were collected in the field. Each data set required a different method. The abandoned settlements of varying age required identification and location on the ground using aerial photographs and information from Maasai residents. To determine the impact of the abandoned settlement sites on large herbivores and carnivores, I collected data on animal occupancy, ground cover, woody vegetation and species composition on the abandoned settlements and in the area around each settlement.

A large amount of dung on a small area has a profound effect on the nature of the soil, and consequently on the vegetation. It was therefore necessary to look at the changes that occur within the soil and the subsequent colonization by grasses, herbs, shrubs and trees. *A. tortilis* was the dominant tree on most of the settlements abandoned for a long time. This observation called for further investigation into the germination of *A.tortilis* seeds through a seedling experiment. The hypothesis here is that these seeds remain dormant on the abandoned settlement until the soil conditions are suitable for their germination. These seeds are dispersed to the settlements through goats. Goats feed on these seeds in the field. At night they deposit the seeds as they defecate. All data were collected between September 1990 and September 1991.

3.2 Aging and Selection of Sites

To identify abandoned settlement sites on the aerial photographs and then locate them on the ground, three series of aerial photographs, 1950, 1961 and 1970 with a scale of 1:20,000 were used. Locating the identified sites on the ground was done using land marks such as hills, trees, valleys and water holes. Abandoned settlements that were established after 1970 were located with the help of Maasai informants. Aerial photographs and ground reconnaissance were used to select thirty two abandoned settlement sites of varying age since abandonment. The age of each abandoned site was determined either by extrapolating from the aerial photographs or with the help of Maasai informants. Sites of less than fifty years were fairly accurately aged by using informants of approximately 70 years old who have lived in the area since they were children. They could remember their age when they occupied a specific settlement.

Occupied settlements on these photographs are very dark due to fresh dung. They have a distinct edge, depicting the thorn fence, and visible huts. The huts are the first to disappear after abandonment followed by the fence. This takes about year to a year and half. The fence deteriorates faster due to lack of maintenance. Disappearance of the huts may be even faster if a settlement is abandoned immediately before the rains. An abandoned site loses its dark colour if no fresh dung is deposited.

Jensen's (1983a) technique was used to age abandoned settlements from photographs. If a settlement had been abandoned first in 1970 it was estimated to be about 20 years, and that abandoned first in 1961 was estimated to be about 30 years by 1990. The same was done with those settlements abandoned first in 1950. They were estimated to be about 40 years old. By extrapolation, settlements much older were identified from the photographs, located on the ground and their ages estimated. Settlements fade with age. A settlement abandoned first in 1950 can be observed to have faded in the subsequent photographs (1961 and 1970) Such a settlement would be estimated to be about 40 years in 1990. A settlement on the 1950 photograph having the same texture implies that it had been abandoned 40 years before 1950. Consequently the settlement would be 80 years by 1990. Using this technique I was able to locate settlements of 50 years to over a century old. The extrapolation technique was checked against the information given by my informers and was found to correlate.

3.3 Determining Animal Occupancy

At each abandoned settlement herbivore use was estimated using fresh dung as an index of use. Dung counts were done monthly, along two randomly selected transects of 10m wide and 250m long radiating from the settlement. The transects began at the edge of the settlement (Figure 2a and 2b). One transect was selected using random numbers between 0 and .999 generated from a calculator. This range of random numbers was divided into quarters: (1) Numbers less than .250, (2) between .250 and .499, (3) between .500 and .749 and (4) those over .749. Assuming four possible transects radiating from the abandoned settlement in different compass directions, (i.e. north, south, east and west) each transect was assigned the range of numbers within a certain quarter. However, the second transect was set at right angles to the first to determine the half of the settlement to be used in onsite sampling. The first transect was assumed to bisect the site. The half that fell on the same side as the second transect (shaded half, figure 2a and 2b) was accepted as the area to be used in sampling onsite data.

The assumption here is that the impact of the settlement on vegetation was evenly distributed along a circle with a given radius. Thus for example sampling any point randomly selected at 50m away from the site would give a good indication of vegetation condition anywhere around the settlement at the distance in consideration. A sweeping method (Whitesides *et al.* 1988) was used throughout the exercise using two observers, each observing half of the transect (5m). Each observer assumed a central position on his side of the transect so as to scan 2.5m on either side. Only one observer did the recording. Each of the two transects radiating from the site was divided into five 10m by 50m sections. Consequently the sampled area was 1000m^2 at each section along the gradient (Figure 2a).

Seventeen herbivore species expected in the area (Western 1973) were sampled. The other species included ostrich and carnivores. Each species was given a code for the purposes of analysis. Due to the difficulties in differentiating zebra and donkey dung the two were lumped

Figure 2. Direction of the transects used in data collection in relation to an abandoned settlement

In the open savanna there were five sampling points per transect marked 1A to 5A and 1B to 5B, while in the bushed savanna there were nine; 1A to 9A and 1B to 9B. The dotted lines indicate the transects used in animal occupancy data collection. The circles show the area around the settlements represented by each point along the gradient

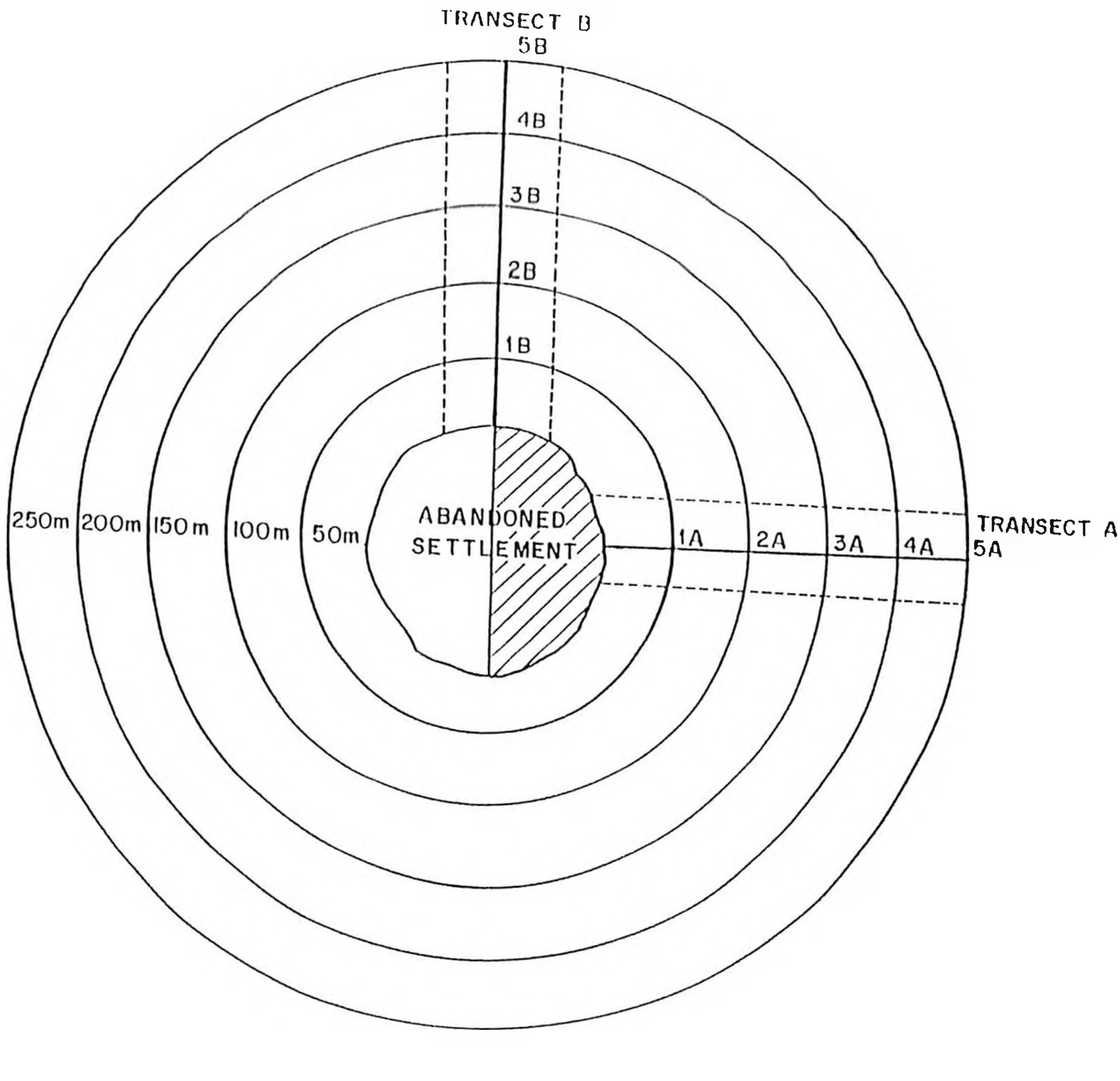


Fig. 2a (Open Savanna)

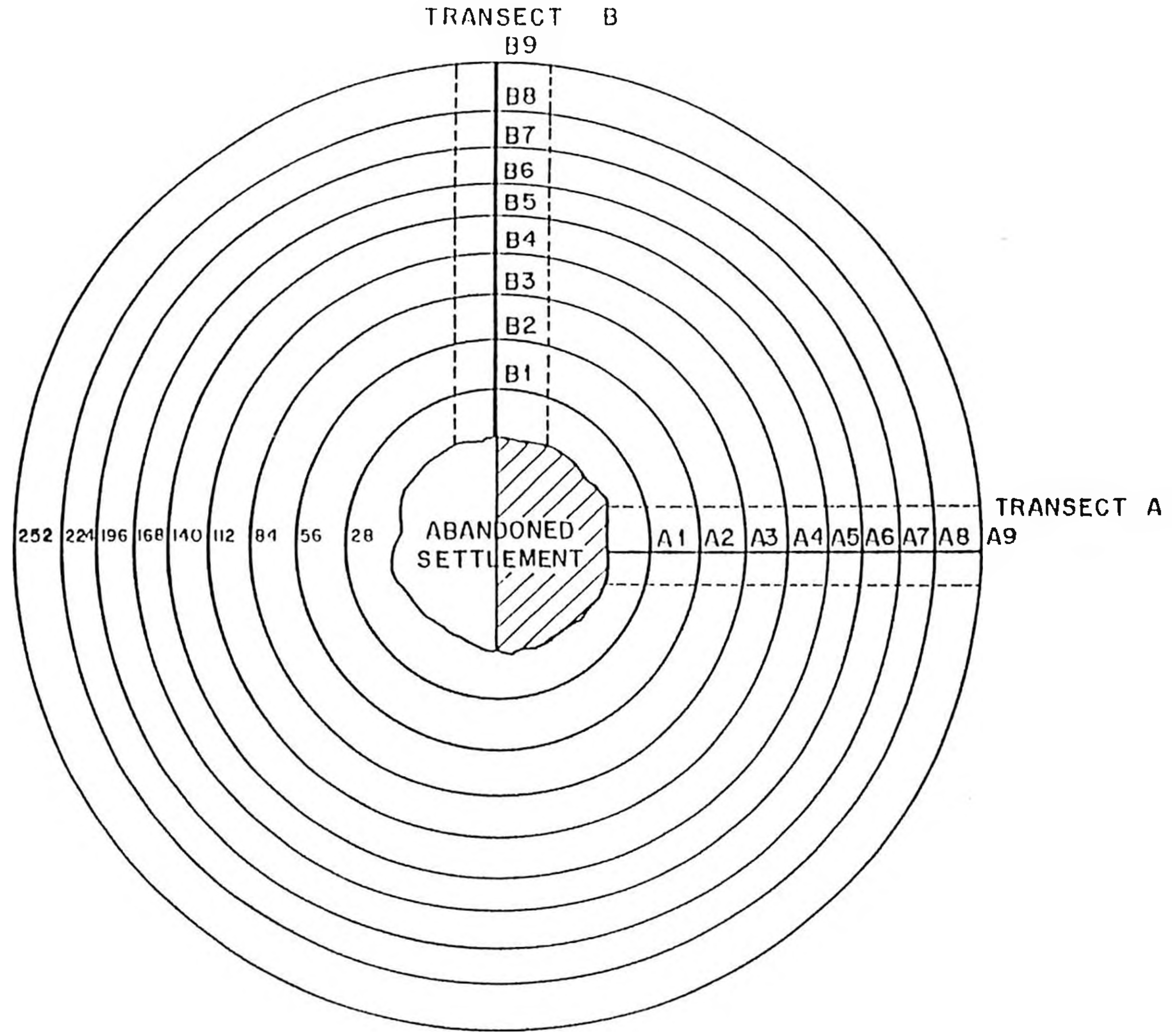


Fig. 2b. (Bushed Savanna)

together as Equidae. The carnivores were also recorded under one group because of the same problem. Goats and sheep were also lumped together as shoats, since Amboseli Maasai always kept the two together.

Only undisturbed dung was counted each month. A single dropping was taken as an entry. Most species would stop while defecating thereby making a dung pile. In the absence of a dung pile the observer followed the line of the dropping from beginning to the end. If it ended in the other half of the transect, a warning to the other observer was necessary to avoid double counting. Each dropping encountered along the transect was identified and the distance from the settlement recorded. Each dropping was then spread out or crushed immediately to avoid double counting.

Sampling onsite was done on one half of each settlement, randomly selected. Onsite denotes the area within and including the settlement perimeter, while offsite is the area immediately beyond the edge of the settlement, extending up to 250m from the settlement. The droppings onsite were identified, recorded and then spread or crushed. The same half was sampled each month as were the transects.

3.4 Determining Ground Cover

Ground cover was measured onsite and offsite for all thirty two abandoned settlements. For this exercise I used the pin-intercept technique (McNaughton 1979). The pin frame consisted of a 1m. long cross bar attached to two sets of "A" shaped stands. Several holes equally spaced were drilled through the cross bar, where the pins were threaded through. The pins may vary in length depending on the height of vegetation to be sampled. Ten pins were used in this exercise, which gave a direct percentage of ground cover. The same transects used for animal occupancy were used in measuring ground cover. Ground cover data was collected during mid dry, late dry and wet seasons. Cover was measured at 50m, 100m, 150m and 200m along each transect during the mid dry and late dry seasons. Sampling during the wet season was reduced to three points at 50m, 100m and 150m because time was limiting. At each distance 15 frames of 10 pins were recorded around the marked point at equal intervals so as to cover the entire width of the 10m. transect. Onsite data was collected on the same half as the animal occupancy data. Again 15 frames of 10 pins were recorded onsite equally distributed to cover the whole half of the settlement. The pin frame used was one 1m long. Since cover is defined as the vertical projection of the shoot area of the species to the ground surface as a fraction or percentage of a reference area, the pins were positioned vertical to the ground to avoid over estimating ground cover.

3.5 Sampling of Woody Vegetation

To determine the impact of settlement on woody vegetation, data were collected along the same transects as animal occupancy, using the Point Centered Quarter (P.C.Q.) method (Mueller-Dombois and Ellenberg 1974). In this method four distances are measured at each sampling point. Four quarters are established at the sampling point through a cross formed by two lines. One line is the compass direction and the second a line running perpendicular to the compass direction through the sampling point. The distance to the mid point of the nearest tree from the sampling point is measured in each quarter. Among the requirements of this method is that a tree or a shrub should be included in only one point along the transect. Since part of the area was more open than the other, the study area was stratified into two; the open and the bushed grassland. Eremito area and part of Charkita are open savanna while Nkiito and Meshanani are bushed savanna. Hence different interpoint distance were use for bushed from the open savanna to avoid biased sampling.

In the open grassland 5 points (Figures 2a) were taken, while in the bushed savanna there were 9 points per transect (Figure 2b). Data recorded at each point included; plant species, tree or shrub height, basal diameter, canopy dimensions (diameter and height) and the distance of each tree or shrub from the point. Trees and shrubs less than one meter high were ignored. The distance from the point center and canopy dimensions were measured with a tape measure. Basal diameter measurements were made using calipers. The height of the trees were measured with a calibrated metal bar. The height of the canopy was taken from the branching point onward or as the tree height if the branches are touching the ground.

Similar data on woody vegetation were collected onsite. At the time of settlement abandonment the area referred to as onsite is covered by a thick layer of dung A tree may be found on onsite, which could have been spared for shade during the construction of the settlement. Maasai often will locate a settlement near a large tree for shade, such that the tree will be inside or just outside the perimeter. On deciding how a big an area they want, the Maasai construct a fence using branches driven into the ground. They also spare a few trees along the line of the fence. While most of the branches driven into the ground will dry up and decay, some may take root. It was some of these trees that make up the woody vegetation community onsite that was observed on old settlements dominated by *A. tortilis*. The distance recorded in this exercise was to the nearest neighbour rather than to a point as in P.C.Q. method. Only one half of each site was sampled, the same half as in the animal occupancy data.

3.6 Determining Grass and Herbaceous Layer Species

This data was collected during the wet season at the peak of vegetation growth in April 1991. The same pin-intercept technique used in measuring ground cover was employed. However the pins are angled rather than vertical. According to McNaughton (1987), angled pins give a better estimate of species composition. Plant species intercepting any of the ten pins placed along a one meter frame and angled at 57 degrees to the horizontal were identified and recorded. The number of times each species intercepted any of the pins was recorded. The same transects used to measure ground cover were used in this exercise. However, the transect extended up to

150m from the settlement. Thus data was collected at three distances from the settlement, i.e 50m, 100m and 150m. Fifteen frames were placed seven meters apart at each distance. The same half of the settlement measured for ground cover was sampled in this exercise. Fifteen frames were measured onsite. Wet season ground cover and species composition were measured simultaneously.

3.7 Soil Characteristics

Twelve abandoned settlements out of the thirty two were selected to represent settlements of all age classes. In each age class representative settlements were selected using random numbers. Each settlement in a certain age class would be assigned a range of numbers between 0 and .999. This range of numbers (0 to .999) was divided into sections equal to the number of settlements in each of the five age classes of twenty years interval. The exercise was repeated for each age class.

At each of these settlements two holes were dug half a meter deep, one onsite and the other 100m beyond the edge of the settlement and across the slope whenever there was a slope. This was done to avoid the effect of erosion. Top soils downhill might be similar to those onsite as the dung could have been washed in that direction. Three soil samples were collected from each hole at 0-10cm ,20-30cm and 40-50cm. A 10cm. gap was left between samples so as to have a clear definition of the horizons. The hole onsite was placed as close to the center of the settlement as possible using two diameters. In the presence of a slope, the offsite hole had located either to the right or left of the settlement, otherwise the choices were many. Either way random numbers were used to determine the position of the hole. The samples were analyzed for determination of sodium, potassium, calcium, magnesium, manganese, phosphorous, carbon and nitrogen content together with pH and electrical conductivity at the National Agricultural Research laboratory.

3.8 *Acacia tortilis* Seedling Experiment

In order to test the effect of dung and soil enrichment on *A. tortilis* seed germination on abandoned settlements, eight settlements were selected for conducting the experiment. These settlements were selected to represent all age classes, as was done in the soil exercise. Some 48 soil samples were taken from the same depths as discussed in soil characteristics section (3.7). The soil samples were then put in pots. Shed *A. tortilis* seeds were collected in the field. Some of the seeds were treated and the rest were left untreated. The treatment here refers to the scarification of the seeds.

The seeds were soaked for three days before sowing them in the pots. Each pot was divided into two halves. In one half of the pot ten treated seeds were planted about a centimeter below the surface and five untreated seeds were planted in the other half. This was done to ensure that all conditions (soil, moisture, temperature etc) except scarification were the same for both set of seeds. A total of 720 seeds were planted of which 480 were treated and 240 untreated. The experiment ran for three months. Germination of the seeds and the mortality of the seedlings were monitored weekly.

CHAPTER 4

ANALYSIS AND RESULTS

4.1 Grasses and Herbs Species Composition

The species composition data were analyzed to discern the effect of abandoned settlement on regeneration both onsite and offsite. Onsite and offsite species diversity (H') and richness (number of species) values were regressed against age of the settlement sites to reveal their relationship. Diversity was calculated using the formula:

Shannon-Wiener diversity index $(H') = -\Sigma p_i * \log_e(p_i)$

p_i = the proportion of each species on the site to the total.

Species diversity and richness onsite were calculated at four levels. Grasses and herbs separately, grasses and herbs combined, and finally grasses, herbs, shrubs and trees (Appendix 1). A lognormal curve for onsite species richness and diversity regressed against settlement age was fitted on the data at all levels. This curve was used because the abandoned settlements as disturbed areas were expected to be recolonized, initially by a few species. The number would increase to a point after which they would stabilize and may decrease. However, if the disturbance was not recurrent vegetation would not disappear completely. All the regressions on species diversity and richness were highly significant (Table 1). Trends were similar at all levels (Figure 3). There was an increase in both species diversity and richness to a peak between 30 and 40 years, with the exception of diversity of grasses, which peak much later between 80 and 90 years (Figure 3h). Past this peak, results at different levels are slightly different. The decrease in herbs species richness (Figure 3c) was higher than for grasses (Figure 3d). Trends of grasses and herbs combined were very similar to those of grasses (Figure 3b). The curve for species richness including grasses, herb, shrubs and trees (Figure 3a) tends to level off with age of the

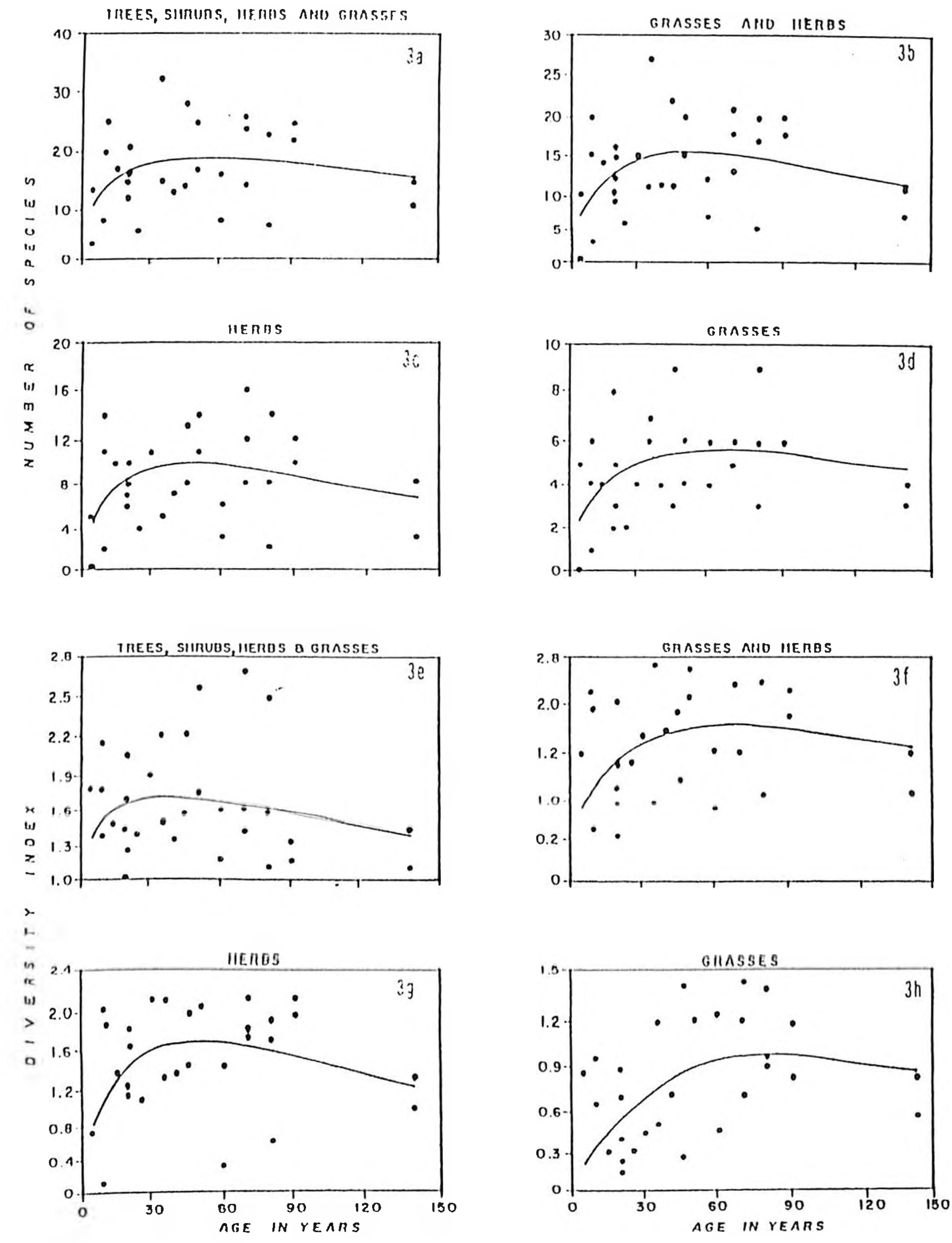
Table 1. Results of lognormal regressions fitted on species richness and diversity against settlemets' age on onsite data.

SOURCE	A	B	C	SUM OF SQUARES	MEAN SQUARE	TOTAL	F(2,29)	P
RICHNESS								
GRASSES, HERBS, SHRUBS & TREES	5.026	1.384	215.152	9537.463	3179.154	10849.000	70.296	<0.001
GRASSES AND HERBS	3.001	1.543	201.006	6004.569	2001.523	6933.000	62.519	<0.001
HERBS	1.841	1.583	171.414	2465.309	821.770	3010.000	43.752	<0.001
GRASSES	1.068	1.500	276.087	780.105	260.035	909.000	58.505	<0.001
DIVERSITY								
GRASSES, HERBS, SHRUBS & TREES	0.963	1.220	129.865	85.910	28.637	91.732	142.639	<0.001
GRASSES AND HERBS	0.456	1.414	267.428	78.902	26.301	88.347	80.754	<0.001
HERBS	0.336	1.538	195.758	71.474	23.824	79.809	82.897	<0.001
GRASSES	0.060	1.793	363.188	18.917	6.306	22.587	49.825	<0.001

n = 31

Equation = $Y * X^{b-1} * e^{x/c}$ e=2.7182

Figure 3. Onsite species richness and diversity plotted against settlements age

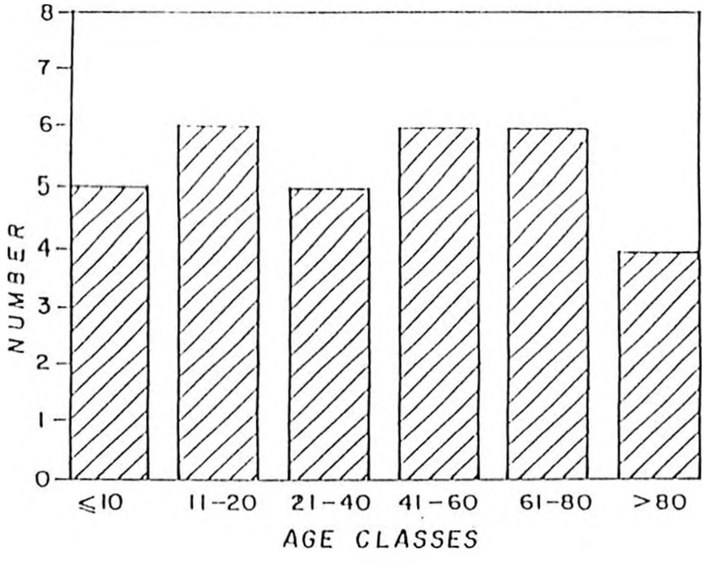

TREES, SHRUBS, HERBS AND GRASSES
3a
GRASSES AND HERBS
3b
HERBS
3c
GRASSES
3d
NUMBER OF SPECIES
TREES, SHRUBS, HERBS & GRASSES
3e
GRASSES AND HERBS
3f
HERBS
3g
GRASSES
3h
DIVERSITY INDEX
AGE IN YEARS
AGE IN YEARS

abandoned settlement. Species diversity for herbs (Figure 3g) alone clearly drops after the peak, but that of grasses alone (Figure 3h) and for grasses and herbs (Figure 3f) combined do not drop as fast after the peak. Diversity for all the species (i.e grasses, herbs, shrubs and trees) was found to decrease after 30 to 40 years (Figure 3e).

Unlike onsite data, species richness and diversity offsite were calculated for grasses and herbs separately and the two combined, at increasing distance from the abandoned settlements (Appendix 2). Trees and shrubs are dealt with in section 4.4. This was done since the effect of settlements on herbaceous and canopy layer were at different levels (see section 1.2). These data were subjected to a two way analysis of variance to establish the effect of settlement age and distance from the settlements on species richness and diversity. The means (with error bars) were calculated for each age class. The distance was in meters, whereby 0m represent onsite. The settlements were grouped into six age classes. The first age class were those settlements that had been abandoned for about a decade. In the second age class were those estimated between 11 and 20 years old, while the third, forth and fifth constituted those estimated at 21 to 40, 41 to 60 and 61 to 80 years respectively. The last age class were those over 80 years. Distribution of the settlements in the different age classes was relatively even (Figure 4). The anova results indicate that age and distance have significant effect on grass species diversity but not on herbs diversity. Only age significantly affected species richness of herbs and the two (grasses and herbs) combined (Table 2).

The results of the analysis of variance are reinforced by the trends of grass species diversity and richness. Age class grass mean diversity and richness plotted against settlement age show low values on recently abandoned settlements and high on those estimated at about 30 years. Older settlements had lower grass diversity and richness but not as low as those recently abandoned settlements (Figure 5a and 5d). Herbs species diversity and richness were also low on recently abandoned settlements and higher on those in between. The highest values were on

Figure 4. Distribution of abandoned settlements in different age classes



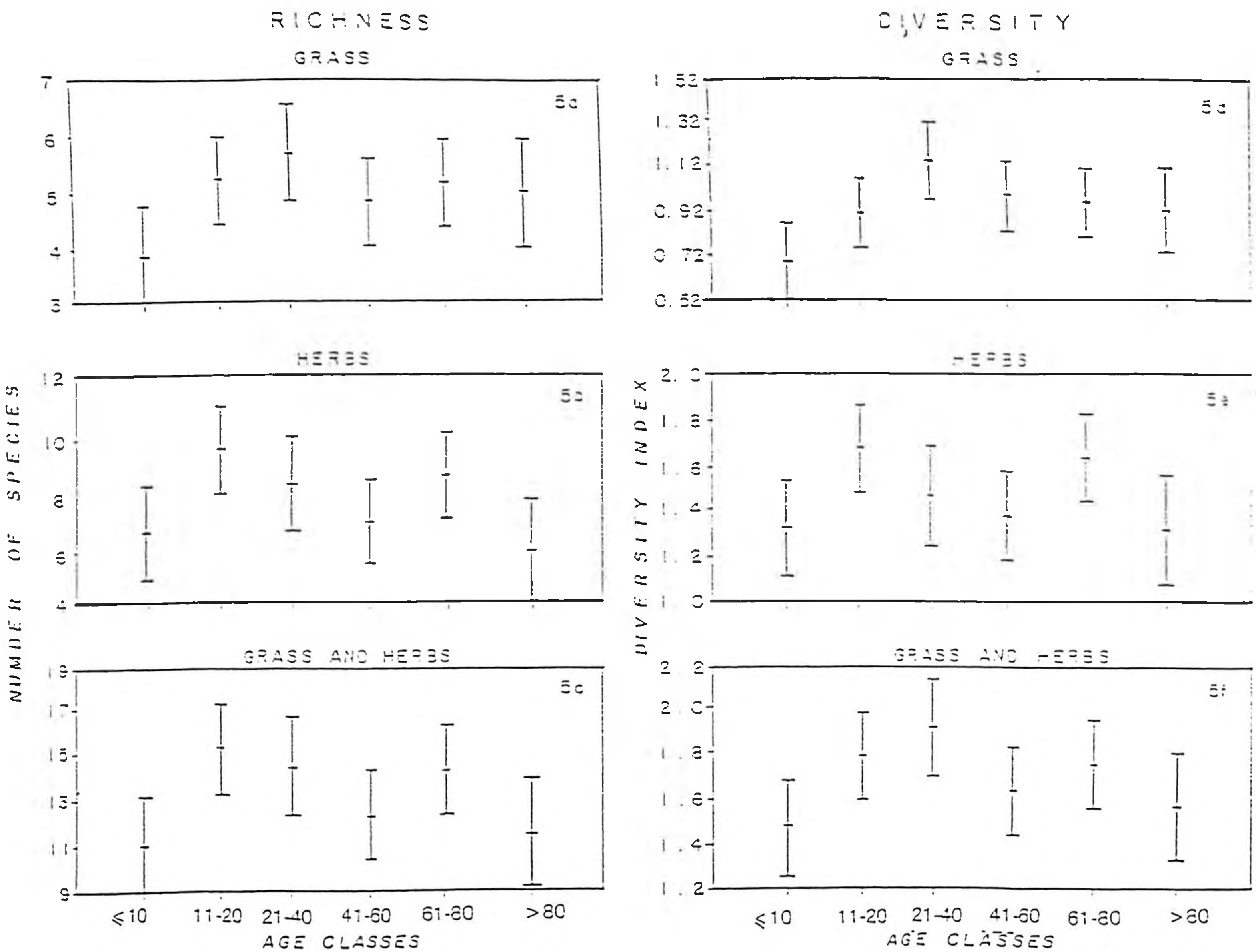
8
7
6
5
4
3
2
1
0
NUMBER
≤10
11-20
21-40
41-60
61-80
>80
AGE CLASSES

Table 2. Effects of settlements age and distance from settlements on species richness and diversity of herbaceous layer.

	DIVERSITY								
	GRASS					HERBS			
SOURCE	SUM OF SQUARES		MEAN SQUARE	F	P	SUM OF SQUARES	MEAN SQUARE	F	P
MAIN EFFECTS	4.229	8	0.529	3.392	0.002	2.794	0.349	1.468	0.056
AGE	2.212	5	0.442	2.839	0.019	2.667	0.533	2.242	0.056
DISTANCE	2.017	3	0.672	4.314	0.007	0.128	0.043	0.179	0.911
AGE BY DISTANCE	4.652	15	0.310	1.990	0.023	2.824	0.188	0.791	0.684
RESIDUAL	16.207	104	0.156			24.741	0.238		
TOTAL	25.089	127				30.359			
	GRASS AND HERBS								
MAIN EFFECTS	4.088	8	0.511	2.155	0.037				
AGE	2.713	5	0.543	2.289	0.051				
DISTANCE	1.374	3	0.458	1.932	0.129				
AGE BY DISTANCE	4.474	15	0.298	1.258	0.243				
RESIDUAL	24.657	104	0.237						
TOTAL	33.219	127							
	RICHNESS								
	GRASS					HERBS			
MAIN EFFECTS	51.604	8	6.451	1.744	0.097	219.330	27.497	2.005	0.053
AGE	36.573	5	7.315	1.978	0.088	192.330	38.466	2.805	0.020
DISTANCE	15.031	3	5.010	1.355	0.261	27.648	9.216	0.672	0.571
AGE BY DISTACE	56.214	15	3.748	1.013	0.448	109.743	7.316	0.533	0.916
RESIDUAL	384.650	104	3.699			1426.333	13.715		
TOTAL	492.469	127				1756.055			
	GRASS AND HERBS								
MAIN EFFECTS	351.824	8	43.978	1.886	0.070				
AGE	325.176	5	65.035	2.788	0.021				
DISTANCE	26.648	3	8.883	0.381	0.767				
AGE BY DISTANCE	218.422	15	14.561	0.624	0.849				
RESIDUAL	2425.683	104	23.324						
TOTAL	2995.930	127							

Figure 5. Trends of herbaceous species richness and diversity with age of abandoned settlements

Figure shows means ± standard errors


RICHNESS
DIVERSITY
GRASS
HERBS
GRASS AND HERBS
NUMBER OF SPECIES
DIVERSITY INDEX
≤10
11-20
21-40
41-60
61-80
>80
AGE CLASSES

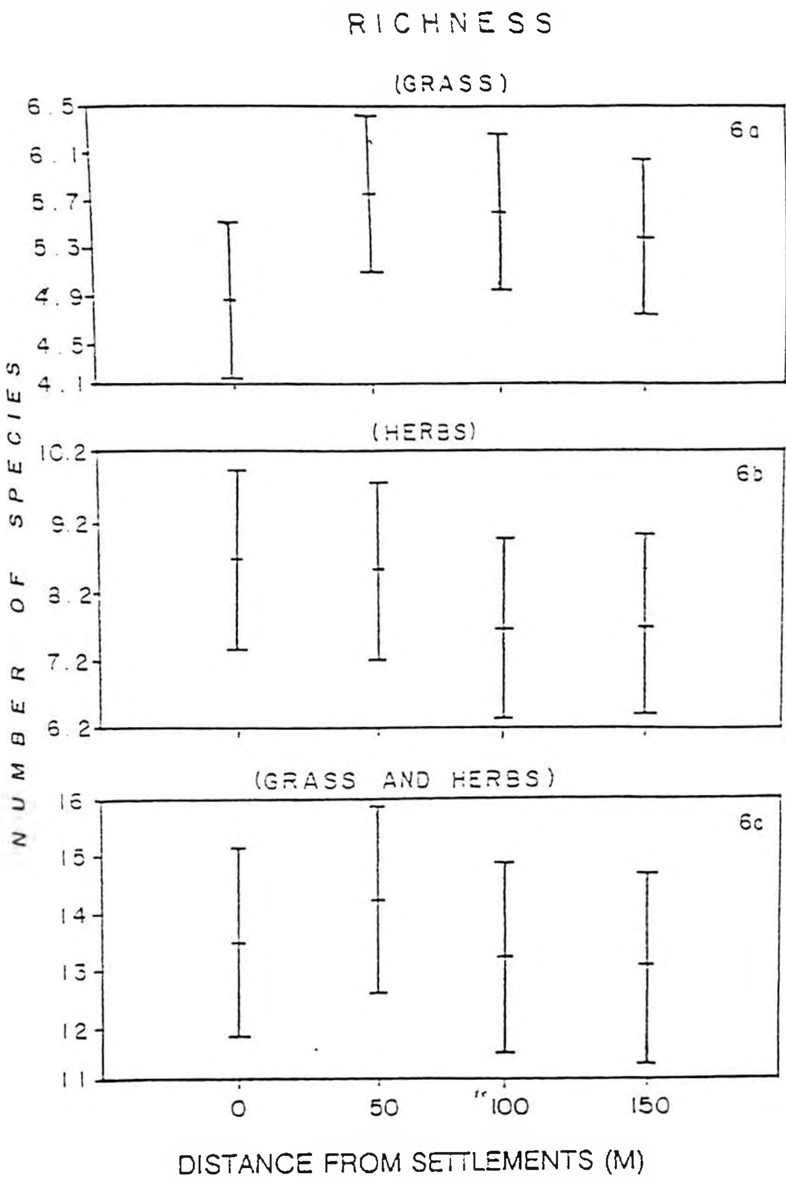
settlements aged about 15 years. Herbs diversity and richness on settlements over 80 years old was about the same as those 10 years and under (Figure 5b and 5e). Diversity and richness trends on the combined level were more similar to the trends of herbs except that diversity peaks at the same time as grass (Figure 5c and 5f).

Age class diversity and richness means were plotted against distance from the settlements for herbs, grasses and herbs plus grasses. Onsite values were included in graph as 0m values. Grass diversity and richness was lowest onsite and highest at 50m and decreased with increasing distance away from the settlements (Figure 6a and 6d). The trends of herbs species diversity and richness were different from those of grass. Diversity of herbs was about the same throughout, while richness was highest onsite and decreased with increasing distance from the settlements (Figure 6b and 6e). At the combined level (grasses and herbs), diversity was lowest onsite. The difference between 50m and 100m was not so apparent but diversity was lower further away (Figure 6f). Species richness showed no particular trend with distance (Figure 6c). From these observations, it is apparent that both age and distance have some effect on species diversity and richness. However effects were more apparent on grasses than herbs.

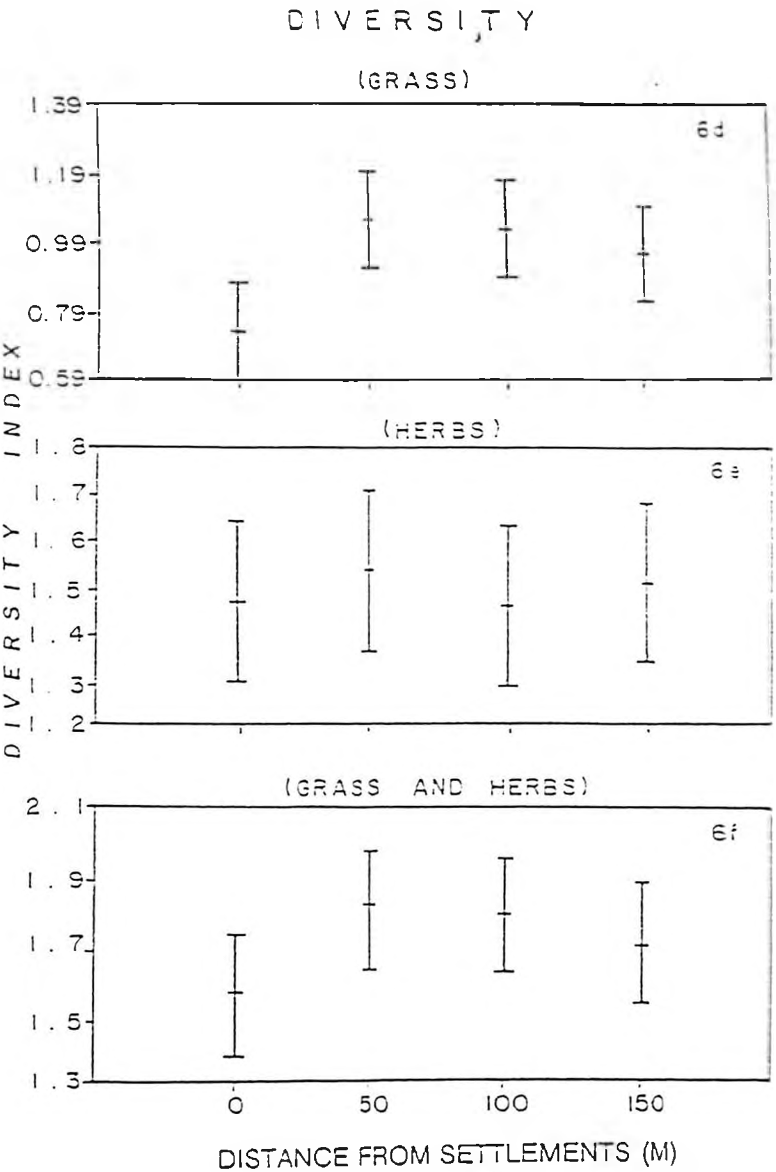
Detrended correspondence analysis (DCA) was applied on onsite data, including grasses, herbs, shrubs and trees. Detrended correspondence analysis clusters together areas that are similar given certain parameters. DCA takes into account the contribution of the individual species in a community, which makes it a good method of testing for similarity between different plant communities. The proportion of each species at each abandoned settlement was calculated using the species biomass, which was used as input in DCA. Biomass of trees and shrubs were calculated using the formulae adapted from the work done by Guy (1981) estimating above ground biomass of trees and shrubs.

Figure 6. Trends of herbaceous species richness and diversity with distance from abandoned settlements

Onsite values fall under 0m on the X-axis. (Figure shows means ± standard errors)



RICHNESS
(GRASS)
6a
6.5
6.1
5.7
5.3
4.9
4.5
4.1
(HERBS)
6b
10.2
9.2
8.2
7.2
6.2
(GRASS AND HERBS)
6c
16
15
14
13
12
11
0
50
100
150
NUMBER OF SPECIES
DISTANCE FROM SETTLEMENTS (M)



DIVERSITY
(GRASS)
6d
1.39
1.19
0.99
0.79
0.59
(HERBS)
6e
1.8
1.7
1.6
1.5
1.4
1.3
1.2
(GRASS AND HERBS)
6f
2.1
1.9
1.7
1.5
1.3
0
50
100
150
DIVERSITY INDEX
DISTANCE FROM SETTLEMENTS (M)

1) Biomass (trees) = $(\text{diameter})^{1.9241} * (\text{height})^{0.8883} * 0.0564$

2) Biomass (shrubs) = $(\text{diameter})^{1.8873} * (\text{height})^{0.4114} * 0.0811$

Biomass of grasses and herbs was calculated using the formula from work done by Western (1973):

3) Biomass = total hits * .8468

DCA scores were calculated on four axis for clustering the settlements according to similarity. In Figure 7, only the first two axis were used in plotting, because the eigenvalues for these axis were higher. Eigenvalues for primary and secondary axes were .538 and .357 respectively and the last two had .150 and .076 respectively. The eigenvalue expresses the strength of each axis in explaining the variability of the input parameters.

The points on the graph were replaced with the age of the settlements, as shown in Figure 7. The results of DCA analysis places recently abandoned settlements towards the upper left corner. The old settlements were more towards the origin of the axis. While those between 50 and 80 years were spread more along the primary axis than secondary axis, those in the second and third age classes were placed relatively in the middle. The change in settlement age along the primary axis was not as much as along the secondary axis, meaning that secondary axis explains similarity of the settlements by age more than any other. This is confirmed by the correlation between the age of the settlements and the DCA scores (Table 3).

Detrended correspondence analysis was also employed on offsite data at increasing distance from the settlements at 50m, 100m and 150m, for biomass of grasses and herbs combined. Again only the first two axis were used in plotting (Figure 8) for the same reason as was for onsite data. The results of this analysis show a cluster at every point along the

Figure 7. Onsite Detrended Correspondence Analysis ordination of abandoned settlements

Ordination scores were calculated using biomass of all species (grasses, herbs, shrubs and trees). The numbers indicating the position of the settlements were settlements' age in years.

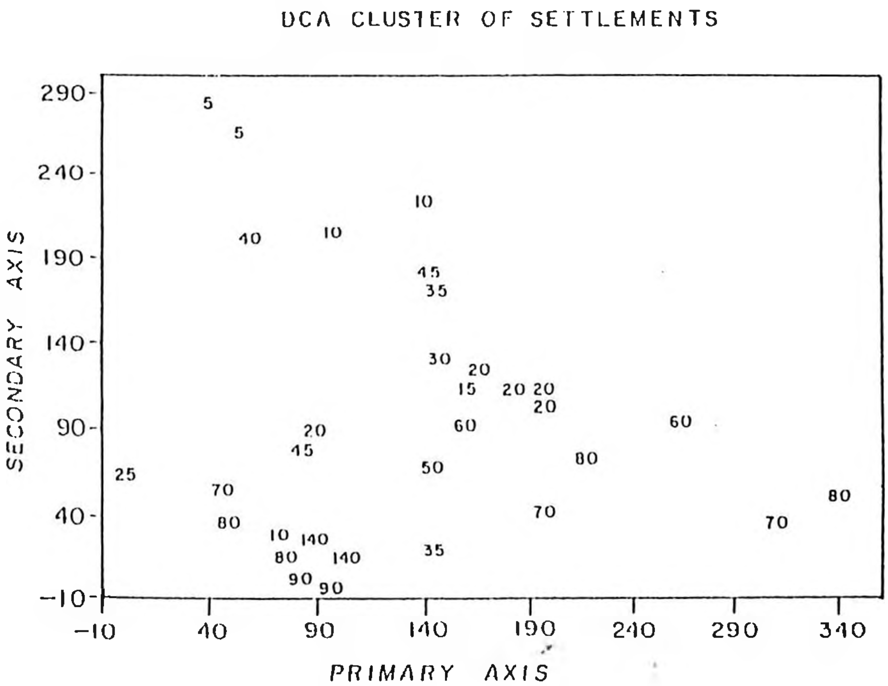
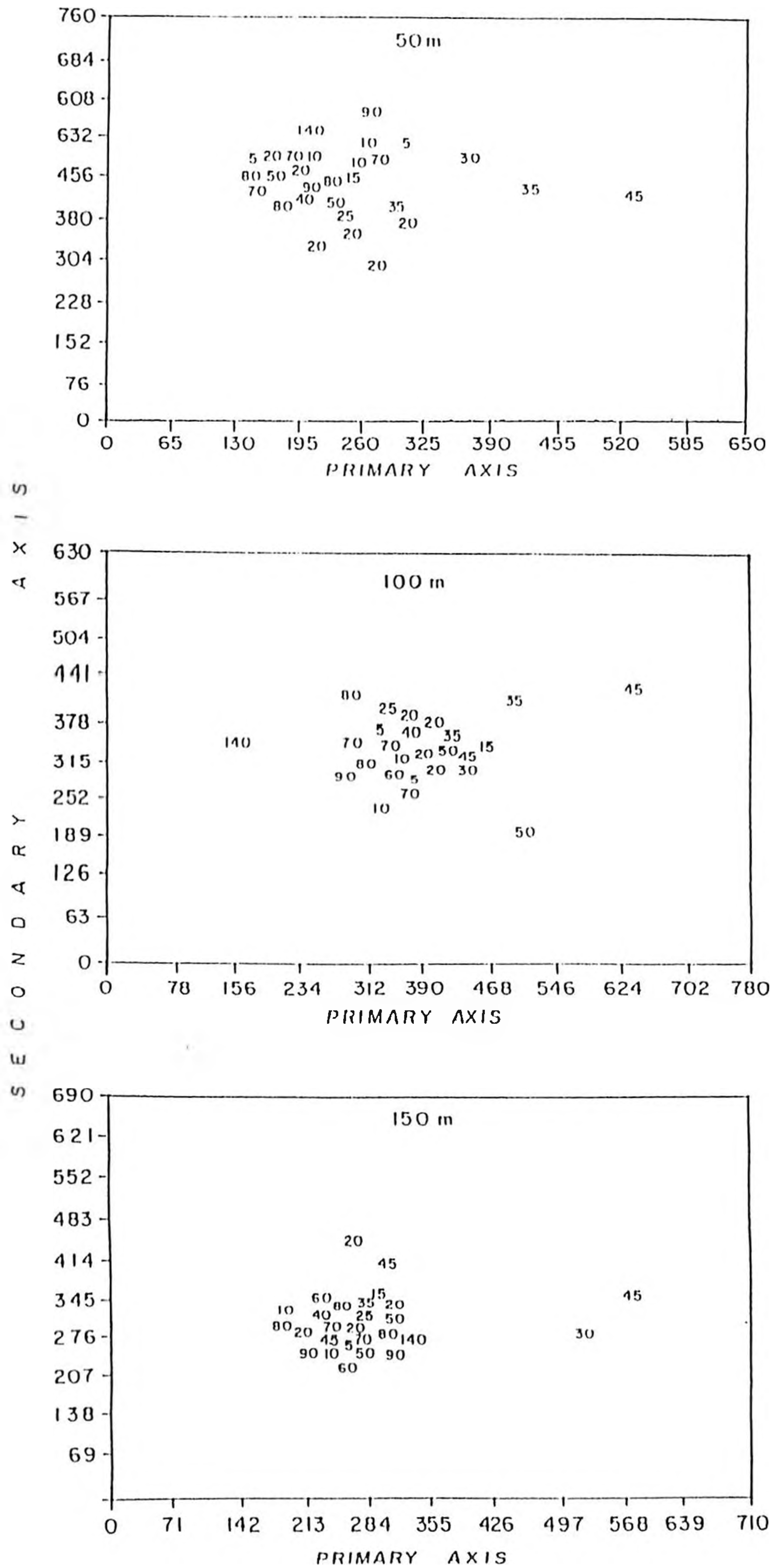

DCA CLUSTER OF SETTLEMENTS
SECONDARY AXIS
PRIMARY AXIS
290
240
190
140
90
40
-10
-10
40
90
140
190
240
290
340

Table 3. Correlation of settlements age and DCA score.

	CORRELATION COEFFICIENT			
		OFFSITE		
AXIS	ONSITE	50m	100m	150m
1	0.1619	-0.2152	-0.3609	-0.0126
2	-0.6514	0.2322	0.0499	-0.2706
3	0.1744	-0.0894	0.0551	-0.0050
4	0.1399	0.1221	0.0464	0.2345

Figure 8. Offsite Detrended Correspondence Analysis ordination of abandoned settlements at increasing distance


50 m
100 m
150 m
SECONDARY AXIS
PRIMARY AXIS
PRIMARY AXIS
PRIMARY AXIS
760
684
608
632
456
380
304
228
152
76
0
0 65 130 195 260 325 390 455 520 585 650
630
567
504
441
378
315
252
189
126
63
0
0 78 156 234 312 390 468 546 624 702 780
690
621
552
483
414
345
276
207
138
69
0 71 142 213 284 355 426 497 568 639 710

gradient,i.e at 50m, 100m and 150m. However, the clusters at 100m and 150m were more dense than the cluster at 50m. There were fewer settlements outside the cluster at 150m than there were at 50m and 100m. Those settlements outside the cluster at 50m are more evenly spread than at 100m and more so along the primary axis (Figure 8). Correlation of DCA scores and settlement age results were relatively low, less than 50%. At 50m and 150m secondary axis have the higher correlation values, while at 100m it was the primary axis that had the higher value (Table 3).

These results reveal differences in plant communities onsite on settlements of different age, while single clusters offsite at increasing distance reflect minimal effect of settlement age on plant community around the settlements. However, the difference in the nature of the cluster at 50m and those further away may imply that settlements had relatively more influence on species composition at 50m than further away.

4.2 Ground Cover

Generally there were differences in ground cover in all three seasons both onsite and offsite. Ground cover was highest and lowest during the wet and late dry season respectively. Onsite the peak during the wet season was about four times as much as the late dry season. Onsite ground cover values regressed against settlements age reveal major differences. For all three seasons onsite ground cover initially increases with age. During the dry season ground cover peaked at about 25 years, while in late dry and wet season it peaked at about 35 years (Figure 9). From this peak cover decreased as a function of age of the settlements, as indicated by the curves fitted on the data which were all highly significant (Table 4). Ground cover on settlements that have been abandoned for a long time was not much higher than those recently abandoned (Figure 9). The late dry season sample size was lower than dry and wet season. Only nine settlements were sampled because sampling time was limited. However, the nine settlements had been selected (see section 3.7) so as to represent settlements of all ages (Appendix 3).

Figure 9. Onsite percent ground cover plotted against abandoned settlements age

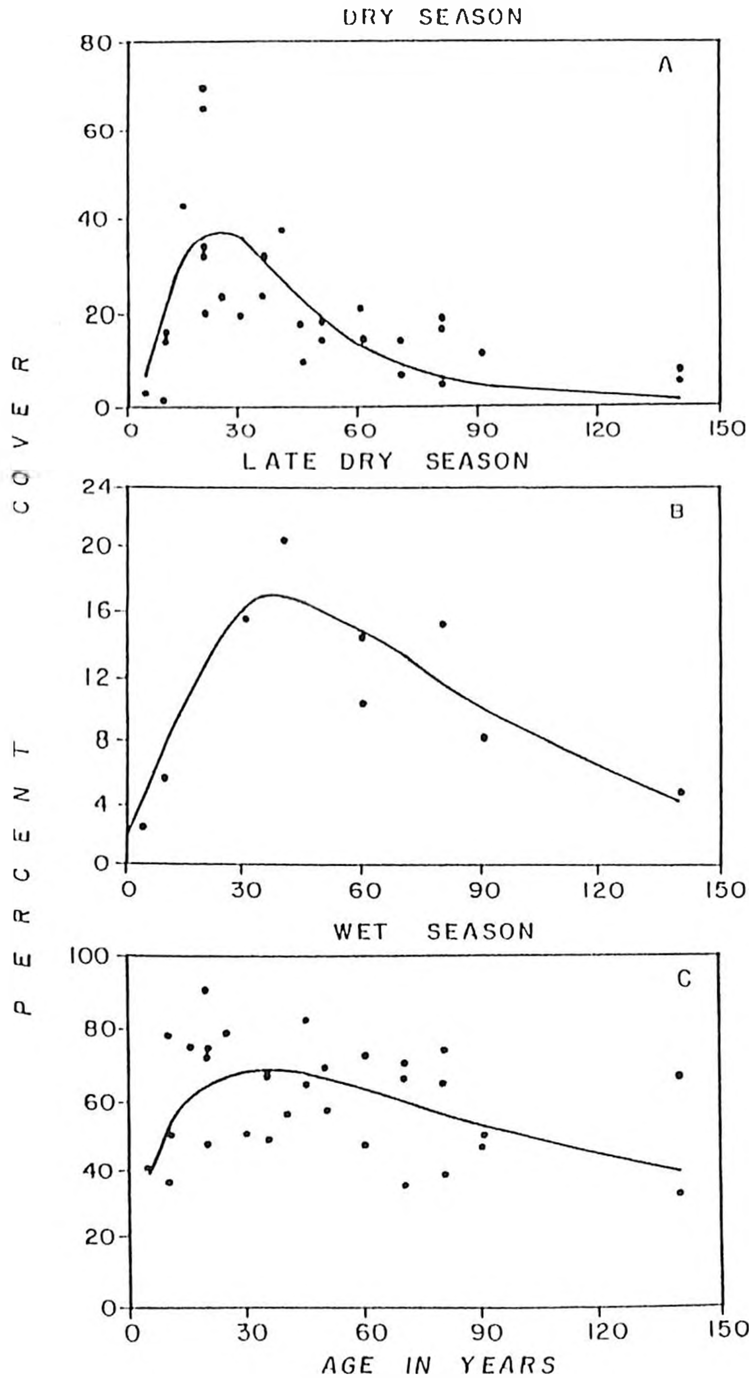

DRY SEASON
A
80
60
40
20
0
0
30
60
90
120
150
LATE DRY SEASON
B
24
20
16
12
8
4
0
0
30
60
90
120
150
WET SEASON
C
100
80
60
40
20
0
0
30
60
90
120
150
AGE IN YEARS
PERCENT COVER

Table 4. Results of lognormal regressions fitted on percent ground cover onsite, against settlements age.

SOURCE	A	B	C	DF	SUM OF SQUARES	MEAN SQUARE	TOTAL	n	F	P
MID DRY	0.284	3.113	74.090	2	16288.68	5429.56	20398.78	32	38.310	<0.001
LATE DRY	0.222	2.551	145.169	2	1273.68	424.56	1324.76	9	49.871	<0.001
WET	17.346	1.519	121.262	2	114425.35	38141.78	122413.33	32	138.470	<0.001

Equation = $Y * X^{b-1} * e^{x/c}$ $e=2.7182$

Analysis of variance was performed on this data to test for the effect of settlement age and distance from the abandoned settlement on ground cover. The effect of distance was considered up to 200m during dry and late dry season, while during the wet season was considered up to 150m. Wet season data was restricted to 150m because of time constraint. The results of this analysis indicate significant effects of distance during all three season separately and combined. The effect of age on ground cover was significant only during the mid dry season and when all the seasons were combined. The interaction effect of age and distance was significant only during the dry season (Table 5). The non-significant results during the late dry season could be attributed to the sample size.

The anova results were reflected on the graphs of mean ground cover plotted against settlement age and distance from the settlements. Mean ground cover for all three seasons combined was observed to be highest on settlements in the second age class and not different on the other age classes (Figure 10a). However, a different trend was observed during mid dry season. Mid dry season mean cover was observed to initially increase with age to peak at second age class and to decrease thereafter. Mean cover during this season was lowest on and around the very old settlements (Figure 10b). During the late dry and the wet season there was no particular trend of ground cover with settlement age (Figure 10c and 10d), but cover on the old settlements was much lower during late dry season than the other age classes.

There were significant differences between and within the seasons both onsite and offsite at increasing distance (Table 6a and 6b). The comparison between and within the seasons were done up to 150m away from the abandoned settlements for the same reason as above. Figure 11 shows high mean ground cover onsite compared to offsite for mid during the dry and wet season (Figure 11a and 11c). Mean cover at 50m during the mid dry season was lower than at 100m and beyond. This trend was more pronounced during the late dry season, where cover at 50m was

Table 5. Effect of settlement age and distance from settlements on ground cover onsite and offsite.

SOURCE	SUM OF SQUARES	df	MEAN SQUARE	F	P
ALL SEASONS					
MAIN EFFECTS	12938.66	8	1617.333	3.298	0.001
AGE	5823.07	5	1164.614	2.375	0.039
DISTANCE	7115.60	3	2371.865	4.837	0.003
AGE BY DISTANCE	6745.96	15	449.731	0.917	0.546
RESIDUAL	131423.48	268	490.386		
TOTAL	151108.29	291			
MID DRY SEASON					
MAIN EFFECTS	5354.28	9	594.920	15.845	<0.001
AGE	2405.69	5	481.137	12.814	<0.001
DISTANCE	2948.60	4	737.149	19.633	<0.001
AGE BY DISTANCE	3622.66	20	181.133	4.824	<0.001
RESIDUAL	4881.14	130	37.547		
TOTAL	13858.08	159			
LATE DRY SEASON					
MAIN EFFECTS	370.42	8	46.303	2.173	0.076
AGE	52.82	4	13.204	0.620	0.654
DISTANCE	317.61	4	79.402	3.726	0.020
AGE BY DISTANCE	336.16	16	21.010	0.986	0.505
RESIDUAL	426.16	20	21.308		
TOTAL	1132.75	44			
WET SEASON					
MAIN EFFECTS	6915.47	8	864.433	3.648	0.001
AGE	1869.09	5	373.818	1.578	0.173
DISTANCE	5046.38	3	1682.125	7.099	<0.001
AGE BY DISTANCE	4126.14	15	275.076	1.161	0.314
RESIDUAL	24641.44	104	236.937		
TOTAL	35683.05	127			

Figure 10. Seasonal trends in ground cover around abandoned settlements of different age classes

Figure shows means ± standard errors

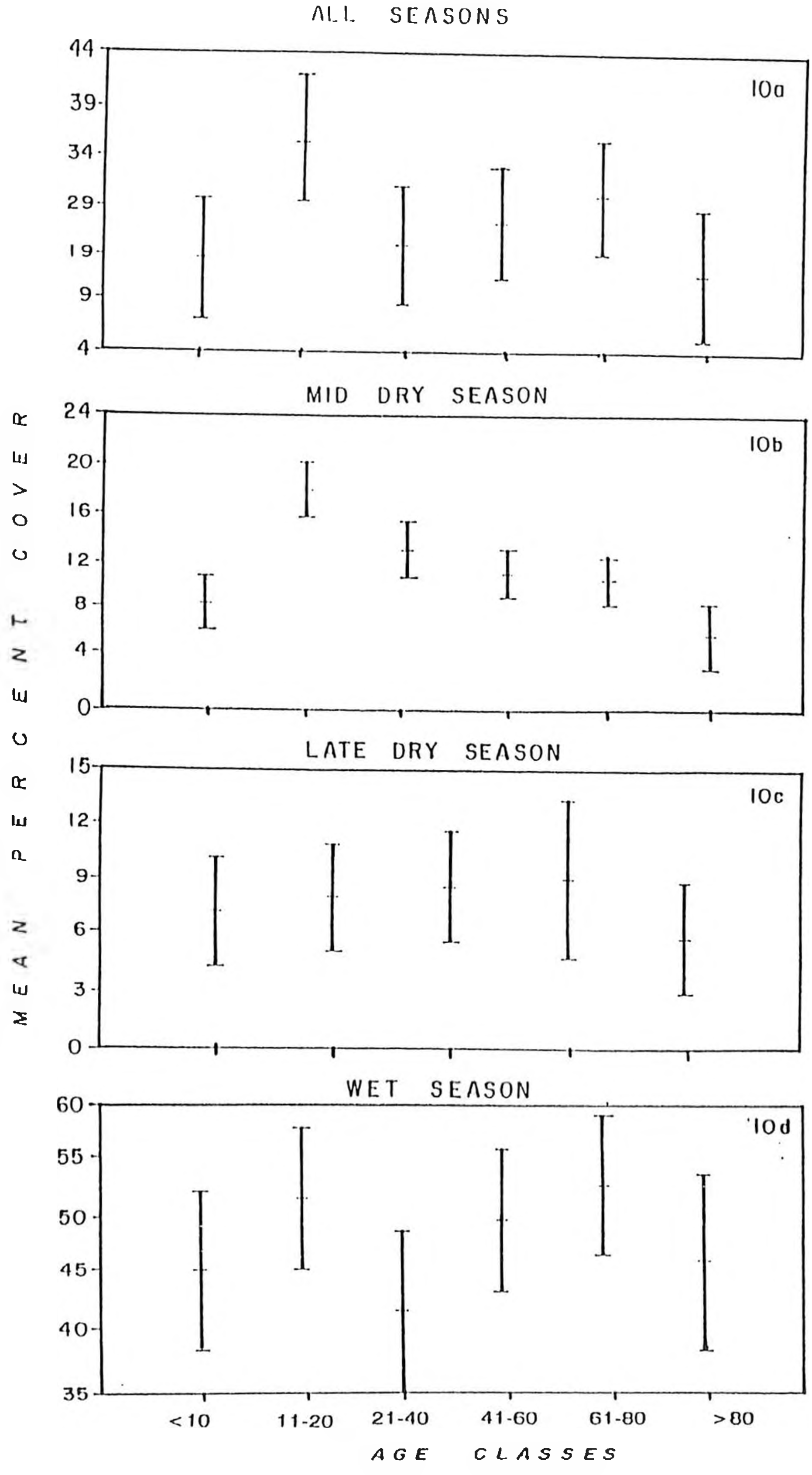

ALL SEASONS
10a
44
39
34
29
19
9
4
MID DRY SEASON
10b
24
20
16
12
8
4
0
LATE DRY SEASON
10c
15
12
9
6
3
0
WET SEASON
10d
60
55
50
45
40
35
MEAN PERCENT COVER
<10
11-20
21-40
41-60
61-80
>80
AGE CLASSES

Table 6a. Seasonal variation in percent ground cover between the three seasons onsite and offsite.

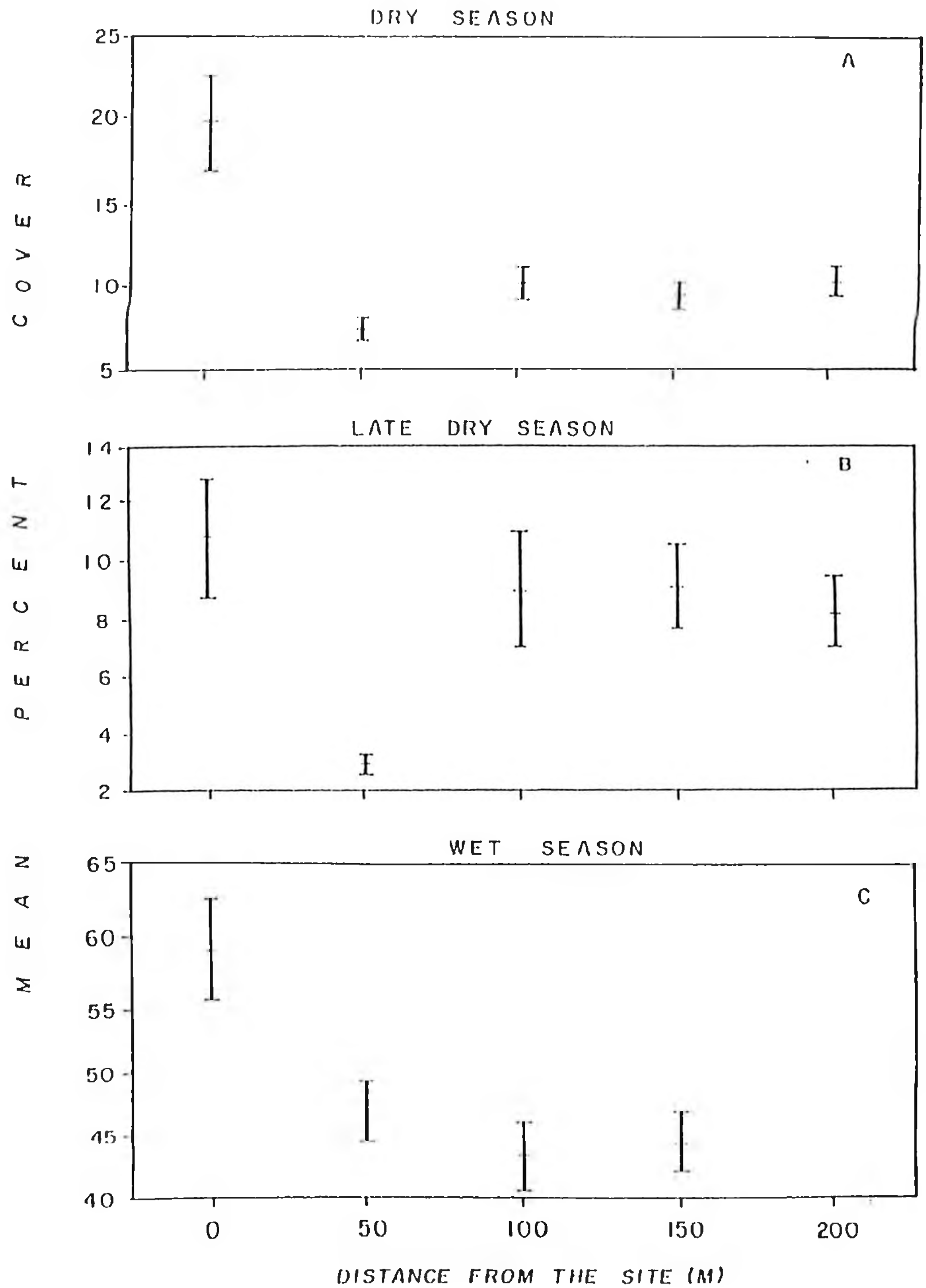
SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	TOTAL	n	F	P
0m	31114.14	2	15557.07	50276.18	72	56.831	<0.001
50m	29551.41	2	14775.71	36130.30	72	157.215	<0.001
100m	19905.76	2	9952.88	28670.27	72	79.491	<0.001
150m	22064.85	2	11032.43	28915.74	72	112.725	<0.001

Table 6b. Variation in percent ground cover between onsite, 50m, 100m, 150m and 200m within each season.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	TOTAL	n	F	P
DRY	2948.600	4	737.149	13858.08	159	10.473	<0.001
LATE DRY	317.608	4	79.402	1132.75	44	3.896	0.009
WET	5046.376	3	1682.125	35683.05	127	6.808	<0.001

Figure 11. Seasonal trends ground cover with distance from abandoned settlements

Onsite values fall under 0m on the X-axis. (Figure shows means ± standard errors)


DRY SEASON
A
25
20
15
10
5
LATE DRY SEASON
B
14
12
10
8
6
4
2
WET SEASON
C
65
60
55
50
45
40
0
50
100
150
200
MEAN PERCENT COVER
DISTANCE FROM THE SITE (M)

much lower than onsite and it was also lower than 100m and beyond (Figure 1⁻b). However, ground cover at 50m recovers fast during the wet season to exceed that at 100m and 150m.

4.3 Onsite Woody Vegetation

Onsite data for trees and shrubs were analyzed to establish the pattern of woody vegetation cover with age of the abandoned settlements. All the species encountered onsite are listed in Appendix 4 with their abbreviations. Density of trees and shrubs onsite was calculated on one half of each settlement (Appendix 5). Biomass was calculated using the same methods as used in section 4.1. One way anova was done on biomass and density data for those species found in abundance (Table 7). Biomass shown in appendix 4 for all species and for *A. tortilis* at settlement E7 was reduced by about 50% for this test, because a very large tree was excluded. This particular tree was much older than the other *A. tortilis* trees on this settlement and might have been there when the settlement was abandoned, considering the age of E7 was estimated at 70 years. Other older settlements did not have trees as big as that. The anova results indicate significant effects of settlement's age on biomass of all species together, all species excluding *A. tortilis* and on *A. tortilis* excluding all the other species. However, age had no significant effect on the other species individually. Further analysis was done excluding settlement B1. Settlement B1 was considered an outlier since it was covered by dung, meaning it had been abandoned for about 10 years and yet it had a lot of *A. tortilis*, as if it had been abandoned about 80 years ago. The amount of *A. tortilis* on this settlement could mean that this settlement was much older and had been reoccupied. The exclusion of this settlement increased the significance level of all those affected by age except that of all the species (Table 7).

Biomass of woody vegetation plotted against settlements age for those resulting in significant effect by age reveal an increase of biomass with age for *A. tortilis* (Figure 12c). Biomass of all species together was also found to follow the same trend as *A. tortilis*, but had

Table 7. Effects of settlements age on woody species establishment onsite of abandoned settlements

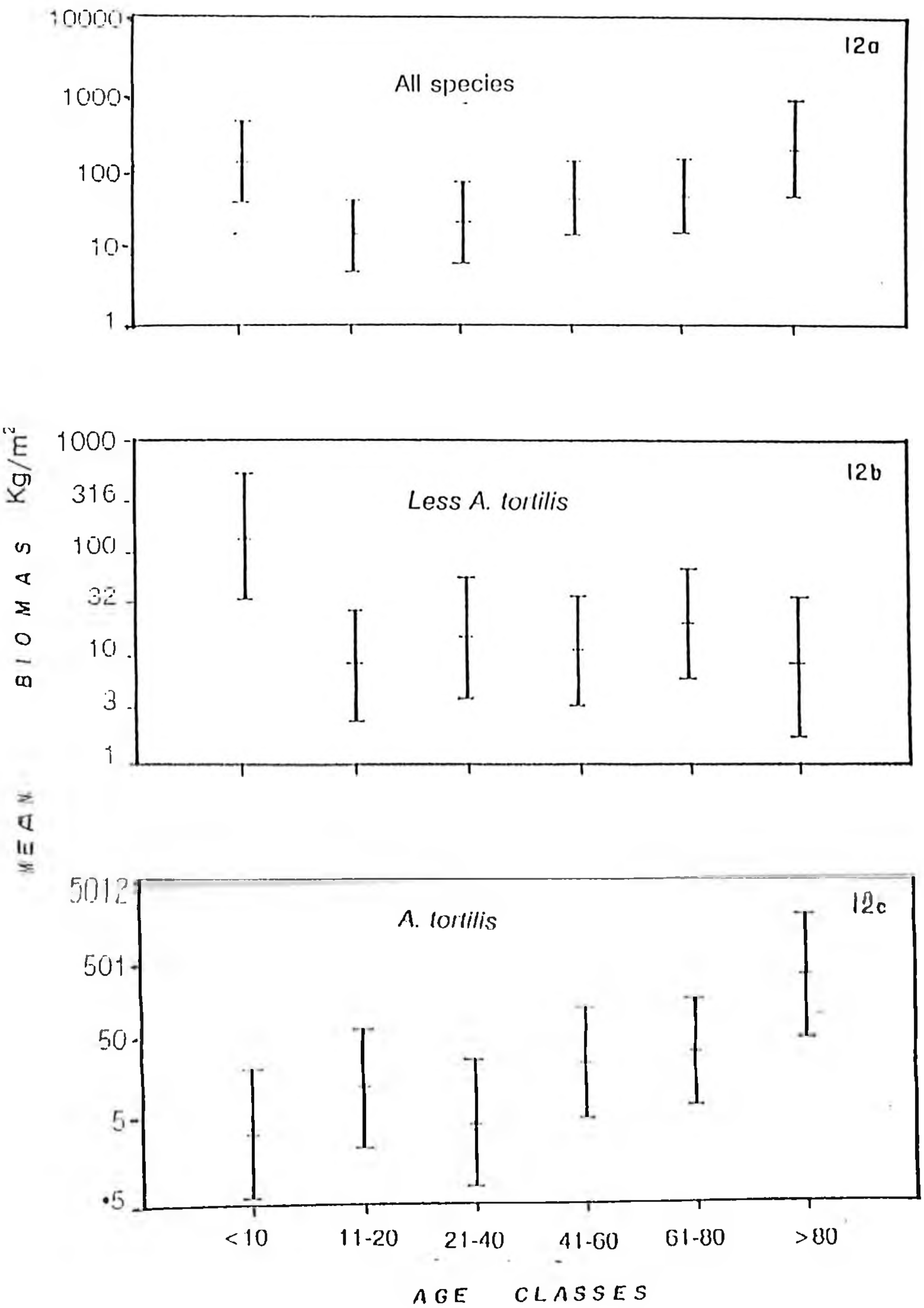
SOURCE	BIOMASS SUM OF SQUARES	BIOMASS MEAN SQUARE	BIOMASS TOTAL	BIOMASS F(5,26)	BIOMASS P	DENSITY SUM OF SQUARES	DENSITY MEAN SQUARE	DENSITY TOTAL	DENSITY F(5,26)	DENSITY P
ALL SPECIES	174684.83	34936.97	453711.60	3.255	0.021	44.010	8.801	209.580	1.382	0.263
Less *A. tortilis*	61693.78	12338.76	141573.39	4.016	0.008	8.556	1.711	59.343	0.809	0.555
A. tortilis	173968.48	34793.70	363799.56	4.765	0.003	42.231	8.446	124.130	2.681	0.044
M. endlichii	16891.07	3378.21	125400.56	0.809	0.554	0.513	0.103	2.726	1.207	0.334
C. africana	3139.09	627.82	18007.17	1.098	0.385	0.146	0.029	0.661	1.484	0.229
L. europium	59.84	11.97	359.59	1.038	0.417	1.395	0.279	13.502	0.599	0.701
S. persica	311.81	62.36	1064.11	2.155	0.090	0.323	0.065	2.119	0.934	0.465
A. nubica	482.33	96.47	1862.83	1.817	0.145	1.395	0.279	13.502	0.599	0.701
A. mellifera	1558.35	311.67	4847.39	2.464	0.059	0.497	0.010	3.110	0.990	0.443

n=31

Note--Density sum of squares, mean sqaures and total have been multiplied by 100000

Figure 12. Onsite trends of woody vegetation biomass with settlements age

The mean and standard errors were plotted using log transformed data, but the y-axis scale show their equivalent anti-log values.



12a
All species
10000
1000
100
10
1
12b
Less A. tortilis
1000
316
100
32
10
3
1
12c
A. tortilis
5012
501
50
5
.5
MEAN BIOMAS Kg/m²
<10
11-20
21-40
41-60
61-80
>80
AGE CLASSES

higher biomass on recently abandoned settlements (Figure 12a). Biomass of all the other species excluding *A. tortilis* was also high on recently abandoned settlements. However it was not observed to change with age on the other age classes (Figure 12b). The exclusion of settlement B1 did not change the trends observed on the graphs. Similar analysis on woody vegetation density onsite revealed significant effect of age only on *A. tortilis*. Again the significance level increased with the exclusion of settlement B1 (Table 7). Density of all species together (Figure 13a) and that of *A. tortilis* (Figure 13c) follow the same trend as their biomass, but density of all the other species less *A. tortilis* (Figure 13b) seemed not to change with age. The exclusion of settlement B1 substantially reduces density on recently abandoned settlements when considering all the species (Figure 13d).

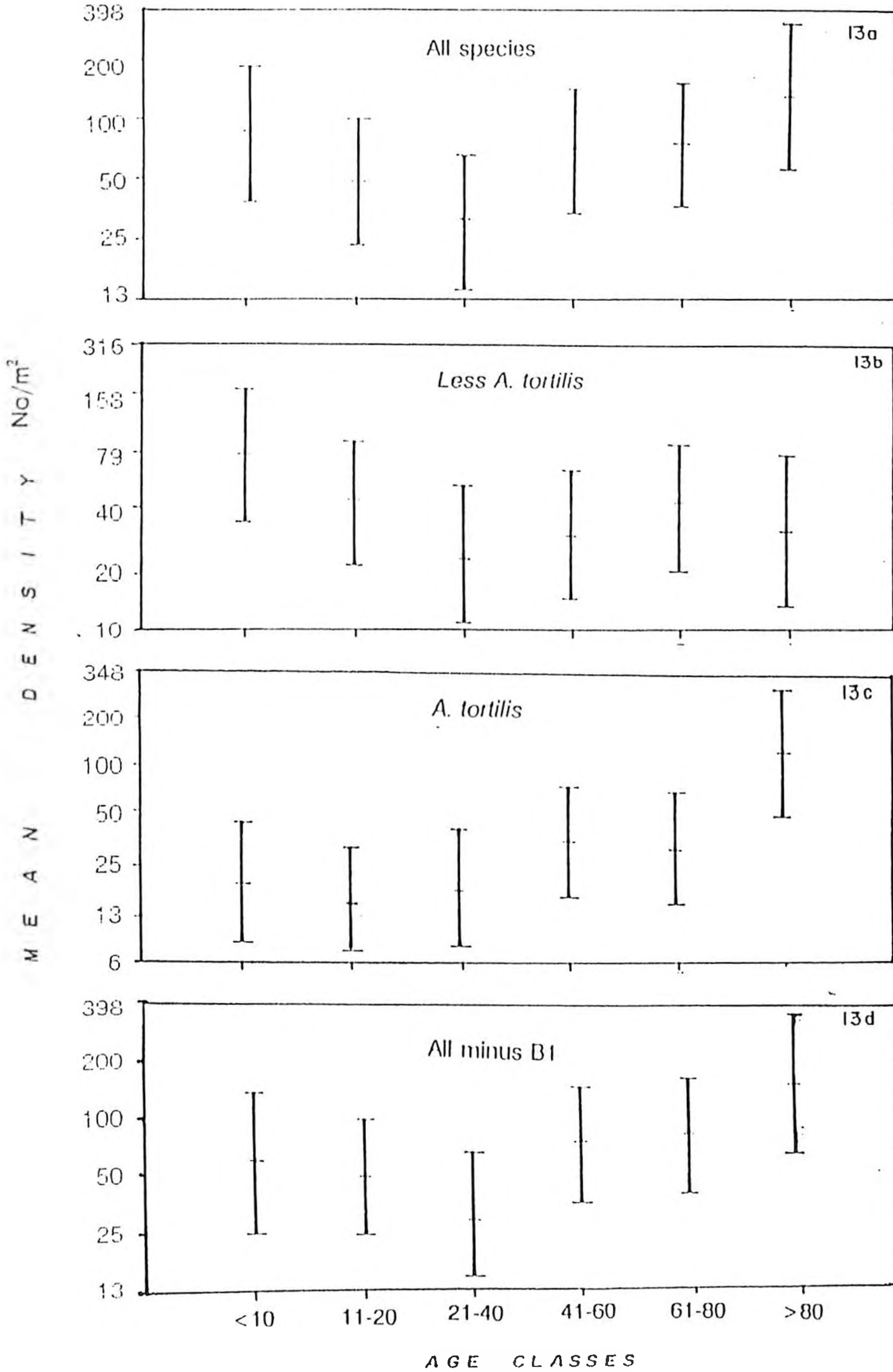
These results indicate that the presence of *A. tortilis* on abandoned settlements largely depends on the age of the settlements. Even distribution of the other species in all age classes reflects no effect of age on their presence. High biomass and density of all species on recently abandoned settlements indicate that these other species could have been present when the settlements were established,and were not destroyed.

4.4 Offsite Woody Vegetation

Biomass and density of trees and shrubs around each abandoned settlement were calculated along a gradient for both bushed and open savanna areas. Using two transects, biomass and density were calculated at each sampling point. The density (numbers/m^2) was calculated by taking the reciprocal of the square of the mean distance to the sampled trees and shrubs from the sampling point. Biomass of trees and shrubs around the abandoned settlements was calculated using the methods described in section 4.1. The calculated values at corresponding points on both transects were added and divided by two to get the mean. This mean (density or biomass) was taken as the representative density or biomass of trees and

Figure 13. Onsite trends of woody vegetation density with settlements age

The means and standard errors were plotted using log transformed data, but the y-axis scale show their equivalent anti-log values.


All species
13a
398
200
100
50
25
13
Less A. tortilis
13b
316
158
79
40
20
10
A. tortilis
13c
348
200
100
50
25
13
6
All minus B1
13d
398
200
100
50
25
13
MEAN DENSITY No/m²
<10
11-20
21-40
41-60
61-80
>80
AGE CLASSES

shrubs in the given area around the abandoned settlements. Density and biomass around the abandoned settlements were calculated at two levels. First for all the species of trees and shrubs encountered in the area (Appendix 6 and 7), secondly for *Commiphora* species and *A. mellifera* (Appendix 8 and 9) excluding *Boscia anguistifolia, Delonix elata, Maerua endlichii, Balanites glabra, A. tortilis, Cordia gharaf, Cadaba ruspolii, A. ancistroclada, A. nubica,* and *A. thomaxii*. These species were excluded since they were not as heavily used as *Commiphora* species and *A. mellifera* in the construction and/or as a source of energy in the settlements around the study area. The first four species most often will be left untouched by the pastoralist to provide shade for both human and their livestock. However *Boscia anguistifolia* and *A. tortilis* might be used as posts for the huts.

Analysis of variance was done on these data separately at both levels to determine the effect of settlement age and distance away from the settlements on woody vegetation. The results indicate no significant effect of age on biomass at both levels. However, the effect of distance was highly significant in both areas on biomass of all species, but not on biomass of *Commiphora* species and *A. mellifera*. Age and distance simultaneously affected biomass of all species in the bushed savanna and in the same area density was significantly affected by settlement age (Table 8a and 8b). Figures 14a to 14d represesnt all species, while 14e and 14f were biomass of *C. africana* and *A. mellifera*. It is important to note that biomass of all species at 0m (i.e onsite) was much higher compared to the other distances (i.e offsite). This could contribute to the significant effect of distance on biomass (Figure 14a and 14b) Biomass of *Commiphora* species and *A. mellifera* were not considered onsite in this section, since it had been established in section 4.3, that they were virtually nonexistent.

Density of all species in bushed savanna remained about the same for the first four age classes, but increased sharply around settlements that had been abandoned for a long time (Figure 15a). Density in bushed savanna was found to increase with distance up to 56m and not

Table 8a. Effects of settlements age and distance from abandoned settlements on all species of trees and shrubs.

SOURCE	BUSHED SAVANNA: BIOMASS SUM OF SQUARES	DF	MEAN SQUARE	F	P	BUSHED SAVANNA: DENSITY SUM OF SQUARES	DF	MEAN SQUARE	F	P
MAIN EFFECTS	245214.88	14	17515.349	14.778	<0.001	10.548	14	0.753	3.721	<0.001
AGE	8864.38	5	1772.875	1.496	0.195	4.477	5	0.895	4.422	<0.001
DISTANCE	236350.51	9	26261.167	22.157	<0.001	6.154	9	0.684	3.376	<0.001
AGE BY DISTANCE	77670.18	45	1726.004	1.456	0.051	4.894	45	0.109	0.537	0.991
RESIDUAL	165930.97	140	1185.221			28.149	139	0.203		
TOTAL	488816.03	199				43.591	198			
OPEN SAVANNA										
MAIN EFFECTS	182550.89	10	18255.08	8.171	<0.001	3.675	10	0.368	1.253	0.293
AGE	19937.82	5	3987.564	1.785	0.141	2.312	5	0.462	1.576	0.192
DISTANCE	167772.27	5	33554.45	15.019	<0.001	1.358	5	0.272	0.926	0.476
AGE BY DISTACE	88049.39	25	3521.976	1.576	0.104	8.436	25	0.337	1.150	0.344
RESIDUAL	80427.04	36	2234.085			10.562	36	0.293		
TOTAL	351027.33	71				22.674	71			

Table 8b. Effects of settlements age and distance from abandoned settlements on *C. africana* and *A. mellifera*.

SOURCE	BUSHED SAVANNA: BIOMASS SUM OF SQUARES	DF	MEAN SQUARE	F	P	BUSHED SAVANNA: DENSITY SUM OF SQUARES	DF	MEAN SQUARE	F	P
MAIN EFFECTS	57.085	13	4.391	1.296	0.224	19.913	13	1.532	1.115	0.353
AGE	26.203	5	5.241	1.547	0.180	13.313	5	2.663	1.938	0.093
DISTANCE	30.882	8	3.860	1.140	0.342	6.600	8	0.825	0.601	0.776
AGE BY DISTANCE	111.583	40	2.790	0.823	0.757	41.059	40	1.027	0.747	0.855
RESIDUAL	426.835	126	3.388			173.107	126	1.374		
TOTAL	595.503	179				234.079	179			
OPEN SAVANNA										
MAIN EFFECTS	0.927	9	0.103	1.087	0.401	0.675	9	0.075	1.100	0.393
AGE	0.601	5	0.120	1.269	0.303	0.457	5	0.091	1.339	0.275
DISTANCE	0.326	4	0.081	0.860	0.499	0.218	4	0.055	0.800	0.535
AGE BY DISTANCE	1.444	20	0.072	0.763	0.733	1.718	20	0.086	1.259	0.278
RESIDUAL	2.841	30	0.095			2.047	30	0.068		
TOTAL	5.212	59				4.441	59			

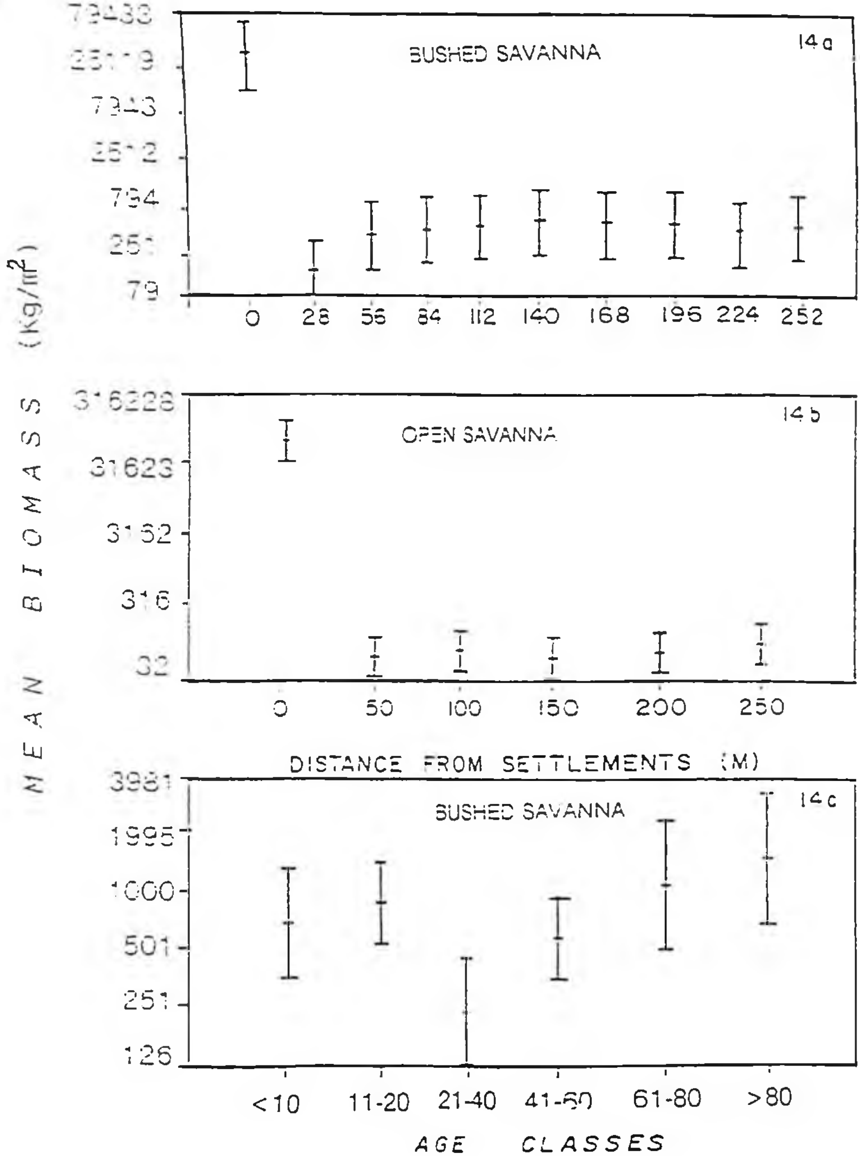
Note-- Density sum of squares and mean square have been multiplied by 1000

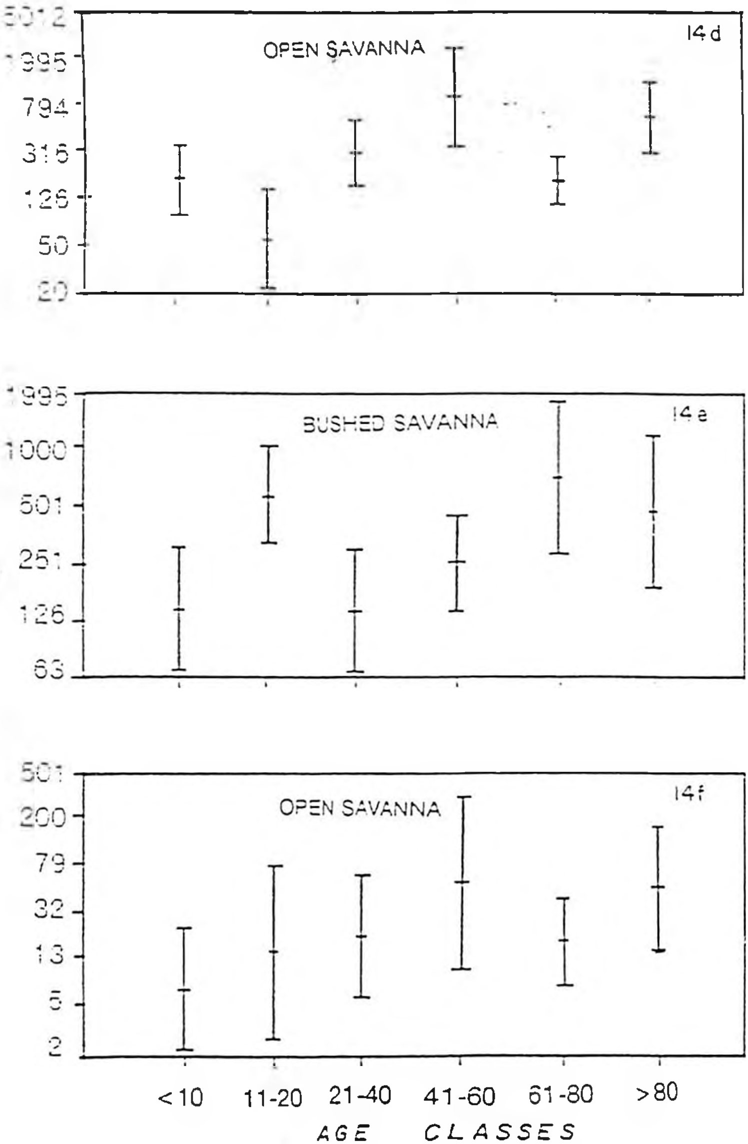
Figure 14. Trends of woody vegetation biomass on and around abandoned settlements of different age classes and at increasing distance

The data was raised by a constant (100) prior to log transformation. The means and standard errors were plotted using log transformed data, but the y-axis scale show their equivalent anti-log values.

Figure 14. Trends of woody vegetation biomass on and around abandoned settlements of different age classes and at increasing distance

The data was raised by a constant (100) prior to log transformation. The means and standard errors were plotted using log transformed data, but the y-axis scale show their equivalent anti-log values.

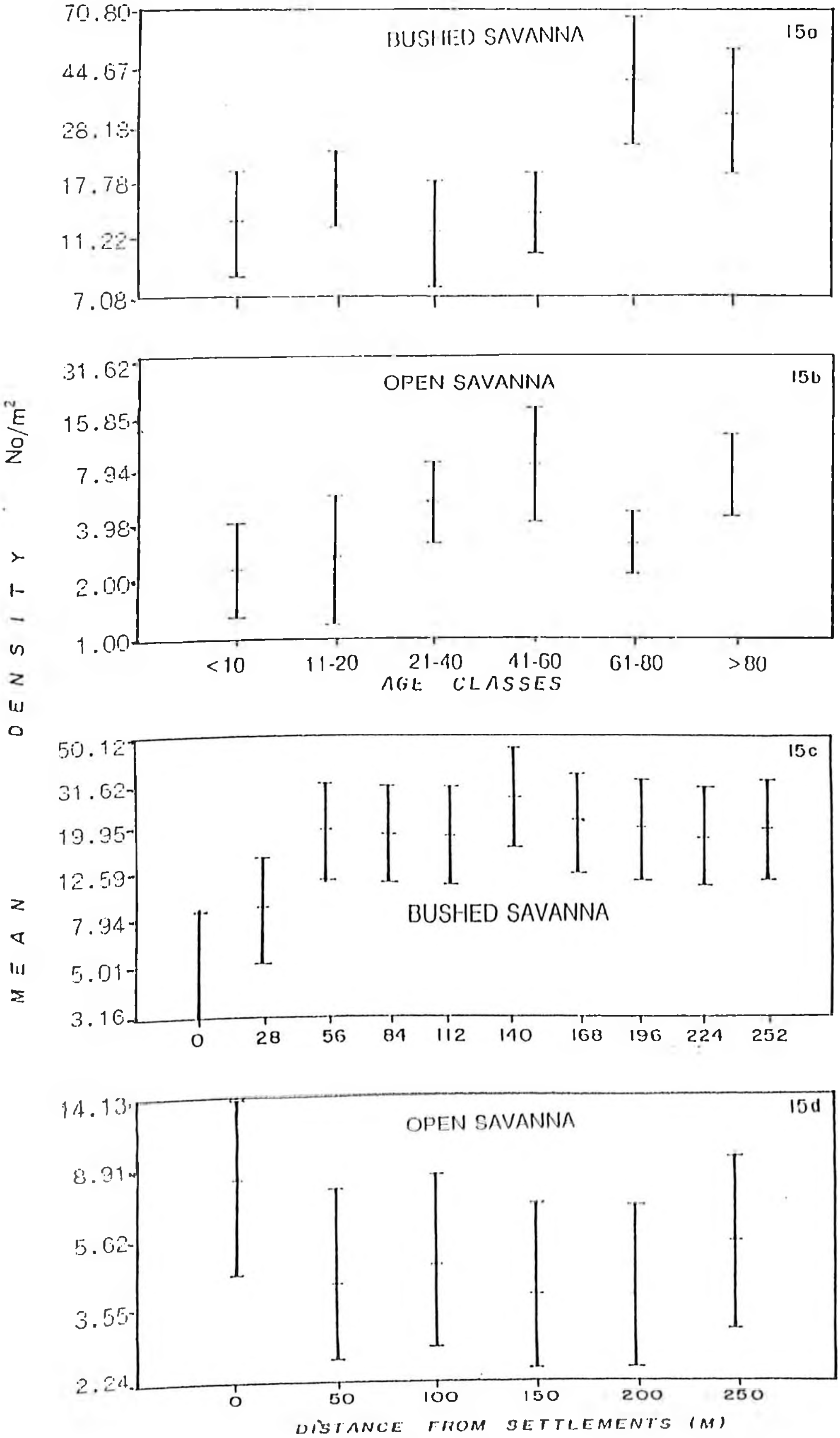

MEAN BIOMASS (Kg/m²)
BUSHED SAVANNA
14a
79433
25119
7943
2512
794
251
79
0
28
56
84
112
140
168
196
224
252
OPEN SAVANNA
14b
316228
31623
3162
316
32
0
50
100
150
200
250
DISTANCE FROM SETTLEMENTS (M)
BUSHED SAVANNA
14c
3981
1995
1000
501
251
126
<10
11-20
21-40
41-60
61-80
>80
AGE CLASSES



OPEN SAVANNA
14 d
5012
1995
794
316
126
50
20
BUSHED SAVANNA
14 e
1995
1000
501
251
126
63
OPEN SAVANNA
14 f
501
200
79
32
13
5
2
<10
11-20
21-40
41-60
61-80
>80
AGE CLASSES

Figure 15. Trends of woody vegetation density on and around abandoned settlements of diffrent age classes and at increasing distance

The data was raised by a constant (1000) prior to log transformation. The means and standard errors were plotted using log transformed data, but the y-axis scale show their equivalent anti-log values.



BUSHED SAVANNA
15a
70.80
44.67
28.18
17.78
11.22
7.08
OPEN SAVANNA
15b
31.62
15.85
7.94
3.98
2.00
1.00
<10
11-20
21-40
41-60
61-80
>80
AGE CLASSES
MEAN DENSITY No/m²
50.12
31.62
19.95
12.59
7.94
5.01
3.16
15c
BUSHED SAVANNA
0
28
56
84
112
140
168
196
224
252
14.13
8.91
5.62
3.55
2.24
OPEN SAVANNA
15d
0
50
100
150
200
250
DISTANCE FROM SETTLEMENTS (M)

to change thereafter (Figure 15c). In the open savanna density onsite was higher than offsite. Offsite density was observed to be about the same all along the transect except at the end where it was a bit higher.

Overall, settlement age seem not to affect canopy cover as much as would be expected. Canopy cover would have been expected to be low around recently abandoned settlement due to wood cutting both for fuel and settlement maintenance and high around settlements that have been abandoned for a long time because of regeneration. Although the graphs indicate some amount of regeneration with age the anova results were not significant.

4.5 Soil Characteristics

Soil samples collected at twelve abandoned settlements were analyzed at National Agricultural Research laboratories to determine their contents of sodium, potassium, calcium, magnesium, phosphorous, nitrogen and carbon. The electrical conductivity and pH were also determined. The results for the first four chemicals were presented in milliequivalent (m.e) and phosphorous in parts per million (p.p.m), while nitrogen and carbon were in percentages (Appendix 10).

Analysis of variance tests were performed on log transformed data to determine whether the soils from the different settlements were chemically different. Since there were zeros in the raw data, all the values were raised by a constant 1 to avoid errors while taking logarithm. The differences were expected to occur between settlements of different ages, down the soil column and by location (i.e whether onsite or offsite). Soil onsite and offsite were tested separately for significant differences with age and depth. There was no significant difference with age onsite except for nitrogen. Significant difference offsite by age was found in pH, calcium and manganese. Carbon and phosphorous were significantly different down the soil column onsite while only potassium was offsite. Between onsite and offsite significant differences were detected only in sodium and potassium content (Table 9).

The significant changes of nitrogen percentages with age arise largely from the high value for settlements aged 90 years (Figure 16d). Only those settlements aged 90 years seem to have more nitrogen than the others. Onsite phosphorous and carbon were found to decrease down the soil column as was potassium offsite (Figure 17). The largest difference was found to occur between the top soil (0-10 cm) and the rest and not so much between medium (20-30 cm) and bottom (40-50 cm) soil in all the cases that depth had significant effect. The difference in sodium and potassium indicates high content of both chemicals onsite and low offsite (Figure 17a and 17b).

While only a few of the chemicals show significant difference either by age, depth or location, the major part of chemicals included in the analysis were found not to be influenced by any of these factors (i.e age, depth and location). Therefore these results indicate that soils from settlements of different ages and at different depths were not very different chemically. Thus the contribution of the large amount of dung deposited during the life of a settlement was not detected by this analysis.

4.6 *Acacia tortilis* Seeds Experiment

Young *A. tortilis* trees had been observed to occur on the settlements that had been abandoned for over 40 years and it is on record that scarification enhances germination rate of the seeds of this species (Lamprey *et al.* 1974). Thus, it was important to establish what effects scarification and the state of soil have on the germination of *A. tortilis* seeds. The state of soil onsite changes as the dung decays and is incorporated within the soil.

Data on *A. tortilis* seeds germination was collected over a period of three months (Appendix 11a and 11b). The experiment was set up to facilitate the examination of scarred and

Table 9. Effects of settlements age on soil chemical composition on and around abandoned settlements and at various depths down the soil column.

AGE

SOURCE	ONSITE SUM OF SQUARES	ONSITE MEAN SQUARE	ONSITE TOTAL	ONSITE n	ONSITE F	ONSITE P	OFFSITE SUM OF SQUARE	OFFSITE MEAN SQUARE	OFFSITE TOTAL	OFFSITE n	OFFSITE F	OFFSITE P
pH	0.517	0.057	1.288	33	1.789	0.123	1.162	0.129	1.972	32	3.665	0.006
Sodium	36.624	4.069	94.090	33	1.700	0.144	50.619	5.624	144.867	32	1.373	0.257
Potassium	83.133	9.237	244.290	33	1.376	0.253	25.039	2.782	175.500	32	0.425	0.908
Calcium	179.398	19.933	439.986	33	1.836	0.113	341.225	37.914	481.598	32	6.212	0.000
Magnesium	44.564	4.952	120.831	33	1.558	0.185	23.025	2.558	87.978	32	0.906	0.536
Manganese	6.142	0.682	16.011	33	1.660	0.155	10.010	1.112	13.621	32	7.086	0.000
Nitrogen	2.536	0.282	4.559	35	3.621	0.005	0.403	0.045	1.450	35	1.113	0.388
Carbon	26.875	2.986	102.125	35	1.032	0.442	6.087	0.676	16.085	34	1.691	0.144
Phosphorus	267.724	29.693	1154.732	33	0.803	0.618	207.599	23.067	967.862	32	0.698	0.704
EC	72.119	8.013	170.998	33	1.945	0.093	34.072	3.786	100.556	31	1.253	0.315

DF = 9

DEPTH

SOURCE	ONSITE SUM OF SQUARES	ONSITE MEAN SQUARE	ONSITE TOTAL	ONSITE n	ONSITE F	ONSITE P	OFFSITE SUM OF SQUARE	OFFSITE MEAN SQUARE	OFFSITE TOTAL	OFFSITE n	OFFSITE F	OFFSITE P
pH	0.067	0.034	1.288	33	0.854	0.436	0.058	0.029	1.972	32	0.455	0.639
Sodium	4.941	2.470	94.090	33	0.859	0.433	6.332	3.166	144.867	32	0.686	0.512
Potassium	11.883	5.941	244.290	33	0.793	0.462	68.420	34.210	175.496	32	9.585	0.001
Calcium	3.967	1.983	439.986	33	0.141	0.869	10.656	5.328	481.598	32	0.339	0.715
Magnesium	11.417	5.709	120.831	33	1.617	0.214	0.779	0.389	87.978	32	0.134	0.875
Manganese	0.147	0.074	16.011	33	0.144	0.867	0.186	0.093	13.621	32	0.208	0.814
Nitrogen	0.233	0.117	4.559	35	0.889	0.421	0.054	0.027	1.450	35	0.642	0.533
Carbon	28.653	14.327	102.125	35	6.435	0.004	0.458	0.229	0.161	34	0.469	0.629
Phosphorus	462.203	231.101	1154.732	33	10.345	0.000	107.291	53.645	967.862	32	1.870	0.172
EC	5.174	2.587	170.998	33	0.484	0.621	14.656	7.328	100.556	31	2.474	0.102

DF = 2

LOCATION

SOURCE	SUM OF SQUARES	MEAN SQUARE	TOTAL	n	F	P
pH	0.110	0.110	3.191	56	1.965	0.167
Sodium	30.160	30.160	247.504	56	7.632	0.008
Potassium	113.502	113.502	491.177	56	16.529	0.000
Calcium	2.187	2.187	821.208	56	0.147	0.707
Magnesium	0.539	0.539	186.596	56	0.159	0.696
Manganese	0.271	0.271	26.23	56	0.574	0.460
Nitrogen	0.229	0.229	5.886	59	2.352	0.131
Carbon	1.648	1.648	84.523	58	1.133	0.292
Phosphorus	22.841	22.841	1911.158	56	0.665	0.427
EC	8.880	8.880	228.152	55	2.187	0.145

DF = 1

EC---Electrical conductivity

LOCATION --Refers to onsite and offsite

Note -- Sum of Squares, Mean square and Total have been divided by 100

Figure 16. Significant trends of soil components with settlements age.

The data was raised by a constant (1) prior to log transformation. The means and standard errors were plotted using log transformed data, but the y-axis scale show their equivalent anti-log values.

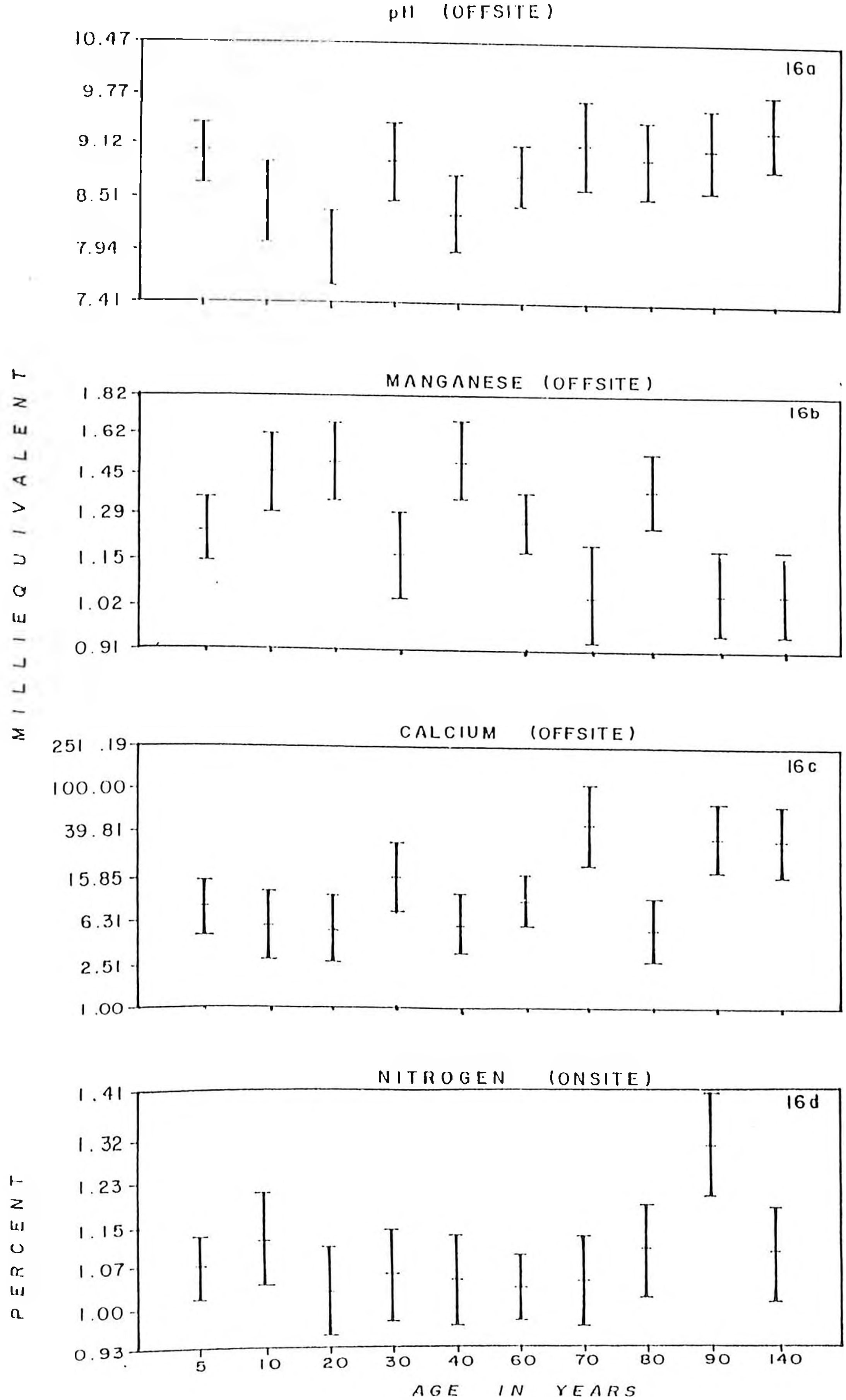
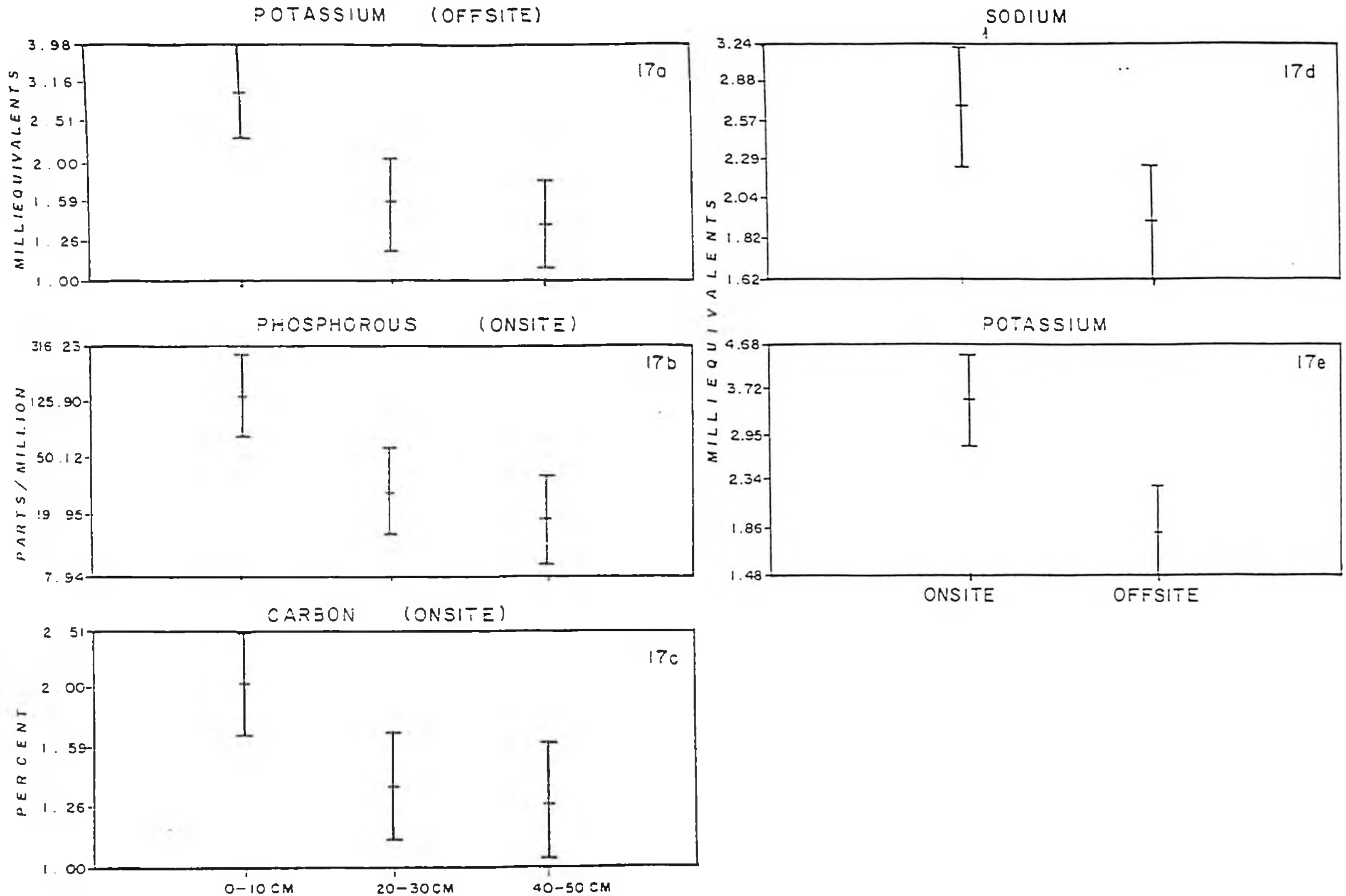

pH (OFFSITE)
16a
10.47
9.77
9.12
8.51
7.94
7.41
MANGANESE (OFFSITE)
16b
1.82
1.62
1.45
1.29
1.15
1.02
0.91
MILLIEQUIVALENT
CALCIUM (OFFSITE)
16c
251.19
100.00
39.81
15.85
6.31
2.51
1.00
NITROGEN (ONSITE)
16d
1.41
1.32
1.23
1.15
1.07
1.00
0.93
PERCENT
5
10
20
30
40
60
70
80
90
140
AGE IN YEARS

Figure 17. Significant trends of soil components with increasing depth and difference in location

The data was raised by a constant (1) prior to log transformation. The means and standard errors were plotted using log transformed data, but the y-axis scale show their equivalent anti-log values.


POTASSIUM (OFFSITE)
17a
MILLIEQUIVALENTS
3.98
3.16
2.51
2.00
1.59
1.26
1.00
PHOSPHOROUS (ONSITE)
17b
PARTS / MILLION
316.23
125.90
50.12
19.95
7.94
CARBON (ONSITE)
17c
PERCENT
2.51
2.00
1.59
1.26
1.00
0–10 CM
20–30 CM
40–50 CM
SODIUM
17d
MILLIEQUIVALENTS
3.24
2.88
2.57
2.29
2.04
1.82
1.62
POTASSIUM
17e
4.68
3.72
2.95
2.34
1.86
1.48
ONSITE
OFFSITE

unscarred *A. tortilis* seeds germination on soils from abandoned settlements of different ages. These data was subjected to analysis of variance testing for significant difference in seed germination of scarred and unscarred seeds between settlements of different ages and at various depths down the soil column as well as onsite and offsite. Since the number of scarred and unscarred seeds were unequal, percentage germination was calculated so as to adequately compare germination success between the two categories of seeds. This data was log transformed to reduce the error range which was giving negative values. Unscarred seeds data was raised by a constant (1) before tranformation, since there were zeros.

A two way anova was done using settlement age and depth on the log transformed data (Table 10), while a one way anova was done to determine difference in germination between onsite and offsite. Neither age nor depth had significant effect on seed germination of either scarred or unscarred seeds (Table 10). Germination rate of the scarred seeds was much higher offsite than onsite (Figure 18c), but unscarred seeds showed no difference. On average about 70% of the scarred seeds germinated, while the success rate on the unscarred seeds was less than 20% (Figure 18a and 18b).

These results indicate that *A. tortilis* seeds will germinate regardless of the nature of soil. However, the difference in germination success between scarred and unscarred seeds indicate a profound influence of scarification on germination of *A. tortilis* seeds.

4.7 Animal Occupancy

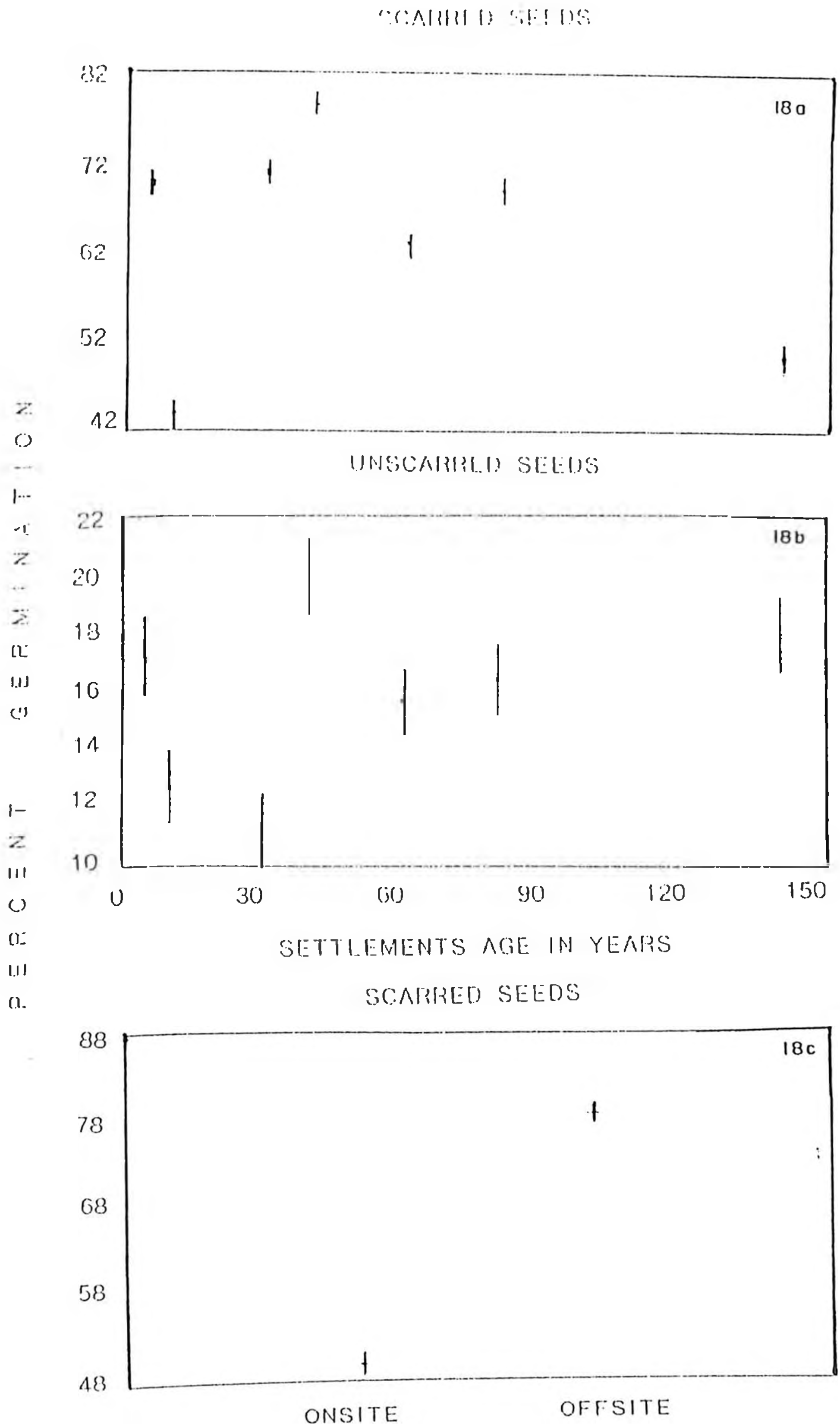
Onsite and offsite dung densities were calculated independently. Monthly mean dung density results for each site are presented in Appendix 12. Onsite density was calculated for only one half of each settlement. Since all the settlements have a circular shape, onsite area was calculated as though it were a circle. The diameter used in calculating the area was the mean of

Table 10. Effect of soil conditions on the germination of *A. tortilis* seeds

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	P
SCARRED SEEDS					
MAIN EFFECTS	0.4797	8	0.0600	0.822	0.591
AGE	0.2971	6	0.0495	0.679	0.668
DEPTH	0.1827	2	0.0913	1.252	0.302
AGE BY DEPTH	0.4884	12	0.0407	0.558	0.856
RESIDUAL	1.9700	27	0.0730		
TOTAL	2.9381	47			
LOCATION	0.4710	1	0.4710	8.783	0.005
TOTAL	2.9381	47			
UNSCARRED SEEDS					
MAIN EFFECTS	0.2742	8	0.0343	0.921	0.515
AGE	0.2681	6	0.0447	1.200	0.336
DEPTH	0.0061	2	0.0031	0.082	0.921
AGE BY DEPTH	0.7974	12	0.0665	1.785	0.103
RESIDUAL	1.0052	27	0.0372		
TOTAL	2.0768	47			
LOCATION	0.0784	1	0.0784	1.805	0.186
TOTAL	2.0768	47			

Figure 18. Percent germination of *A. tortilis* seeds plotted against settlements age and by location

Figure shows means ± standard errors


SCARRED SEEDS
82
72
62
52
42
18a
UNSCARRED SEEDS
22
20
18
16
14
12
10
18b
0
30
60
90
120
150
SETTLEMENTS AGE IN YEARS
SCARRED SEEDS
88
78
68
58
48
18c
ONSITE
OFFSITE

two diameters measured across each settlement at right angles. Offsite dung density was calculated along a gradient from the abandoned settlements.

Analysis of variance was done on these data to test for the effect of settlement age, distance from the settlements and time of year on the distribution of dung on and around the abandoned settlements. Age, distance and time of year all effected dung distribution significantly (Table 11).

Monthly mean dung densities (lumped for sites) plotted against time of year (9 months) show a high seasonal variation, both onsite and offsite. Dung density onsite and around the abandoned settlements increased during the dry season and decreased drastically during the wet season, only to increase again before the end of the year (Figure 19).

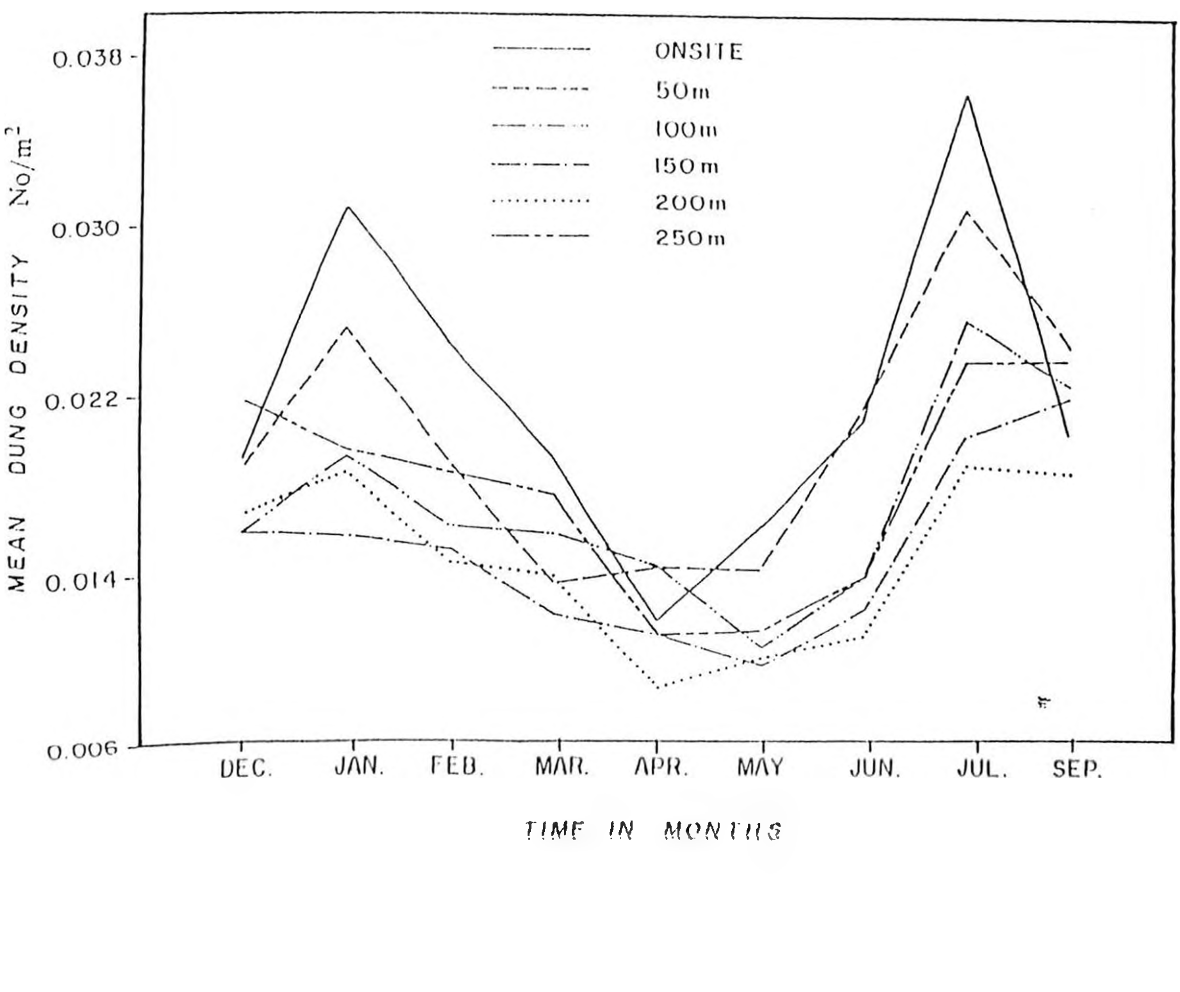
A two way analysis of variance was done on age class mean dung density by distance from the settlements and months. In all six age classes the results were consistent by months, but not by distance. Time of year had significant effects on the distribution of dung on all age classes, while distance was effective on second, third and fourth age classes. The interaction effect of months and distance was not significant (Table 12). With the exception of the second age class similar trends were observed on age classes mean dung densities plotted against time of year. Dung density were high at the beginning, there was a drop in mid year after which there was an increase (Figure 20). In the second age class dung density during April and July were exceptionally low relative to other months.

Age class mean dung densities were plotted against distance from the settlements. Onsite values were represented by 0m on the distance scale. With the exception of the first and the last age classes dung density decreased as a function of distance away from the settlements (Figure 21). On the first and the last age classes highest dung densities were recorded at 50m. It was observed that there was a tendency for dung density to increase at the end of the transect on all the age classes.

Table 11. Effects of settlements age, distance from the settlements and time of year on distribution of dung on and around abandoned settlements.

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	P
COVARIATES					
DISTANCE	0.006	1	0.006	47.182	<0.001
MAIN EFFECTS	0.033	13	0.003	20.048	<0.001
MONTH	0.032	8	0.004	30.809	<0.001
AGE	0.002	5	0.000	3.793	0.002
MONTH BY AGE	0.016	40	0.000	3.156	<0.001
Explained	0.056	54	0.001	8.038	<0.001
Residual	0.190	1481	0.000		
Total	0.245	1535	0.000		

Figure 19. Seasonal trends in dung density onsite and offsite throughout the study period



ONSITE
50m
100m
150m
200m
250m
0.038
0.030
0.022
0.014
0.006
MEAN DUNG DENSITY No/m²
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
SEP.
TIME IN MONTHS

Table 12. Effects of distance from settlements and time of year on distribution of dung on and around settlements of different age classes.

SOURCE	LESS THAN 11 YEARS: SUM OF SQUARES	DF	MEAN SQUARE	F	P	BETWEEN 11 AND 20 YEARS: SUM OF SQUARES	DF	MEAN SQUARE	F	P
MAIN EFFECTS	13.8012	13	1.0616	7.251	<0.001	19.5367	13	1.5028	22.101	<0.001
DISTANCE	0.8499	5	0.1700	1.161	0.330	7.5289	5	1.5058	22.145	<0.001
MONTH	12.9513	8	1.6189	11.057	<0.001	12.0078	8	1.5010	22.074	<0.001
DISTANCE BY MONTH	3.3864	40	0.0847	0.578	0.980	3.3610	40	0.0840	1.236	0.168
RESIDUAL	31.6250	216	0.1464			18.3592	270	0.0680		
TOTAL	48.8128	269				41.2569	323			

SOURCE	BETWEEN 21 AND 40 YEARS: SUM OF SQUARES	DF	MEAN SQUARE	F	P	BETWEEN 41 AND 60 YEARS: SUM OF SQUARES	DF	MEAN SQUARE	F	P
MAIN EFFECT	8.9297	13	0.6869	6.503	<0.001	27.3419	13	2.1032	13.561	<0.001
DISTANCE	1.8115	5	0.3623	3.430	0.005	5.8980	5	1.1796	7.606	<0.001
MONTH	7.1182	8	0.8898	8.423	<0.001	21.4439	8	2.6805	17.283	<0.001
DISTANCE BY MONTH	1.9701	40	0.0493	0.466	0.998	4.2176	40	0.1054	0.680	0.930
RESIDUAL	22.8168	216	0.1056			41.8755	270	0.1551		
TOTAL	33.7166	269				73.4350	323			

SOURCE	BETWEEN 61 AND 80 YEARS: SUM OF SQUARES	DF	MEAN SQUARE	F	P	OVER 80 YEARS: SUM OF SQUARES	DF	MEAN SQUARE	F	P
MAIN EFFECTS	22.5659	13	1.7358	13.948	<0.001	14.7488	13	1.1345	6.184	<0.001
DISTANCE	1.0405	5	0.2081	1.672	0.142	0.8692	5	0.1738	0.947	0.452
MONTH	21.5254	8	2.6907	21.620	<0.001	13.8797	8	1.7350	9.456	<0.001
DISTANCE BY MONTH	2.3364	40	2.6907	0.469	0.998	2.7264	40	0.0682	0.371	1.000
RESIDUAL	33.6017	270	0.0584			29.7228	162	0.1835		
TOTAL	58.5040	323				47.1980	215			

Note-- Sum of squares and mean squares were multiplied by 1000.

Figure 20. Seasonal trends in dung density around abandoned settlements of different age classes

Figure shows means ± standard errors

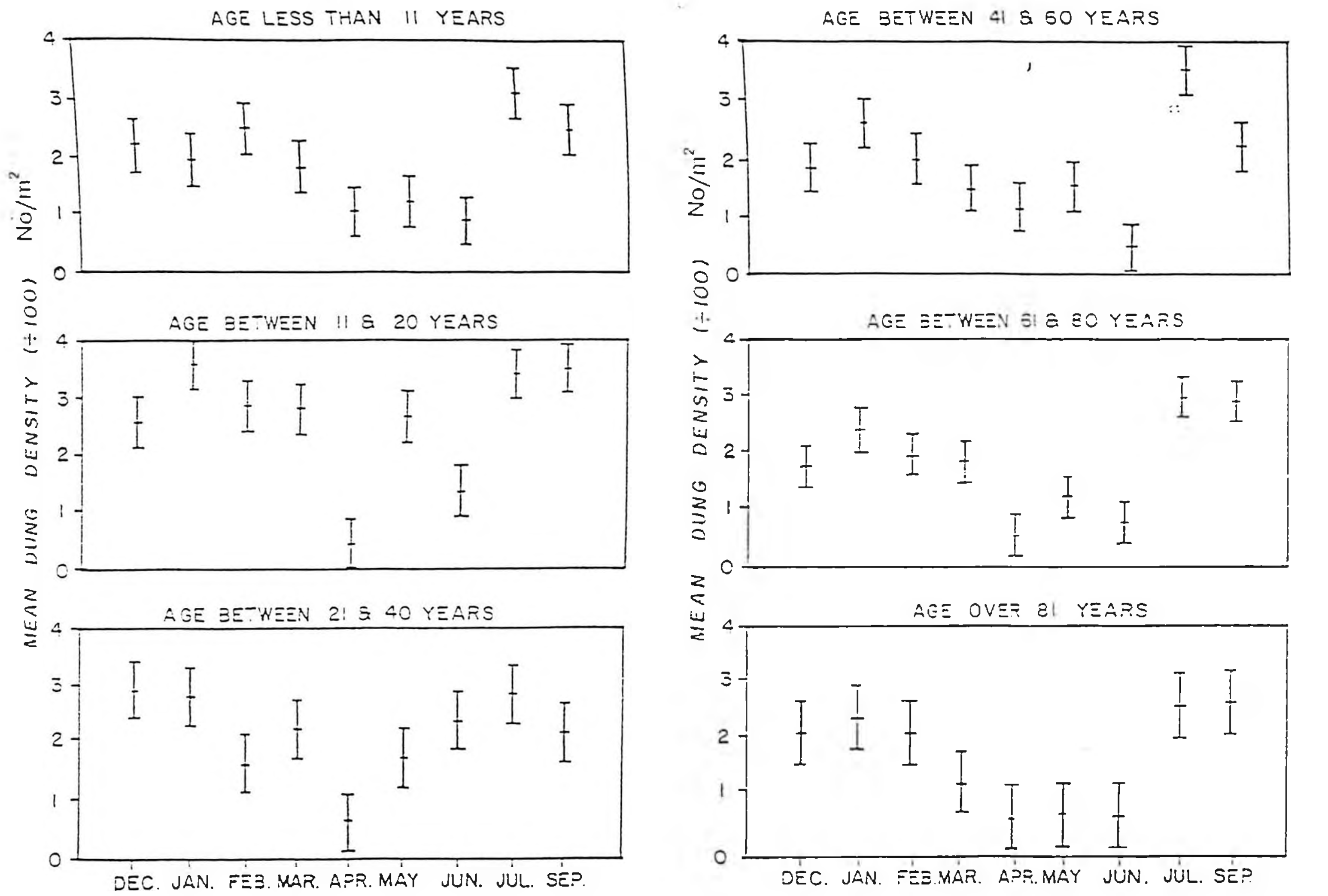
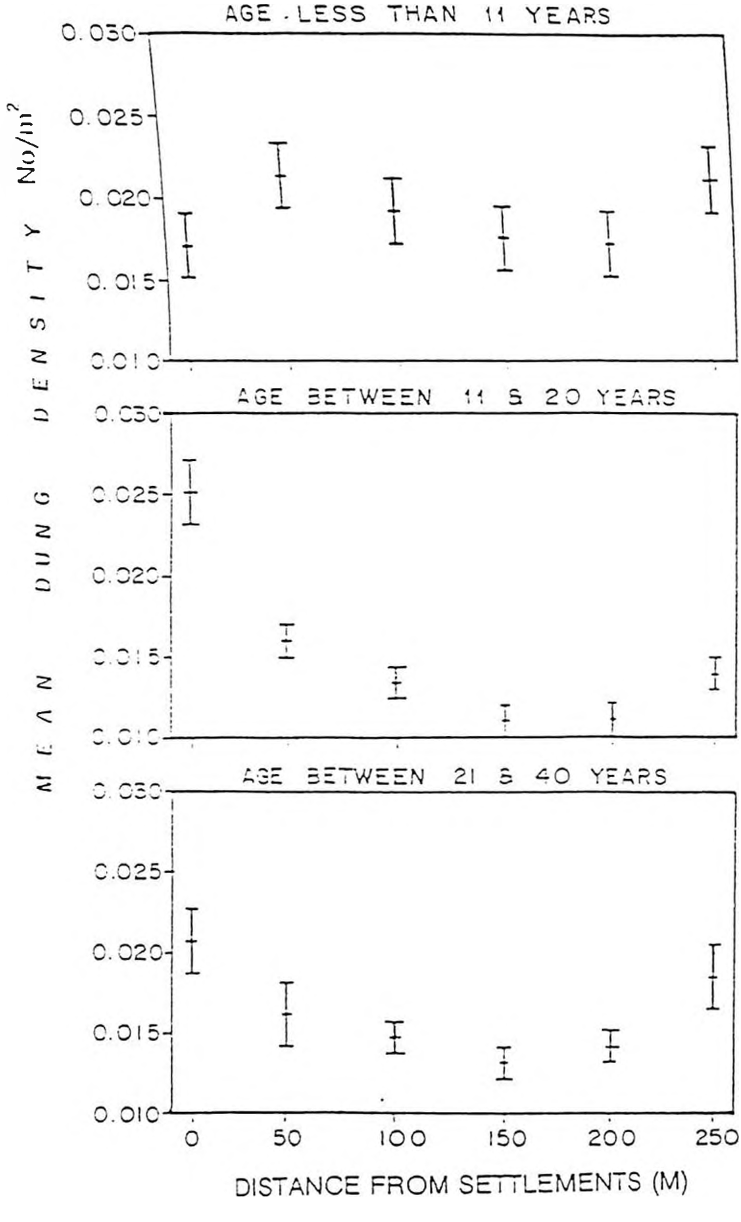
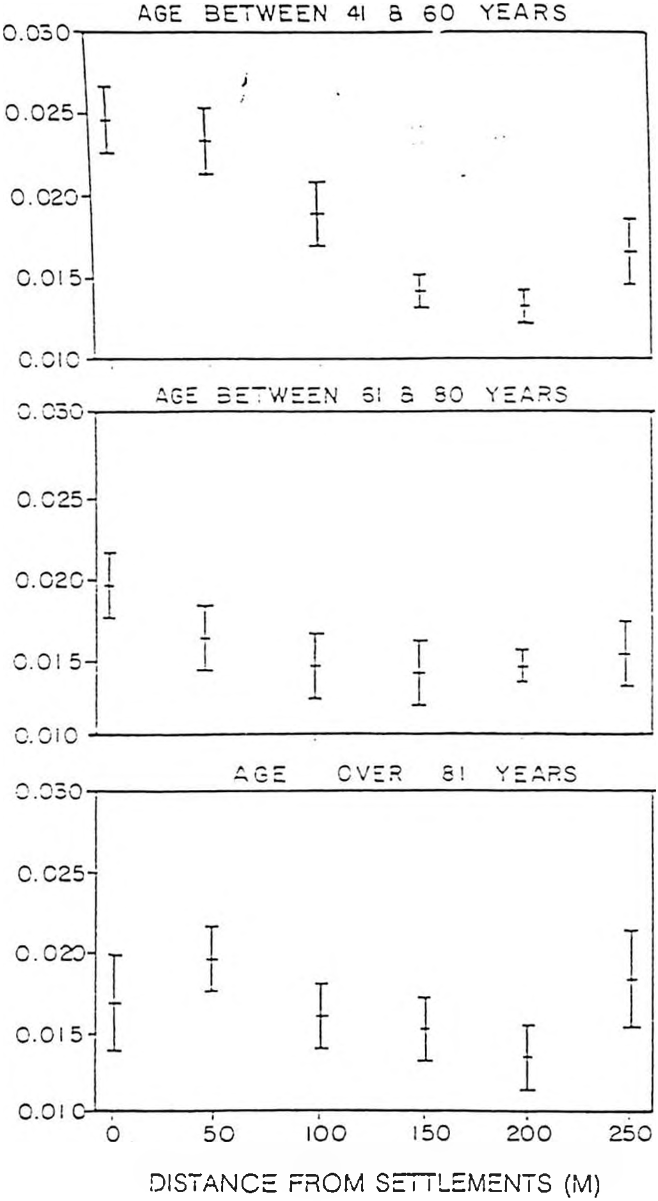

AGE LESS THAN 11 YEARS
AGE BETWEEN 11 & 20 YEARS
AGE BETWEEN 21 & 40 YEARS
AGE BETWEEN 41 & 60 YEARS
AGE BETWEEN 61 & 80 YEARS
AGE OVER 81 YEARS
MEAN DUNG DENSITY (÷100) No/m2
0
1
2
3
4
DEC. JAN. FEB. MAR. APR. MAY JUN. JUL. SEP.

Figure 21. Dung distribution in different age classes and at increasing distance

Figure shows means ± standard errors



MEAN DUNG DENSITY No/m^2
AGE LESS THAN 11 YEARS
AGE BETWEEN 11 & 20 YEARS
AGE BETWEEN 21 & 40 YEARS
0.030
0.025
0.020
0.015
0.010
0
50
100
150
200
250
DISTANCE FROM SETTLEMENTS (M)


AGE BETWEEN 41 & 60 YEARS
AGE BETWEEN 61 & 80 YEARS
AGE OVER 81 YEARS
0.030
0.025
0.020
0.015
0.010
0
50
100
150
200
250
DISTANCE FROM SETTLEMENTS (M)

The results of this analysis reveal a variation in animal occupancy of the abandoned settlements both onsite and offsite. With the exception of the settlements that had been abandoned for about a decade and those aged over eighty years, animal occupancy pattern was similar for all the settlements in between. The animals seem to prefer onsite for offsite. There was also a higher tendency of the animals to occupy the 50m zone offsite more than the areas further away from the abandoned settlement.

There were clear differences in animal occupancy of the settlements between dry and wet seasons. The animals preferred abandoned settlements and the area immediately around them during the dry season and then move out to other areas during the wet season. During the dry season animal occupation onsite was clearly higher than offsite, but in wet season there seems to be no preference and animal occupation seems to be evenly distributed between onsite and offsite at increasing distance away from the settlements.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

5.1 Grasses and Herbs Species Composition

The results of the analysis of the herbaceous layer species composition reveal clear patterns of species richness and diversity onsite. Both species richness and diversity were least on recently abandoned settlements and highest on the settlements in between, while on much older settlements species richness and diversity were just a bit higher than on very young settlements. Low species richness and diversity on young settlements could have been due to the unavailability of nutrients and/or high quantities of nitrogen in the large amount of dung. As the settlement ages, the dung decays and is incorporated in the soil. This changes the soil conditions, making it suitable for plant life. Plant species that first invade onsite must tolerate nitrogen toxicity, as nitrogen levels are usually very high, in yet undecayed dung on recently abandoned settlements. These plants may induce further changes in the environment, after which other plants move in.

Onsite there were twice as many herbs species as there were grasses, they also increased faster and peaked earlier. This observation indicate that herbs were the pioneer plant species in recolonizing the abandoned settlements. Grass diversity was lagging behind richness. Diversity indices are lower when a few or a single species is dominant. Lagging of grass diversity behind richness on the abandoned settlements may have reflected dominance by a few or a single grass species. Previous work established that *C. plectostachyus* predominated on and around recently abandoned settlements (Stelfox 1986). As this grass species was very characteristic of settlements that had been abandoned for about a decade it could have been the dominant grass species. Low diversity indices suggest that other grass species either come in later or take a long time before they are well established.

Diversity of herbs initially increases faster than richness but later on both were about the same, suggesting no dominance initially by any one or a few species. This meant that majority of herbs that recolonize abandoned settlements came in at about the same. While richness and diversity of herbs species were observed to decrease after the peak, grasses were more or less stabilizing. This meant that grass species that were established persisted while some herbs species disappeared and at the same time some became dominant.

Diversity onsite including trees and shrubs was observed to peak earlier while richness lagged by over 20 years, but as diversity decreased after the peak richness was observed to stabilize. This phenomenon demonstrates that some species were becoming dominant, thereby suppressing others. As herbs species had been found to decrease with settlement age it seems that trees and shrubs were affecting their presence. Most of the herbs that initially invaded the abandoned settlements as pioneers were disappearing from the settlement as a result of competition by grasses and eventually through being shaded out by trees. This takes a few decades as the abandoned settlements undergo different secondary successional stages from an open area covered only by dung to a community dominated by herbs through grassland to bushland. These results were consistent with the findings of previous work in succession. Whittaker (1965) and Monk (1967) have suggested increase in diversity with successional sequences and Odum (1963) has indicated that the curve probably levels off and may drop near the later portion of a successional sequence. Oosting and Humphreys (1931) worked on the trends of succession of an old field. They found that herbs begin with the abrupt appearance of large numbers of individuals which rarely maintain their importance for more than a year. The succeeding year finds the numbers materially reduced and thereafter there is a more or less gradual decline as trees become dominant. Many herbs of open old fields disappear entirely when the trees appear.

Although settlements' age did not affect herbaceous layer species composition offsite significantly, the nature of the settlements clusters suggest higher impact of abandoned settlements at 50m than further away. This was expected, since the area immediately off the settlements was bound to be disturbed more by the animals while converging at the settlement every evening. Dung deposition was also bound to be higher in this area (50m) as the livestock would spend sometime here before leaving in the morning and in the evening before entry. This facilitates the concentration of nutrients.

Comparisons of species richness and diversity onsite and offsite paint different pictures for grasses and herbs. There were fewer grass species onsite as there were offsite and only a few of those onsite were dominant. Number of herbs onsite and at 50m were equal but higher than at 100m and 150m. However diversity was about the same throughout suggesting no dominance. These results show that abandoned settlements influence species composition onsite more and relatively less further away. But since the abandoned settlements are many their impact on the Amboseli ecosystem was proportionately large.

5.2 Ground Cover

Having selected settlements that have been abandoned for different lengths of time, it was possible to determine the changes that take place through time after a settlement has been abandoned. An abandoned settlement takes a few years before a plant community is established, because of the thick layer of dung, which takes some time to decay to a state that allows vegetation growth. Thus there was very little or no ground cover on recently abandoned settlements.

Ground cover onsite increased with settlement age to a peak which varied with the seasons after which it decreased and more so during the dry season. During the wet season cover was twice as much as in mid dry season and was four times higher than during the late dry season. Although the pattern of change in ground cover with settlement age was still apparent during the wet season the difference in cover between settlements of different age was very much reduced. But during the mid dry and the late dry season ground cover was very high on settlements aged between 15 and 30 years and low on settlements aged over 90 years.

Contribution of the abandoned settlements to the savannas in terms of ground cover was remarkable. The dry and the wet seasons cover onsite was much higher than offsite. Cover offsite during the dry season was about 50% of cover onsite, while during the wet season it was about 75% of cover onsite. This reflects a high contribution of abandoned settlements to the savanna in terms of ground cover. This also means that the importance of the abandoned settlements was more during the dry season as reflected in the drastic drop in ground cover onsite by about 50% during the late dry season.

An important observation was that ground cover at 50m was very low during the dry seasons in relation to the other areas. However, ground cover recovered tremendously during the wet season in the same area, which reflected a high turn over rate characteristic of some annuals. High reduction of ground cover at this area may have been due to heavy use by animals.

Cover on and around settlements of different ages was different only during the dry season. Settlements that had been abandoned for between a decade and forty years had a lot of ground cover, but cover on the others was comparatively low. This situation shows the importance of abandoned settlements at different successional stages to savanna ecology especially during the dry season. Herbivores would take advantage of the resources around this settlements.

As Jensen (1983a) found, old settlements were often marked by groups of herbivores, including Maasai stock grazing on them. The frequency of these observations suggested that herbivores preferentially fed on abandoned settlements. The combination of low shrub cover and high grass cover by perennial grasses apparently improves the grazing value of the abandoned settlements. Local Maasai acknowledged the attraction of these oases of nutritious grass, as Peterson and McGinnes (1979) reported on Maasai herders' evaluation of common grasses in terms of grazing quality. *Cynodon* species were recognized as good grazing, particularly in the dry season, but were avoided in the early growth stages when they may contain toxic secondary compounds. *C. plectostachyus* was very common on the abandoned settlements aged between 15 and 60 years.

5.3 Onsite Woody Vegetation

According to past studies large numbers of *A. tortilis* had been observed on abandoned settlements. The establishment of such a community of plants would be possible only if the settlement remained undisturbed for a sufficiently long time. Looking at settlements of different ages biomass of woody species onsite was found to increase with age of the abandoned settlements. But this trend changed with the exclusion of *A. tortilis*. Biomass of all the other species excluding *A. tortilis* did not change with settlement age although it was higher on recently abandoned settlements. Biomass of *A. tortilis* on recently abandoned settlements was much lower than of the other species, but on the settlements that had been abandoned for a long time the reverse was true. It was noted that biomass of all the species together was just slightly higher than of *A. tortilis*.

These observations suggest that many of *A. tortilis* trees on recently abandoned settlements were young, while mature trees were on older settlements. Thus the abandoned settlement accommodates *A. tortilis* contributing to the diversification of the savanna. This species prefers deep soil with high moisture content. In Amboseli it was growing mainly along valleys and rarely on the ridge. For the other species of trees and shrubs it might be an indication of some regeneration. The drop in mean biomass of these species after two decades may have been due to young trees that may have come up within that time. However since biomass of these other species did not change with age after the drop may mean that the growth rate of these trees is much lower than of *A. tortilis*.

These changes of plant communities onsite have a profound impact on savanna ecology. At the time of abandonment the settlement was an opening in the middle of the bush, or what would be referred to as a gap. Any gap in a stable community is bound to be re-colonized if the disturbance is not recurrent. The gap is subject to some ecological changes through re-colonization making it a very dynamic micro-community. In the span of over a century it turns from being a gap in the bush through grassland to a bush community dominated by *A. tortilis*. At each particular stage of succession the island was important to the animal community. Soon after abandonment, some herbivore species may use the open abandoned settlement as they would be secure from predators. The animals may continue using the area even after it is invaded by herbs as it would still be an open area. The herbs are succeeded by a grass community turning it into a grassland. While the herbivores rest and feed they replenish the soil through defecation. As the place gradually change into bushland the browsers move in as grazers make less use of the area.

5.4 Offsite Woody Vegetation

Canopy cover in the study area was dominated by *Commiphora* species, of which there were three species, these were *C. africana, C. campestris* and *C. erythrea*. Other species that were found in abundance were *A. thomaxii, A. nubica*, *A. mellifera*, *Boscia anguistifolia* and *Maerua endlichii*. With the exception of the area along the valleys and on settlements abandoned for a long time, *A. tortilis* records were isolated cases. The effect of the construction of settlements was different on different trees and shrubs, because of their distribution in this area coupled with the selective use of wood by Amboseli Maasai in the construction and maintenance of the settlements.

Fences are built using *Commiphora* species and *A. mellifera* as they are the most common and because of their nature in case of *A. mellifera*. *Commiphora* species have a high water content and are very light when dry (Jensen 1983b). It deteriorates quickly making regular fence repair necessary. Therefore a large amount of *Commpihora* species around the settlement are harvested just to maintain the fences during the live of a settlement. Other species like *Boscia anguistifolia* are used as posts for building huts. *A. tortilis* is relatively hard wood and was also preferred for building huts whenever it was available.

The effect of settlements on woody vegetation in bushed savanna was not as extensive as in the open. In the bushed savanna biomass and density were low immediately close to the settlements up to about 60m, while in the open savanna biomass and density showed no difference all along the transect. The difference may be due to the availability of wood. In the bushed savanna there was plenty of wood and therefore no need to move too far from the settlement. In the open savanna scarcity of wood prompted looking for it further away. This means that in the open savanna settlements may have overlapped.

Some regeneration was observed after settlements were abandoned as biomass did increase with settlements' age. However, regeneration was slow as the difference in biomass around old and young settlements was not much considering the difference in age. This prolongs the time of recovery for the affected area. High density of the abandoned settlements may also affect regeneration due to the overlapping effect. This would be an advantage to grazers as the area remains open much longer. Herbivore presence in this area also retards regeneration through trampling, thus keeping seedlings down.

It was difficult however to determine at what age the area around the abandoned settlements could be regarded as having fully recovered from the effect of the settlement. A comparable study in an area with a lower density of abandoned settlements and preferably less incidence of re-occupation would be feasible. It would be possible then to determine at which age of the abandoned settlement the surrounding area had acquired vegetation similar to the original.

5.5 Soil Characteristics.

The type of vegetation found in an area reflects nature of the soil found in that area as different soils will suit different plant communities. It was observed that settlements of different ages had distinct plant communities onsite, which was not the case offsite. This suggests that onsite soil may have changed with settlement's age. In succession, a plant community may establish itself in an area if environmental conditions including soil are favourable. Succession onsite was demonstrated by the different plant communities of herbs, grasses and eventually trees and shrubs.

Past studies have established that nutrient concentration through dung accumulation has visible effects on vegetation growth on abandoned and around current Maasai settlements. The concentrations of these nutrients may influence ground cover both on and around the settlements. Ground cover which depends on the nature of plant community will change with different communities.

At the time of settlement abandonment the settlements are covered by a thick layer of dung. This dung in time decays and is incorporated into the soil. Dung on the settlements is an added component in the semi arid area, highly concentrated in small areas. So the incorporation of such a large amount of dung is expected to considerably change the nature of soil both physically and chemically. However the results of the test on soil chemical properties reveals no major differences in soils found onsite on settlements of different ages as was expected. But unless the large amount of dung left on the settlements after abandonment was removed by some agent, like erosion etc, it is bound to have a long lasting effect on the soils onsite. Most of the settlements were located on ground with gentle slopes if any, eliminating the effect of erosion.

Therefore dung deposits in most cases must have decayed and was incorporated into the soil onsite. Nitrogen associated with soil humus is in the form of organic nitrogen, which is protected from rapid microbial release. Since there was a lot of humus on recently abandoned settlements nitrogen would have been high on top soils of the recently abandoned settlements and low on settlements that have been abandoned for a long time.

The different plant communities observed on settlements of different ages, suggest that soils onsite differed with settlements' age and depth. The problem in detecting the difference demonstrated by the different plant communities might have been due to the sample size, as only twelve out of thirty two abandoned settlements were sampled. Alternatively, the laboratory technique used might have not been sensitive enough. Increasing sample size and especially collecting replicates may give much better results.

5.6 *Acacia tortilis* Seedling Experiment

A. tortilis seeds will germinate on soils at any stage of development with settlement age. Although scarred and unscarred seeds will germinate, scarred seeds are at an advantage over unscarred due to scarification. The fact that most of the scarred seeds germinated within three months means that in natural conditions most of them would germinate even before the settlement was abandoned. Should this happen they would not survive to maturity. Therefore there may be an alternative explanation as to how the seeds survive and eventually germinate and mature on old settlements.

It was established that by the end of the experiment (3 months) only a few of the unscarred seeds, had germinated. These seeds also in natural conditions would not survive to maturity. It may not be correct to assume that the unscarred seeds that had not germinated by the end of the experiment would not. If they were viable seeds, given sufficient time they may germinate. The tough seed coat of *A. tortilis* seeds coupled with the protection from parasitism after going through the ruminants gut may prolong their life in a dormant state.

Darlington (1931) reported that seeds of four species buried by Beal in 1879 were still viable, indicating that some seeds may remain viable for years when buried under proper conditions. Buried under proper conditions seeds of *A. tortilis* that have gone through the gut of a ruminant may last for several decades. Should this be the case, it can be argued that these were the seeds that eventually germinated after several decades in the soil. It could be during this time the tough seed coat deteriorates gradually and eventually allows germination. By this time the settlement will have been abandoned for several decades. It has been established that the mode of dispersion of these seeds to the settlement was through goats. Therefore most of the seeds that end up on the settlements may have passed through the ruminant gut. Since the seed experiment suggest no germination advantage in soils of abandoned settlements, presence of *A. tortilis* on old settlements may be due to the accumulation of their seeds rather than improved soils.

5.7 Animal Occupancy

Animal occupation on and around abandoned settlements was not only seasonal but also varied with settlements' age and distance from abandoned settlements. Throughout the study period, animal occupation on and around the abandoned settlements was relatively high during the dry and lowest in the wet seasons. Animals dispersed to areas further away from the settlements during the wet season only to come back to the settlements and the area adjacent during the dry season. At the settlements, the animals showed higher preference of onsite and the area immediately offsite at 50m.

Attraction of animals to the settlements during the dry season may have been due to the availability of certain resources within and immediately around the abandoned settlements, that were not available elsewhere. Whatever attracted the animals to the settlements during the dry season may not have been important during the wet season or the particular resources were abundant in the areas further away from the settlements during the wet season. The alternative theory may be confirmed by the fact that the few animals around the settlements during the wet season did not show any preference in respect to onsite and offsite, which means there was no much difference between onsite and offsite, reflecting even distribution of governing resources.

The resources might have been quality of graze and/or security as the animals came to rest in the open areas. Although security may have been a factor, availability of good graze might have had more influence in the distribution of the animals. If high occupancy in this area was to be explained in terms of security, then seasonality in occupancy should not exist, as the abandoned settlements remained open areas throughout.

Percent ground cover onsite during the dry season was much higher than offsite. Unlike the wet season where cover offsite was about 15% less than onsite, the difference during the dry season was 100%. Ground cover on most of the abandoned settlements aged less than sixty years was dominated by *C. plectostachyus*. Stelfox (1986) found high crude protein from grass species immediately around the settlements, where this species predominated. Maasai pastoralist recognized this species as good for milk production. Livestock and wild animals had been observed to congregate on the abandoned settlements (Jensen 1983a).

It was likely that settlements whose ground cover was dominated by *C. plectostachyus* were high quality pastures and that animals had recognized that. In this respect it seems that animals were attracted to the settlements during the dry season because of availability of good graze. During the wet season good pastures elsewhere would prompt dispersion of the animals to other areas.

While animal occupation was highest onsite on all the other age classes on the first and last age classes highest occupation was recorded at 50m. This difference may be due to the availability of resources. Ground cover and herb layer species composition onsite was low on recently abandoned settlements and those aged 80 years and over. Recently abandoned settlements were mostly covered by dung. Ground cover on old settlements was low may be due to a shading out effect. On recently abandoned settlements onsite and 50m zone were open areas, but 50m had some vegetation. In this respect animals preferred the later as they could feed and rest. As ground cover on old settlements was low only browsers could have been attracted by the availability of browse. So they would feed onsite then rest at 50m as it was an open area.

5.8 Conclusions

The importance of abandoned Maasai settlements in the savanna ecology in short and long term have been demonstrated in all aspects addressed in this study. Settlements play an important role in the opening up of bushed savanna and maintaining them in that state by retarding regeneration in some areas. Retardation of regeneration occurs whenever there was either reoccupation on or near an abandoned settlement. Even in the absence of reoccupation or any overlapping effect, regeneration would still take some time because seedlings are kept down by grazers through trampling. Opening up the bushed savanna affects the distribution of herbivores and carnivores.

The settlements could be looked at in the context of island biogeography theory. It provides an island of high nutrient concentration in an area of poor nutrients. This affects the type of species that could recolonize the settlements. Initially very few species of herbs and grasses including *C. plectostachyus* could survive on the island because of concentration of nutrients in the dung, which could have been toxic. As the settlements go through various successional stages they contribute in the diversification of the savanna. With the decaying of the dung after abandonment species richness, diversity and ground cover on these islands increases tremendously in comparison to the background. These eutrophic sites not only support unique plant communities but also increases the quality of graze in the savanna as they support such grass species as *C. plectostachyus.* In the later stages of succession these areas accommodate microhabitats different from the surrounding dominated by *A. tortilis.* This species was found along the valleys and in very isolated cases along the ridge probably on old abandoned settlements.

These secondary successional stage were also important to the herbivore community and to some extent the carnivores. Immediately after abandonment, the area offers security in that it was an open area. Later on the area was covered by grasses and herbs attracting grazers. During the dry and late dry seasons these islands were very important to herbivore community and to some extent also the carnivores. These areas were highly productive and they attracted large numbers of animals during the dry season when the other areas had poor quality graze. In effect, throughout the cycle the abandoned settlements affected the distribution and composition of large herbivores community.

Abandoned settlements are important features in the savanna and contribute abundantly toward conservation of some species of herbivores and carnivores in the redistribution of resources. While the settlements increase the density of some plant species that attract browsers and grazers they also open more grazing land. In the long term, settlements contribute to the survival of these animals and would be important to their conservation.

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APPENDICES

Appendix 1. Onsite species richness and diversity calculated at four levels. 1. Grasses, herbs, shrubs and trees. 2. Grasses 3. Herbs 4. Grasses and Herbs.

		RICHNESS				DIVERSITY			
SITE	AGE	1	2	3	4	1	2	3	4
R1	5	13	5	5	10	1.797	0.855	0.724	1.483
P1	5	3	0	0	0	1.004	0.000	0.000	0.000
E1	10	25	6	14	20	2.138	0.657	2.012	1.957
L6	10	8	1	2	3	1.374	0.000	0.121	0.631
B1	10	20	4	11	15	1.799	0.946	1.864	2.127
M	15	17	4	10	14	1.479	0.298	1.369	1.313
R	20	16	5	10	15	2.047	0.878	1.650	2.030
P	20	12	3	6	9	1.019	0.163	1.144	0.554
K	20	21	8	8	16	1.441	0.700	1.832	1.129
C	20	15	5	7	12	1.725	0.401	1.231	1.366
I	20	15	2	8	10	1.254	0.217	1.648	0.940
U	25	6	2	4	6	1.401	0.309	1.104	1.401
MU	30	18	4	11	15	1.901	0.442	2.111	1.668
L	35	32	7	20	27	2.207	1.183	2.113	2.407
S	35	15	6	5	11	1.499	0.506	1.322	0.950
T	40	13	4	7	11	1.354	0.715	1.363	1.706
Q	45	14	3	8	11	1.575	0.249	1.445	1.188
E12	45	28	9	13	22	2.209	1.400	1.980	1.908
W	50	17	4	11	15	1.768	0.885	1.690	2.049
B5	50	25	6	14	20	2.549	1.198	2.042	2.344
L2	60	16	6	5	12	1.617	1.226	1.442	1.490
B11	60	8	4	3	7	1.180	0.456	0.334	0.850
B12	70	14	5	8	13	1.623	0.705	1.821	1.471
E7	70	26	5	16	21	1.423	1.181	1.752	2.191
E10	70	24	6	12	18	2.700	1.426	2.137	2.491
B2	80	23	6	14	20	1.583	0.954	1.918	2.217
L5	80	7	3	2	5	1.116	0.896	0.636	1.030
E8	80	23	9	8	17	2.480	1.389	1.725	2.195
M1	90	22	6	12	18	1.176	0.812	2.144	1.861
B3	90	25	10	10	20	1.334	1.162	1.971	2.119
B16	140	11	4	3	7	1.117	0.813	1.011	1.032
B17	140	15	3	8	11	1.407	0.546	1.330	1.483

Appendix 2. Offsite species richness and diversity calculated at increasing distance away from sites

		RICHNESS						DIVERSITY								
		GRASSES			HERBS			GRASSES			HERBS			GRASSES & HERBS		
SITE	AGE	50m	100m	150m	50m	100m	150m	50m	100m	150m	50m	100m	150m	50m	100m	150m
R1	5	4	4	3	3	2	4	0.689	0.907	0.489	0.950	0.673	1.149	1.085	1.297	1.043
P1	5	9	6	4	12	9	9	1.691	0.629	0.222	2.044	1.863	1.934	2.567	1.923	1.421
E1	10	4	5	3	9	12	7	0.773	0.801	0.292	1.851	1.874	1.242	1.877	1.788	1.297
L6	10	7	5	6	4	5	5	1.227	0.813	1.074	1.205	1.140	1.414	1.489	1.423	1.489
B1	10	4	4	2	11	6	8	0.853	0.813	0.225	1.760	1.436	1.558	1.871	1.775	1.125
M	15	4	7	5	10	14	10	0.622	1.721	0.946	1.567	2.256	1.858	1.728	2.697	2.195
R	20	5	7	4	10	10	9	0.694	1.110	0.561	1.981	1.880	1.984	1.675	2.068	1.733
P	20	7	6	11	15	10	16	1.611	1.038	1.838	2.200	1.584	2.193	2.635	2.005	2.716
K	20	6	8	6	6	6	6	1.363	1.008	1.157	1.030	1.302	1.515	1.809	1.849	1.935
C	20	5	4	5	7	11	7	0.306	0.707	0.486	1.754	1.930	1.694	1.258	1.797	1.222
I	20	5	6	7	17	12	11	0.965	1.440	1.773	1.942	1.790	1.256	2.227	2.320	2.103
U	25	7	10	6	11	8	10	1.190	1.467	1.103	1.559	1.516	1.205	2.084	2.170	1.847
MU	30	7	5	4	12	1	1	1.765	1.444	1.356	1.952	0.000	0.000	2.496	1.607	1.479
L	35	8	7	5	10	11	10	1.856	1.562	0.972	1.957	2.065	1.582	2.601	2.535	1.971
S	35	9	6	7	13	9	10	1.955	1.466	1.235	1.773	1.744	2.078	2.517	2.305	2.065
T	40	6	5	7	6	5	8	0.972	0.824	0.793	1.315	1.190	1.660	1.805	1.560	1.598
Q	45	6	9	9	7	8	11	1.441	1.701	1.951	0.902	1.535	2.006	1.816	2.278	2.672
E12	45	3	3	3	2	3	3	0.995	1.010	1.030	0.693	1.040	1.099	1.378	1.563	1.586
W	50	7	6	5	10	8	9	0.958	1.250	1.057	1.627	1.063	1.492	1.955	1.741	1.982
B5	50	3	3	3	9	7	8	0.669	0.749	0.652	1.812	1.533	1.755	1.350	1.587	1.701
L2	60	4	4	5	3	6	7	0.369	0.444	0.971	0.766	1.108	1.443	0.774	1.149	1.569
B11	60	10	6	5	8	7	4	1.394	0.861	1.019	1.916	1.610	1.168	2.000	1.463	1.297
B12	70	5	7	7	7	6	7	0.933	1.079	1.154	1.731	1.255	1.716	1.459	1.553	1.687
E7	70	2	5	4	9	6	9	0.056	0.619	0.273	1.877	1.514	1.664	1.406	1.483	1.393
E10	70	6	5	7	13	7	6	1.254	0.974	1.464	1.989	1.336	1.473	2.174	1.819	2.127
B2	80	6	5	5	11	8	9	0.931	1.043	1.254	1.757	1.615	1.460	2.034	2.028	2.055
L5	80	5	6	8	3	9	4	0.390	0.791	0.835	0.824	1.814	1.321	0.701	1.323	1.049
E8	80	4	7	6	13	13	14	0.811	1.524	1.310	2.089	1.939	2.289	2.159	2.426	2.195
M1	90	7	3	8	5	5	8	1.511	0.742	1.553	0.976	1.454	1.938	1.964	1.530	2.409
B3	90	7	7	3	6	10	9	1.278	0.943	0.255	1.117	1.814	1.347	1.857	1.910	1.270
B16	140	6	5	5	4	7	3	1.296	1.062	1.194	0.759	1.246	1.079	1.722	1.834	1.617
B17	140	6	3	4	5	2	3	0.902	0.446	0.348	1.550	0.683	0.868	1.384	0.705	0.686

Appendix 3. Mean percent ground cover both onsite and offsite at increasing distance from each site for three seasons.

		DRY SEASON					WET SEASON				LATE DRY SEASON				
SITE	AGE	0m	50m	100m	150m	200m	0m	50m	100m	150m	0m	50m	100m	150m	200m
R1	5	0.00	8.75	8.75	8.75	10.83	0.00	41.33	32.67	36.67	2.50	1.74	3.75	3.75	6.25
P1	5	2.78	3.75	5.00	5.00	3.33	40.67	28.00	23.00	32.00					
E1	10	14.45	10.00	13.75	12.50	14.17	70.67	71.34	66.00	62.00					
B1	10	1.39	6.25	7.50	5.00	10.83	36.00	45.33	37.33	40.67					
L6	10	15.83	13.75	12.50	8.75	8.33	50.67	61.33	64.67	60.00	5.60	3.42	22.50	12.50	12.50
M	15	42.22	5.00	10.00	8.75	3.75	75.33	46.67	36.00	36.67					
C	20	20.00	8.75	18.75	11.25	14.17	48.00	62.67	63.33	67.33					
R	20	32.78	5.00	5.00	7.50	8.33	72.67	40.67	42.00	43.33					
P	20	64.45	6.25	11.25	17.50	14.17	74.67	40.00	43.33	51.33					
K	20	31.10	15.00	13.75	22.50	15.83	72.00	33.33	36.00	26.00					
I	20	69.17	10.00	12.50	17.50	21.67	90.67	58.00	41.33	38.67					
U	25	22.50	8.75	11.25	8.75	8.33	79.34	38.00	40.00	44.67					
MU	30	19.45	5.00	11.25	16.25	4.17	50.67	31.33	8.00	12.00	15.56	4.11	7.50	3.75	3.75
S	35	23.33	5.00	7.50	11.25	6.67	48.67	42.00	20.67	30.00					
L	35	31.44	5.00	6.25	6.25	12.50	68.00	49.33	23.34	36.67					
T	40	36.67	12.50	15.00	13.75	20.00	56.67	54.00	48.67	58.67	20.28	3.25	6.25	15.00	3.75
E12	45	18.06	5.00	3.75	2.50	11.67	82.67	9.33	11.33	8.67					
Q	45	10.00	2.50	16.25	13.75	25.00	65.34	28.67	46.67	44.00					
B5	50	14.45	8.75	10.00	13.75	9.17	57.33	56.67	56.00	57.33					
W	50	18.06	6.25	11.25	11.25	7.50	69.34	56.00	55.33	44.00					
B11	60	14.17	7.50	2.50	8.75	8.33	47.33	66.67	54.67	49.33	10.28	2.35	7.50	11.25	8.75
L2	60	21.39	16.25	12.50	6.25	14.17	73.33	54.67	46.00	54.00	14.40	1.71	11.25	11.25	11.25
E10	70	9.44	11.25	28.75	3.75	4.17	35.33	48.00	41.33	52.00					
E7	70	14.45	5.00	11.25	11.25	11.67	71.34	41.33	35.33	44.00					
B12	70	7.22	5.00	2.50	10.00	6.67	66.67	60.67	60.67	64.67					
E8	80	5.00	10.00	13.75	11.25	16.67	38.67	70.00	68.67	58.67					
B2	80	16.95	3.75	10.00	6.25	10.83	66.00	51.33	32.00	41.33	15.28	4.35	8.75	8.75	10.00
L5	80	18.89	11.25	16.25	8.75	7.50	74.66	47.33	50.67	48.67					
B3	90	11.95	6.25	7.50	5.00	5.83	50.67	51.33	65.33	62.00					
M1	90	11.11	1.25	6.25	5.00	7.50	46.67	24.00	35.33	37.33	8.06	3.63	2.50	3.75	5.00
B17	140	8.33	2.50	2.50	1.25	5.83	67.50	35.00	52.00	38.00					
B16	140	5.56	5.00	2.50	3.75	3.33	32.78	55.00	47.00	41.00	4.72	1.64	10.00	11.25	12.50

Appendix 4. Onsite biomass (Kg/m^2) of trees and shrubs.

SITE	AGE	ALL	AT	ME	THO	CA	CC	AA	LE	SP	AN	AM	BG	CR	CG
P1	5	237.56		70.92		116.21	30.44								
R1	5	118.09		56.93						17.73		43.44			
L6	10	132.53	1.04		70.56	2.31			1.73			56.89			
E1	10	160.20		123.06		1.25			0.08		0.14		35.67		
B1	10	249.67	186.98	3.67					7.70	28.74	23.03				
H	15	11.30	6.60						3.88		0.82				
R	20	0.81									0.81				
I	20	40.12	31.44			0.72			1.89		5.21	0.86			
K	20	35.43	28.92	0.47		0.09			5.90			0.05			
C	20	19.09	4.59							3.29		11.21			
P	20	46.64	29.07	1.18					16.39						
U	25														
MU	30	13.57	7.69	2.50					3.38						
L	35	150.74	140.59	2.19		5.48					2.30	0.18			
S	35	37.57		26.61						5.33	1.78				3.85
T	40	199.69		198.71								0.98			
O	45	263.38	182.40	77.24					3.74						
E12	45	63.31		46.02					5.92	1.16	0.50	9.40		0.30	
W	50	192.77	190.06	2.70											
B5	50	36.51	26.56	2.98	5.99	0.33				0.67					
L2	60	7.34	1.39					1.38			0.18	4.39			
B11	60	36.53	36.53												
B12	70	16.81	16.81												
E7	70	960.18	660.13	285.04					5.74	2.81	6.47				
E10	70	66.24	28.06	12.95		1.43			2.00	0.64	21.15				
L5	80	4.49	1.49								3.00				
E8	80	55.53	4.58	13.82					0.97	2.29	33.37	0.51			
B2	80	358.31	328.94	29.02					0.35						
K1	90	279.34	277.54	0.11					0.14	1.54					
B3	90	297.89	292.98	0.07					2.31	1.87	0.66				
B16	140	169.83	165.41	1.81					0.81		1.80				
B17	140	327.99	294.94	1.79	15.33	15.93									

All = All species of trees and shrubs, AT = *Acacia. tortilis*, ME = *Maerua endlichii*, THO = *A. thomaxii*, CA = *Commiphora africana*, CC = *C. campestris*, AA = *A. ancistroclada*, LE = *Lycium europium*, SP = *Salvadora persica*, AN = *A. Nubica*, AM = *A. mellifera*, BG = *Balanite glabra*, CR = *Cadaba raspolii*, CG = *Cordia gharaf*.

Appendix 5. Onsite density (Number/m²) of trees and shrubs.

SITE	DIA	AGE	ALL	A1	HI	HHO	CA	CC	AA	LI	SP	AN	AM	BG	GR	CG
P1	83	5	0.33		0.07		0.22	0.04								
R1	64	5	0.62		0.19						0.19		0.25			
B1	66	10	3.57	1.64	0.18					0.29	0.35	1.11	re			
L6	82	10	1.14	0.08		0.49	0.08			0.15			0.30			
F1	78	10	0.25		0.04		0.04			0.04		0.08		0.04		
H	63	15	0.45	0.06						0.26		0.13				
C	60	20	0.64	0.07							0.14		0.42			
K	65	20	1.21	0.06	0.12		0.06			0.84			0.06			
P	95	20	0.40	0.08	0.03					0.28						
R	61	20	0.07	0.00								0.07				
I	114	20	0.25	0.08			0.04			0.06		0.06	0.02			
U	94	25														
HU	64	30	0.31	0.06	0.06					0.19						
L	60	35	1.41	1.06	0.14		0.07					0.07	0.07			
S	83	35	0.22		0.07						0.04	0.07				0.04
T	103	40	0.05		0.02								0.02			
E12	64	45	1.49		0.25					0.75	0.25	0.06	0.12		0.06	
Q	81	45	0.82	0.50	0.04					0.23						
W	77	50	1.33	1.25	0.09											
B5	88	50	0.46	0.33	0.03	0.03	0.03									
L2	91	60	0.25	0.03					0.03			0.03	0.15			
B11	95	60	0.28	0.28												
E10	88	70	1.41	0.10	0.30		0.03			0.23	0.03	0.72				
E7	102	70	1.40	0.34	0.37					0.39	0.05	0.24				
B12	90	70	0.16	0.16												
B2	93	80	1.35	1.27	0.06					0.03						
E8	75	80	1.54	0.14	0.14					0.14	0.05	1.04	0.05			
L5	96	80	0.08	0.03							re	0.03				
H1	72	90	3.00	2.80	0.05					0.05	0.10					
B3	82	90	1.33	0.95	0.04					0.23	0.08	0.04				
B17	69	140	1.23	0.96	0.05	0.11	0.11									
B16	102	140	0.64	0.54	0.05					0.02		0.02				

NOTE-- Density have been multiplied by 100.

DIA --- Diameter of settlements in meters

Appendix 6. Mean density (Numbers/m^2) of all the trees and shrubs encountered within the study area. Calculated at increasing distance from abandoned settlements.

BUSHED SAVANNA

SITE	AGE	28m	56m	84m	112m	140m	168m	196m	224m	252m
P1	5	0.013	0.045	0.018	0.020	0.049	0.052	0.019	0.045	0.026
B1	10	0.003	0.002	0.002	0.001	0.002	0.002	0.005	0.001	0.003
L6	10	0.014	0.157	0.069	0.025	0.023	0.032	0.024	0.026	0.069
H	15	0.002	0.004	0.002	0.003	0.007	0.006	0.005	0.015	0.007
K	20	0.005	0.014	0.016	0.010	0.022	0.008	0.025	0.028	0.016
R	20	0.013	0.013	0.016	0.034	0.027	0.018	0.021	0.019	0.023
P	20	0.048	0.023	0.041	0.156	0.023	0.022	0.202	0.027	0.030
I	20	0.020	0.028	0.021	0.006	0.019	0.017	0.038	0.006	0.052
U	25	0.002	0.003	0.008	0.013	0.063	0.014	0.008	0.004	0.011
L	35	0.011	0.044	0.061	0.028	0.014	0.007	0.009	0.023	0.013
T	40	0.002	0.005	0.006	0.005	0.013	0.020	0.008	0.013	0.017
Q	45	0.005	0.004	0.003	0.005	0.013	0.010	0.007	0.013	0.010
B5	50	0.041	0.036	0.040	0.042	0.042	0.026	0.021	0.022	0.017
W	50	0.001	0.008	0.009	0.014	0.043	0.006	0.007	0.016	0.046
L2	60	0.013	0.008	0.013	0.028	0.027	0.011	0.013	0.024	0.009
B11	60	0.002	0.042	0.060	0.027	0.014	0.053	0.019	0.006	0.004
L5	80	0.020	0.033	0.035	0.036	0.023	0.027	0.044	0.015	0.016
B2	80	0.062	0.051	0.041	0.034	0.129	0.080	0.029	0.057	0.055
B16	140	0.003	0.009	0.007	0.007	0.019	0.046	0.010	0.025	0.011
B17	140	0.010	0.054	0.031	0.043	0.046	0.055	0.044	0.034	0.036

OPEN SAVANNA

SITE		50m	100m	150m	200m	250m
R1	5	0.0015	0.0136	0.0048	0.0061	0.0048
E1	10	0.0012	0.0011	0.0014	0.0005	0.0018
C	20	0.0025	0.0022	0.0023	0.0018	0.0060
MU	30	0.0054	0.0157	0.0100	0.0123	0.0150
S	35	0.0073	0.0100	0.0056	0.0029	0.0063
E12	45	0.0236	0.0082	0.0054	0.0104	0.0060
E7	70	0.0048	0.0113	0.0091	0.0041	0.0049
B12	70	0.0021	0.0022	0.0053	0.0015	0.0007
E10	70	0.0213	0.0089	0.0059	0.0043	0.0022
E8	80	0.0007	0.0010	0.0009	0.0011	0.0010
M1	90	0.0056	0.0026	0.0032	0.0075	0.0100
B3	90	0.0041	0.0043	0.0043	0.0097	0.1497

Appendix 7. Mean biomass (Kg/m^2) of all species the trees and shrubs encountered within the study area. Calculated at increasing distance from abandoned settlements.

BUSHED SAVANNA

SITE	AGE	28m	56m	84m	112m	140m	168m	196m	224m	252m
P1	5	0.669	2.850	1.739	1.661	5.190	2.135	0.784	4.306	1.974
B1	10	0.005	0.015	1.212	0.047	0.044	0.037	0.013	0.003	0.026
L6	10	0.244	7.961	0.590	0.259	0.279	1.878	9.364	0.496	2.476
M	15	0.307	0.279	0.123	0.136	0.212	0.606	0.347	0.628	0.276
K	20	0.772	1.398	2.344	11.759	2.493	0.366	13.033	2.919	2.644
R	20	0.081	0.606	0.088	0.168	0.436	0.614	0.500	0.041	0.127
P	20	0.556	0.460	0.823	2.876	1.025	1.529	1.936	1.408	1.544
I	20	0.071	0.560	0.680	0.350	1.099	0.752	2.489	1.710	1.833
U	25	0.004	0.028	0.050	0.131	0.578	0.173	0.099	0.069	0.110
L	35	0.611	1.550	4.032	2.056	0.502	0.084	0.228	3.115	0.138
T	40	0.128	0.122	0.088	0.049	0.048	0.042	0.282	0.259	0.444
Q	45	0.208	0.154	0.538	0.404	0.766	0.343	0.815	0.236	0.913
B5	50	0.899	0.692	0.764	1.238	0.517	0.960	0.221	0.245	0.234
W	50	0.118	0.070	0.070	0.151	0.566	0.090	0.067	0.263	0.447
L2	60	0.617	0.590	0.673	1.891	1.331	0.254	0.256	0.303	0.381
B11	60	0.019	0.623	2.993	1.432	0.496	1.834	0.563	0.032	0.063
L5	80	4.177	1.519	1.011	0.707	1.128	5.414	0.735	2.035	2.459
B2	80	0.381	0.428	0.641	0.514	0.253	0.342	0.541	0.144	0.150
B16	140	0.036	0.198	0.047	0.294	0.709	4.445	0.540	2.078	1.070
B17	140	0.123	2.016	1.678	2.451	4.009	3.795	1.719	3.674	2.046

OPEN SAVANNA

SITE	AGE	50m	100m	150m	200m	250m
R1	5	0.100	0.098	0.141	0.045	0.088
E1	10	0.007	0.063	0.045	0.047	0.018
C	20	0.025	0.014	0.019	0.009	0.040
MU	30	0.066	0.718	0.058	1.429	0.182
S	35	0.034	0.075	0.043	0.021	0.023
E12	45	2.053	0.259	0.421	0.340	0.124
E7	70	0.052	0.164	0.259	0.022	0.233
B12	70	0.022	0.019	0.020	0.013	0.093
E10	70	0.155	0.401	0.054	0.202	0.198
E8	80	0.042	0.032	0.034	0.217	0.048
M1	90	0.062	0.063	0.122	0.237	0.244
B3	90	0.396	0.098	0.112	0.143	1.908

Appendix 8. Mean density (numbers/m^2) of *Commiphora* species and *A. mellifera* calculated at increasing distance from abandoned settlements.

BUSHED SAVANNA

SITE	AGE	28m	56m	84m	112m	140m	168m	196m	224m	252m
P1	5	0.018	0.045	0.018	0.027	0.050	0.058	0.019	0.047	0.037
B1	10	0.000	0.000	0.000	0.000	0.007	0.002	0.045	0.000	0.000
L6	10	0.013	0.157	0.069	0.026	0.023	0.032	0.032	0.299	0.064
M	15	0.002	0.004	0.002	0.003	0.005	0.007	0.005	0.015	0.006
K	20	0.013	0.022	0.041	0.197	0.039	0.017	0.220	0.027	0.026
R	20	0.020	0.026	0.021	0.006	0.023	0.017	0.038	0.006	0.052
P	20	0.038	0.016	0.016	0.035	0.025	0.018	0.020	0.019	0.026
I	20	0.023	0.014	0.011	0.010	0.021	0.009	0.025	0.030	0.016
U	25	0.002	0.003	0.010	0.013	0.063	0.014	0.008	0.021	0.008
L	35	0.011	0.042	0.063	0.109	0.014	0.008	0.009	0.019	0.016
F	40	0.001	0.006	0.006	0.012	0.009	0.004	0.007	0.011	0.018
Q	45	0.012	0.005	0.004	0.005	0.012	0.010	0.009	0.020	0.010
B5	50	0.046	0.035	0.064	0.043	0.042	0.029	0.017	0.021	0.016
W	50	0.001	0.007	0.009	0.012	0.038	0.007	0.007	0.016	0.063
L2	60	0.013	0.007	0.012	0.029	0.024	0.015	0.013	0.046	0.005
B11	60	0.002	0.042	0.060	0.038	0.014	0.053	0.019	0.006	0.004
L5	80	0.062	0.051	0.041	0.034	0.128	0.080	0.029	0.059	0.070
B2	80	0.021	0.033	0.035	0.036	0.024	0.027	0.042	0.014	0.016
B16	140	0.012	0.003	0.006	0.044	0.018	0.067	0.016	0.026	0.010
B17	140	0.004	0.043	0.027	0.043	0.050	0.055	0.040	0.034	0.036

OPEN SAVANNA

SITE	AGE	50m	100m	150m	200m	250m
R1	5	0.002	0.017	0.004	0.006	0.004
E1	10	0.000	0.000	0.001	0.001	0.005
C	20	0.003	0.003	0.003	0.003	0.006
NU	30	0.014	0.015	0.006	0.014	0.042
S	35	0.000	0.000	0.002	0.002	0.004
E12	45	0.043	0.013	0.006	0.003	0.003
E7	70	0.012	0.009	0.009	0.013	0.014
B12	70	0.003	0.004	0.001	0.001	0.001
E10	70	0.024	0.016	0.005	0.006	0.006
E8	80	0.000	0.001	0.001	0.001	0.001
M1	90	0.007	0.001	0.004	0.023	0.007
B3	90	0.008	0.007	0.004	0.008	0.003

Appendix 9. Mean biomass (Kg/m^2) of *Commiphora* species and *A. mellifera* calculated at increasing distance from abandoned settlements.

BUSHED SAVANNA

SITE	AGE	28m	56m	84m	112m	140m	168m	196m	224m	252m
P1	5	0.430	2.850	1.479	2.113	5.206	2.359	0.784	4.311	0.666
B1	10	0.000	0.000	0.000	0.000	0.050	0.018	0.018	0.000	0.000
L6	10	0.067	7.961	0.590	0.225	0.279	1.878	0.476	0.422	1.464
M	15	0.298	0.277	0.123	0.094	0.212	0.613	0.347	0.628	0.260
K	20	0.192	1.337	2.344	16.998	4.005	0.291	5.783	2.919	2.092
R	20	0.081	0.600	0.088	0.168	0.495	0.614	0.500	0.041	0.127
P	20	0.019	0.443	0.823	2.876	0.975	0.777	1.407	1.408	1.699
I	20	0.250	0.560	0.296	0.350	1.088	0.827	2.482	1.920	1.833
U	25	0.003	0.029	0.059	0.131	0.578	0.173	0.089	0.240	0.050
L	35	0.596	1.339	4.171	8.045	0.502	0.080	0.189	2.251	0.155
T	40	0.003	0.017	0.077	0.077	0.020	0.014	0.095	0.245	0.432
Q	45	0.005	0.011	0.520	0.273	0.766	0.343	0.851	0.231	0.913
B5	50	0.915	0.643	1.066	1.269	0.517	0.200	0.191	0.224	0.227
W	50	0.111	0.070	0.070	0.113	0.380	0.091	0.067	0.263	0.512
L2	60	0.438	0.288	0.466	1.893	1.273	0.287	0.249	0.382	0.007
B11	60	0.012	0.623	2.993	0.986	0.496	1.834	0.102	0.032	0.037
L5	80	4.177	1.519	1.010	0.707	1.128	5.414	0.735	0.906	1.637
B2	80	0.394	0.428	0.641	0.514	0.256	0.343	0.502	0.144	0.150
B16	140	0.005	0.000	0.009	0.956	0.281	5.109	0.402	1.949	0.573
B17	140	0.064	1.196	1.566	2.451	2.668	3.795	1.524	3.674	2.046

OPEN SAVANNA

SITE	AGE	50m	100m	150m	200m	250m
R1	5	0.006	0.067	0.014	0.021	0.016
E1	10	0.001	0.001	0.001	0.002	0.004
C	20	0.006	0.007	0.019	0.011	0.053
MU	30	0.003	0.529	0.047	2.207	0.314
S	35	0.000	0.000	0.003	0.017	0.023
E12	45	0.133	0.077	0.063	0.017	0.045
E7	70	0.009	0.084	0.090	0.014	0.243
B12	70	0.010	0.028	0.002	0.011	0.005
E10	70	0.112	0.440	0.027	0.099	0.072
E8	80	0.000	0.001	0.003	0.002	0.002
M1	90	0.061	0.019	0.132	0.370	0.108
B3	90	0.007	0.023	0.045	0.033	0.035

Appendix 10. Laboratory results of soil test

SITE	LOC	DEPTH	AGE	pH	Na	K	Ca	Mg	Mn	P	N	C	EC
R1	I	T	5	7.50	0.62	1.74	3.60	3.05	0.38	58	0.09	0.52	0.70
R1	I	M	5	8.30	1.50	7.50	35.00	2.20	0.06	42	0.16	0.54	4.00
R1	O	M	5	8.40	2.70	0.14	8.00	7.30	0.08	80	0.08	0.34	0.40
R1	I	B	5	8.00	0.26	0.14	20.00	1.60	0.20	17	0.02	0.34	0.20
R1	O	T	5								0.06	0.18	
R1	I	B	5	7.80	2.20	0.70	38.00	3.45	0.08	6	0.07	0.43	2.80
P1	I	M	5	7.50	0.54	1.50	5.00	4.50	0.13	21	0.05	0.25	0.40
P1	O	T	5	8.90	0.54	8.10	6.00	0.75	0.32	80	0.05	0.35	1.00
P1	I	B	5	7.70	3.50	2.70	5.00	1.35	0.38	42	0.08	0.20	1.80
P1	I	T	5	8.30	1.50	0.34	16.00	1.20	0.10	262	0.01	4.22	5.00
P1	O	B	5	7.50	0.20	0.14	5.00	1.25	0.26	38	0.06	0.20	0.25
P1	O	M	5	7.50	0.26	0.54	5.20	3.05	0.36	4	0.04	0.19	0.15
L6	I	M	10	8.10	3.50	6.90	5.00	1.10	0.20	105	0.06	0.80	1.20
L6	I	T	10	8.10	2.70	6.40	19.60	7.90	0.52	268	0.27	1.59	2.95
L6	O	M	10	7.30	0.44	0.88	3.60	1.85	0.44	210	0.01	0.40	0.17
L6	I	B	10	7.90	0.44	2.70	7.20	1.10	0.34	1	0.06	0.11	0.27
L6	O	B	10	7.80	2.20	0.78	6.60	4.20	0.40	1	0.07	0.45	2.80
L6	O	T	10	7.30	0.44	1.28	5.00	3.95	0.52	7	0.05	0.28	0.25
I	O	T	20	7.00	0.44	0.96	4.00	1.40	0.56	209	0.00	0.55	0.40
I	O	B	20	7.00	0.34	0.64	4.00	1.60	0.52	46	0.02	0.25	0.18
I	I	B	20	7.90	1.18	2.20	4.00	1.20	0.30	137	0.01	0.02	0.40
I	O	M	20	6.90	0.54	1.28	6.00	3.05	0.42	10	0.02	0.32	
I	I	T	20	7.10	0.88	2.20	7.60	3.95	0.68	12	0.06	0.47	0.27
I	I	M	20	8.40	2.00	3.30	5.00	2.60	0.62	32	0.02	0.25	0.60
MU	I	T	30	8.70	3.50	5.30	36.00	3.05	0.06	29	0.10	0.51	0.60
MU	I	M	30	8.90	3.00	5.30	34.00	1.70	0.78	10	0.07	0.36	0.80
MU	O	B	30	8.30	4.40	0.14	20.00	6.90	0.04	27	0.07	0.34	2.85
MU	O	M	30	7.40	0.62	1.50	4.00	1.60	0.44	119	0.01		0.22
MU	I	B	30	8.30	2.20	0.18	20.00	1.80	0.08	4	0.01	0.26	5.00
MU	O	T	30	8.10	0.44	0.38	40.00	4.30	0.06	7	0.03	0.42	0.40
T	I	B	40	7.80	4.80	0.88	34.00	6.70	0.06	12	0.07	0.60	6.00
T	O	M	40	7.50	0.32	0.62	3.60	2.05	0.44	122	0.02	0.11	0.18
T	I	T	40								0.04	0.23	
T	O	B	40	7.30	0.26	0.32	8.00	3.45	0.54	8	0.03	0.19	0.50
T	I	M	40	7.40	1.06	2.20	6.00	3.75	0.54	5	0.04	0.13	0.80
T	O	T	40	7.20	0.44	1.00	4.00	3.45	0.52	48	0.05	0.24	0.15

Appendix 10. Continued.

SITE	LOC	DEPTH	AGE	pH	Na	K	Ca	Mg	Mn	P	N	C	EC
L2	O	M	60	8.00	0.32	0.62	40.00	3.85	0.06	58	0.22	1.17	0.27
L2	O	B	60	7.80	0.62	1.28	5.00	4.50	0.13	19	0.07	0.27	0.25
L2	I	M	60	8.20	2.00	0.14	20.00	1.70	0.48	17	0.00	0.24	1.60
L2	I	T	60	8.20	0.62	1.50	4.40	2.10	0.56	244	0.02	0.06	0.28
L2	I	B	60	7.90	0.88	2.00	4.00	1.40	0.40	9	0.02	0.22	0.60
L2	O	T	60								0.04	0.34	
B11	O	T	60	7.40	3.50	0.96	3.60	3.65	0.38	74	0.06	0.39	0.15
B11	I	M	60	8.00	1.50	3.50	5.20	2.20	0.06	44	0.06	0.29	0.50
B11	O	B	60	8.20	0.18	0.20	9.00	2.10	0.26	19	0.02	0.41	1.70
B11	I	T	60	8.00	0.88	1.96	11.20	1.20	0.50	256	0.02	0.65	0.18
B11	O	M	60	7.30	0.36	0.70	7.00	3.15	0.48	13	0.07	0.21	0.40
B11	I	B	60	7.20	0.54	0.70	7.20	3.45	0.50	52	0.09	0.22	0.24
E10	O	B	70	7.90	0.36	0.36	40.00	3.00	0.06	6	0.07	0.49	0.50
E10	I	B	70	7.90	0.62	6.90	5.00	1.40	0.38	82	0.09	0.42	0.18
E10	O	T	70	8.30	0.44	5.30	50.00	3.95	0.04	137	0.12	0.49	0.26
E10	I	T	70	8.20	0.96	2.00	2.60	1.00	0.20	216	0.03	0.59	0.40
E10	I	M	70	8.50	1.96	2.60	30.00	2.05	0.40	38	0.02	0.09	0.80
E10	O	M	70								0.06	0.45	
B2	I	B	80	8.20	2.00	5.30	9.60	2.10	0.36	42	0.08	0.47	0.90
B2	O	T	80	8.50	4.40	5.90	6.00	1.70	0.44	56	0.06	0.24	0.40
B2	I	M	80	7.40	3.50	0.96	4.00	2.50	0.36	77	0.05	0.24	0.12
B2	O	B	80	7.80	3.50	0.54	4.00	4.60	0.36	29	0.05	0.21	0.28
B2	I	T	80	8.10	1.40	2.70	20.00	6.90	0.26	256	0.18	0.93	0.29
B2	O	M	80	7.60	0.28	0.42	3.00	1.70	0.32	29	0.01	0.45	0.15
M1	I	M	90	8.00	3.10	5.90	35.00	3.65	0.06	10	0.11	0.97	2.40
M1	I	T	90	8.30	3.70	12.00	5.20	5.55	0.06	266	0.32	5.35	1.20
M1	O	M	90	8.20	2.00	0.18	25.00	2.05	0.06	6	0.21	0.15	1.80
M1	I	B	90								0.50	0.33	
M1	O	B	90	7.80	2.20	0.18	40.00	4.20	0.06	10	0.04	0.23	5.00
M1	O	T	90	8.10	2.00	0.36	40.00	3.25	0.06	1	0.05	0.23	0.40
B16	O	T	140	8.30	1.06	3.50	20.00	4.20	0.06	157	0.19	1.47	0.50
B16	I	M	140	8.40	1.74	0.62	40.00	4.20	0.04	46	0.06	0.33	0.55
B16	I	T	140	8.30	1.18	7.70	50.00	7.90	0.24	262	0.18	1.33	0.25
B16	O	M	140	8.50	0.26	0.18	40.00	6.90	0.04	25	0.08	0.32	0.20
B16	I	B	140	8.10	1.18	2.20	30.00	2.50	0.08	12	0.05	0.03	1.00
B16	O	B	140	8.10	0.28	0.18	45.00	4.05	0.08	12	0.02	0.47	0.22

Under column LOC (Location) I=Onsite and O=Offsite

Under column DEPTH--- T=0-10cm M=20-30cm and B=40-50cm

Blanks indicates data not received from laboratory

Appendix IIa. *A. tortilis* seeds germination. Number of scarred seeds that had germinated each week and the total.

SITE	LOC	DEPTH	AGE	WEEKS 1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
P1	I	T	5	4	8	4	0	0	0	0	0	0	0	0	0	8
P1	I	M	5	2	2	1	0	0	0	0	0	0	0	0	0	2
P1	I	B	5	0	0	8	8	7	6	5	5	5	3	3	2	8
P1	O	T	5	4	10	9	9	9	9	9	9	6	6	6	6	10
P1	O	M	5	0	0	10	10	10	9	9	9	6	6	6	6	10
P1	O	B	5	4	9	9	6	6	6	5	5	5	5	5	5	9
L6	I	T	10	4	4	3	0	0	0	0	0	0	0	0	0	4
L6	I	M	10	0	0	2	4	4	2	2	1	0	0	0	0	4
L6	I	B	10	1	1	0	0	0	0	0	0	0	0	0	0	1
L6	O	T	10	0	0	6	6	5	5	3	0	0	1	1	0	6
L6	O	M	10	6	7	7	7	7	7	7	7	7	7	7	7	7
L6	O	B	10	8	8	9	7	6	6	5	5	5	5	5	5	9
MU	I	T	30	10	10	10	7	7	7	7	7	7	7	7	7	10
MU	I	M	30	3	6	7	7	6	6	4	3	3	0	3	0	7
MU	I	B	30	6	8	7	7	5	5	4	4	4	4	4	4	8
MU	O	T	30	6	8	7	7	6	6	6	6	6	5	5	5	8
MU	O	M	30	0	2	10	10	9	9	9	6	5	5	0	0	10
MU	O	B	30	2	2	2	0	0	0	0	0	0	0	0	0	2
T	I	T	40	2	8	7	6	6	6	6	6	6	6	6	6	8
T	I	M	40	0	0	6	6	5	3	2	1	1	1	1	1	6
T	I	B	40	0	0	6	5	5	4	4	4	4	3	3	3	6
T	O	T	40	0	0	10	10	9	9	9	9	9	9	9	9	10
T	O	M	40	7	10	10	8	6	6	6	6	6	5	5	5	10
T	O	B	40	0	0	7	8	8	8	7	7	5	5	5	4	8
L2	I	T	60	0	4	3	0	0	0	0	0	0	0	0	0	4
L2	I	M	60	8	8	8	6	6	6	6	6	6	6	6	6	8
L2	I	B	60	2	5	5	4	4	4	4	4	4	4	4	4	5
L2	O	T	60	6	7	7	5	5	5	4	4	5	5	4	4	7
L2	O	M	60	1	1	2	2	4	2	0	0	0	0	0	0	4
L2	O	B	60	3	6	6	5	3	2	1	1	1	1	1	1	6
B11	I	T	60	5	5	5	2	0	0	0	0	0	0	0	0	5
B11	I	M	60	6	7	7	6	6	6	6	6	6	5	5	5	7
B11	I	B	60	0	4	4	2	2	2	2	2	2	2	2	2	4
B11	O	T	60	8	10	7	4	4	3	3	3	3	3	3	3	10
B11	O	M	60	0	0	9	9	7	6	6	6	6	6	6	6	9
B11	O	B	60	6	10	9	5	4	4	4	3	3	3	3	3	10
B2	I	T	80	1	4	5	4	4	3	3	3	3	3	3	3	5
B2	I	M	80	7	8	8	7	6	6	6	6	5	4	2	2	8
B2	I	B	80	3	5	7	6	5	5	4	3	3	3	3	3	7
B2	O	T	80	0	0	8	6	7	8	8	7	6	6	6	6	8
B2	O	M	80	7	8	8	7	6	6	6	6	6	6	6	6	8
B2	O	B	80	4	6	6	6	5	5	5	5	5	5	5	5	6
B16	I	T	140	0	0	2	2	2	2	2	2	1	1	1	1	2
B16	I	M	140	7	9	9	8	8	8	8	8	8	8	8	8	9
B16	I	B	140	1	1	1	1	0	0	0	0	0	0	0	0	1
B16	O	T	140	8	10	8	6	6	6	6	3	3	3	3	3	10
B16	O	M	140	8	10	9	5	5	5	5	4	4	4	4	4	10
B16	O	B	140	6	9	9	6	6	6	6	5	5	5	5	5	9

Under column LOC (Location) I=Onsite and O=Offsite
Under column DEPTH--- T=0-10cm M=20-30cm B=40-50cm
TOTAL=Total number of seeds tha eventually germinated

Appendix 11b. *A. tortilis* seeds germination. Number of unscarred seeds that had germinated each week and the total.

				WEEKS												
SITE	LOC	DEPTH	AGE	1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
P1	I	T	5	0	0	0	0	0	0	0	0	0	0	0	0	0
P1	I	M	5	0	0	0	0	0	0	0	0	0	0	0	0	0
P1	I	B	5	0	0	0	0	0	0	0	0	0	0	1	1	1
P1	O	T	5	0	0	0	0	0	0	0	0	0	0	0	0	0
P1	O	M	5	0	0	1	1	1	1	1	3	0	0	0	0	3
P1	O	B	5	1	1	1	1	1	2	2	2	2	2	2	2	2
L6	I	T	10	0	0	0	0	0	0	0	0	0	0	0	0	0
L6	I	M	10	0	0	0	0	0	0	0	0	0	0	0	0	0
L6	I	B	10	0	0	0	0	0	0	0	0	0	0	0	0	0
L6	O	T	10	0	0	0	0	1	1	1	0	0	0	0	1	1
L6	O	M	10	0	0	0	0	0	0	0	0	0	0	0	0	0
L6	O	B	10	0	0	0	1	0	0	0	0	0	0	0	0	1
MU	I	T	30	1	1	0	1	0	0	0	0	0	0	0	0	1
MU	I	M	30	0	0	0	0	0	0	0	0	0	0	0	0	0
MU	I	B	30	0	0	0	0	0	0	0	0	0	0	0	0	0
MU	O	T	30	0	0	0	0	0	0	0	0	0	0	0	0	0
MU	O	M	30	0	0	0	0	0	0	0	0	0	0	0	0	0
MU	O	B	30	0	0	0	0	0	0	0	0	0	0	0	0	0
T	I	T	40	0	0	0	0	0	0	0	0	0	0	0	0	0
T	I	M	40	0	0	0	4	4	1	0	0	0	0	0	0	4
T	I	B	40	0	0	0	0	0	0	0	0	0	0	0	0	0
T	O	T	40	0	0	0	1	1	1	1	1	1	0	0	0	1
T	O	M	40	0	0	0	0	0	1	1	1	0	0	0	0	1
T	O	B	40	0	0	1	2	2	0	0	0	0	0	0	0	2
L2	I	T	60	0	0	0	0	0	0	0	0	0	0	0	0	0
L2	I	M	60	0	0	1	1	1	1	1	1	1	1	1	1	1
L2	I	B	60	0	0	1	1	1	1	1	0	0	0	0	0	1
L2	O	T	60	0	1	1	1	1	1	1	1	0	1	1	1	1
L2	O	M	60	0	0	0	0	0	0	0	0	0	0	0	0	0
L2	O	B	60	0	0	0	0	0	0	0	0	0	0	0	0	0
B11	I	T	60	0	0	0	0	0	0	0	0	0	0	0	0	0
B11	I	M	60	0	0	1	1	1	1	1	1	1	1	1	1	1
B11	I	B	60	0	0	1	0	0	0	0	0	0	0	0	0	1
B11	O	T	60	0	0	0	0	0	0	0	0	0	0	0	0	0
B11	O	M	60	0	0	0	1	0	0	0	0	0	0	0	0	1
B11	O	B	60	0	0	0	0	2	0	0	0	0	0	0	0	2
B2	I	T	80	0	0	2	0	0	0	0	0	0	0	0	0	2
B2	I	M	80	0	0	0	0	0	0	0	0	0	0	0	0	0
B2	I	B	80	0	0	0	0	0	0	0	0	0	0	0	0	0
B2	O	T	80	0	0	2	2	2	2	1	2	2	2	2	2	2
B2	O	M	80	0	0	0	0	0	0	0	0	0	0	0	0	0
B2	O	B	80	0	0	0	0	0	0	0	0	0	0	0	1	1
B16	I	T	140	0	0	3	0	0	1	1	1	1	1	1	1	3
B16	I	M	140	0	0	0	0	0	0	0	0	0	0	0	0	0
B16	I	B	140	0	0	0	0	0	0	0	0	0	0	0	0	0
B16	O	T	140	0	0	1	0	0	0	0	0	0	0	0	0	1
B16	O	M	140	0	0	1	0	0	0	0	0	0	0	0	0	1
B16	O	B	140	1	1	0	0	0	0	0	0	0	0	0	0	1

Under column LOC (Location) I=Onsite and O=Offsite
Under column DEPTH--- T=0-10cm M=20-30cm and B=40-50cm
TOTAL-- denotes total number that eventually germinated

Appendix 12. Monthly mean dung density calculated onsite and at increasing distance in meters from the settlements.

SITE	AGE	DIST	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	SEP
			M	O	N	T	H	S			
R1	5	0	.000	.003	.002	.005	.000	.002	.005	.001	.008
R1	5	50	.023	.014	.019	.015	.019	.016	.014	.027	.025
R1	5	100	.022	.018	.017	.014	.022	.011	.009	.017	.034
R1	5	150	.021	.007	.034	.015	.013	.008	.005	.019	.029
R1	5	200	.014	.022	.017	.018	.018	.003	.002	.007	.022
R1	5	250	.033	.029	.032	.021	.007	.008	.004	.012	.014
P1	5	0	.009	.015	.033	.013	.000	.003	.025	.047	.022
P1	5	50	.021	.012	.047	.010	.020	.018	.012	.018	.016
P1	5	100	.017	.043	.029	.026	.019	.018	.023	.059	.015
P1	5	150	.012	.009	.020	.009	.015	.008	.012	.011	.018
P1	5	200	.014	.022	.038	.013	.013	.015	.010	.014	.016
P1	5	250	.019	.017	.042	.013	.013	.011	.015	.018	.026
B1	10	0	.018	.018	.018	.016	.009	.009	.005	.026	.015
B1	10	50	.031	.020	.021	.016	.028	.014	.004	.020	.017
B1	10	100	.020	.020	.007	.007	.015	.010	.004	.008	.013
B1	10	150	.009	.025	.006	.007	.015	.011	.008	.011	.029
B1	10	200	.024	.013	.016	.006	.014	.017	.003	.011	.018
B1	10	250	.019	.016	.017	.020	.007	.013	.006	.013	.033
L6	10	0	.017	.025	.039	.017	.011	.006	.014	.022	.019
L6	10	50	.049	.015	.025	.018	.007	.013	.014	.041	.017
L6	10	100	.032	.015	.019	.020	.011	.008	.010	.032	.019
L6	10	150	.032	.006	.024	.017	.011	.013	.035	.040	.020
L6	10	200	.030	.009	.011	.011	.007	.017	.012	.021	.015
L6	10	250	.037	.008	.021	.024	.014	.007	.010	.041	.017
E1	10	0	.006	.041	.039	.050		.032		.080	.023
E1	10	50	.020	.021	.032	.025		.030		.069	.047
E1	10	100	.027	.012	.017	.024		.010		.062	.029
E1	10	150	.021	.037	.034	.016		.003		.053	.038
E1	10	200	.029	.027	.028	.038		.004		.059	.053
E1	10	250	.029	.039	.041	.037		.024		.056	.062
M	15	0	.023	.044	.026	.031		.035	.037	.039	.030
M	15	50	.007	.029	.014	.012		.014	.024	.017	.025
M	15	100	.017	.011	.015	.009		.013	.020	.020	.026
M	15	150	.006	.009	.017	.018		.012	.019	.013	.023
M	15	200	.014	.013	.010	.009		.008	.021	.017	.018
M	15	250	.019	.006	.012	.014		.007	.023	.018	.014
R	20	0	.012	.036	.033	.025		.012		.036	.019
R	20	50	.010	.015	.026	.009		.011		.016	.019
R	20	100	.006	.009	.019	.009		.011		.016	.026
R	20	150	.013	.022	.014	.007		.015		.013	.024
R	20	200	.009	.009	.024	.010		.015		.021	.017
R	20	250	.014	.016	.017	.022		.012		.015	.025
K	20	0	.027	.021	.023	.033		.024		.034	.016
K	20	50	.022	.045	.016	.014		.022		.030	.021
K	20	100	.020	.026	.016	.023		.012		.024	.018
K	20	150	.018	.011	.017	.022		.003		.018	.016
K	20	200	.012	.007	.009	.015		.015		.008	.014
K	20	250	.020	.014	.012	.011		.004		.007	.015

Appendix 12. Contiued.

SITE	AGE	DIST	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	SEP
			M	O	N	T	H	S			
I	20	0	.017	.026	.022	.020	.019	.036	.040	.022	.015
I	20	50	.012	.029	.016	.028	.011	.019	.024	.024	.022
I	20	100	.008	.029	.008	.016	.009	.016	.016	.010	.013
I	20	150	.006	.014	.009	.007	.010	.005	.016	.007	.013
I	20	200	.013	.022	.008	.015	.010	.008	.008	.016	.016
I	20	250	.016	.022	.028	.016	.006	.010	.020	.011	.017
P	20	0	.018	.029	.019	.029		.019		.040	.020
P	20	50	.009	.026	.015	.017		.014		.023	.023
P	20	100	.013	.029	.021	.014		.011		.012	.015
P	20	150	.014	.008	.010	.018		.008		.008	.008
P	20	200	.014	.009	.006	.020		.004		.013	.017
P	20	250	.029	.007	.011	.017		.016		.015	.021
C	20	0	.038	.082	.029	.028		.058		.064	.047
C	20	50	.014	.014	.014	.019		.022		.020	.028
C	20	100	.013	.020	.026	.012		.014		.012	.017
C	20	150	.011	.010	.014	.006		.021		.017	.016
C	20	200	.011	.022	.012	.009		.017		.011	.020
C	20	250	.012	.021	.013	.007		.017		.038	.052
U	25	0	.010	.061	.027	.031		.019	.050	.049	.013
U	25	50	.018	.038	.005	.017		.024	.045	.054	.035
U	25	100	.013	.024	.007	.016		.016	.026	.031	.039
U	25	150	.013	.016	.006	.011		.021	.011	.021	.024
U	25	200	.014	.016	.007	.018		.021	.014	.013	.029
U	25	250	.022	.024	.015	.025		.020	.022	.043	.033
MU	30	0	.047	.003	.010	.008	.004	.009	.024	.024	.010
MU	30	50	.037	.007	.015	.008	.007	.004	.020	.011	.005
MU	30	100	.030	.010	.015	.013	.007	.004	.014	.011	.007
MU	30	150	.027	.003	.008	.004	.002	.005	.011	.011	.009
MU	30	200	.027	.027	.012	.006	.002	.003	.019	.020	.014
MU	30	250	.031	.016	.018	.022	.007	.002	.017	.012	.014
L	35	0	.018	.011	.013	.014		.011		.022	.012
L	35	50	.014	.007	.002	.009		.010		.016	.018
L	35	100	.007	.011	.014	.009		.007		.007	.008
L	35	150	.012	.005	.010	.010		.007		.014	.019
L	35	200	.013	.021	.011	.010		.011		.008	.016
L	35	250	.021	.011	.023	.017		.004		.018	.025
S	35	0	.037	.019	.019	.028		.034	.024	.023	.019
S	35	50	.021	.021	.021	.010		.010	.008	.013	.025
S	35	100	.023	.009	.014	.029		.011	.014	.024	.022
S	35	150	.034	.019	.012	.028		.015	.017	.013	.015
S	35	200	.025	.031	.008	.018		.017	.014	.022	.012
S	35	250	.049	.016	.014	.020		.014	.021	.033	.017
T	40	0	.017	.038	.017	.026	.019	.025	.043	.034	.010
T	40	50	.014	.029	.006	.021	.013	.022	.035	.028	.007
T	40	100	.013	.041	.007	.021	.028	.011	.025	.020	.010
T	40	150	.013	.038	.012	.015	.024	.018	.022	.011	.009
T	40	200	.020	.021	.011	.025	.008	.005	.024	.015	.011
T	40	250	.015	.037	.013	.022	.027	.017	.022	.024	.009

Appendix 12. Continued.

			MONTHS								
SITE	AGE	DIST	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	SEP
Q	45	0	.017	.023	.021	.012		.013		.035	.012
Q	45	50	.008	.027	.008	.005		.011		.016	.013
Q	45	100	.007	.014	.016	.008		.011		.012	.011
Q	45	150	.009	.008	.018	.010		.009		.016	.017
Q	45	200	.002	.017	.014	.014		.006		.022	.009
Q	45	250	.021	.022	.022	.023		.006		.013	.017
E12	45	0	.022	.029	.060	.040	.009	.010		.035	.020
E12	45	50	.021	.029	.009	.010	.005	.010		.024	.015
E12	45	100	.011	.027	.016	.009	.008	.013		.024	.010
E12	45	150	.012	.016	.011	.016	.008	.020		.018	.020
E12	45	200	.011	.032	.024	.017	.012	.018		.023	.011
E12	45	250	.009	.030	.019	.008	.005	.026		.022	.015
W	50	0	.008	.053	.014	.034	.038	.022	.033	.064	.024
W	50	50	.015	.049	.009	.005	.043	.018	.059	.057	.021
W	50	100	.008	.015	.008	.002	.025	.011	.021	.024	.024
W	50	150	.011	.019	.012	.007	.019	.013	.014	.017	.022
W	50	200	.008	.012	.002	.006	.015	.010	.018	.030	.017
W	50	250	.008	.011	.007	.010	.014	.010	.026	.035	.027
B5	50	0	.012	.034	.019	.009	.012	.005		.041	.022
B5	50	50	.011	.022	.022	.009	.011	.006		.049	.034
B5	50	100	.012	.037	.020	.018	.020	.001		.062	.068
B5	50	150	.009	.018	.017	.013	.008	.002		.040	.031
B5	50	200	.014	.028	.022	.008	.003	.004		.023	.015
B5	50	250	.014	.044	.022	.024	.006	.008		.030	.017
B11	60	0	.034	.063	.039	.010	.010	.023		.049	.028
B11	60	50	.038	.071	.033	.013	.015	.050		.078	.044
B11	60	100	.022	.027	.014	.014	.015	.021		.033	.032
B11	60	150	.019	.031	.012	.005	.010	.005		.035	.019
B11	60	200	.021	.023	.001	.003	.007	.018		.022	.017
B11	60	250	.015	.026	.008	.016	.013	.052		.021	.020
L2	60	0	.039	.019	.061	.024	.019	.026		.047	.036
L2	60	50	.044	.015	.053	.028	.018	.023		.060	.026
L2	60	100	.031	.011	.039	.046	.018	.026		.078	.019
L2	60	150	.037	.005	.019	.015	.008	.013		.038	.016
L2	60	200	.046	.011	.008	.008	.007	.014		.030	.017
L2	60	250	.032	.010	.014	.024	.019	.008		.030	.023
B12	70	0	.023	.027	.008	.006		.004	.009	.020	.014
B12	70	50	.022	.061	.017	.012		.006	.017	.013	.027
B12	70	100	.031	.039	.034	.020		.017	.010	.036	.022
B12	70	150	.019	.038	.022	.022		.019	.008	.033	.018
B12	70	200	.015	.040	.029	.018		.016	.008	.030	.025
B12	70	250	.021	.040	.031	.018		.008	.011	.025	.033
E10	70	0	.006	.022	.009	.014	.016	.010	.008	.019	.022
E10	70	50	.009	.013	.008	.009	.006	.010	.010	.007	.026
E10	70	100	.004	.011	.007	.018	.010	.009	.003	.008	.016
E10	70	150	.012	.011	.008	.011	.006	.006	.008	.006	.061
E10	70	200	.015	.012	.016	.016	.006	.007	.012	.009	.021
E10	70	250	.006	.006	.018	.011	.004	.007	.003	.010	.015

Appendix 12. Continued.

			M	O	N	T	H	S			
SITE	AGE	DIST	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	SEP
E7	70	0	.005	.025	.019	.016		.015		.017	.015
E7	70	50	.006	.019	.012	.007		.015		.014	.009
E7	70	100	.005	.007	.015	.006		.013		.010	.013
E7	70	150	.002	.009	.018	.006		.010		.014	.024
E7	70	200	.002	.010	.011	.011		.005		.007	.021
E7	70	250	.002	.018	.008	.018		.007		.007	.017
E8	80	0	.015	.026	.010	.005		.006		.034	.023
E8	80	50	.011	.023	.015	.013		.003		.063	.052
E8	80	100	.015	.021	.019	.030		.008		.035	.054
E8	80	150	.011	.019	.021	.027		.005		.043	.028
E8	80	200	.008	.029	.023	.023		.006		.034	.023
E8	80	250	.022	.023	.020	.024		.010		.050	.017
B2	80	0	.027	.055	.055	.016	.025	.009	.024	.083	.050
B2	80	50	.013	.028	.025	.024	.014	.005	.032	.060	.030
B2	80	100	.014	.014	.008	.010	.006	.002	.017	.028	.032
B2	80	150	.017	.014	.009	.007	.003	.004	.004	.018	.030
B2	80	200	.014	.020	.015	.026	.007	.007	.005	.032	.031
B2	80	250	.026	.031	.026	.015	.015	.004	.006	.036	.057
L5	80	0	.047	.035	.033	.030		.024		.058	.026
L5	80	50	.018	.008	.008	.018		.012		.032	.027
L5	80	100	.017	.014	.008	.024		.011		.023	.026
L5	80	150	.021	.007	.015	.014		.019		.027	.026
L5	80	200	.037	.003	.013	.018		.023		.029	.015
L5	80	250	.022	.012	.009	.021		.016		.019	.022
B3	90	0	.019	.026	.017	.008		.007		.071	.048
B3	90	50	.025	.031	.015	.018		.009		.047	.053
B3	90	100	.015	.015	.040	.029		.012		.062	.063
B3	90	150	.012	.020	.013	.006		.005		.047	.056
B3	90	200	.023	.021	.019	.013		.002		.031	.042
B3	90	250	.073	.018	.019	.017		.005		.045	.054
M1	90	0	.026	.007	.014	.006	.003	.007	.009	.025	.010
M1	90	50	.017	.002	.006	.007	.005	.011	.011	.017	.042
M1	90	100	.024	.006	.013	.012	.013	.004	.006	.008	.019
M1	90	150	.028	.011	.010	.004	.006	.003	.008	.005	.014
M1	90	200	.019	.007	.013	.012	.002	.010	.008	.008	.017
M1	90	250	.011	.014	.011	.012	.003	.008	.017	.024	.025
B16	140	0	.007	.017	.009	.004	.004	.004	.010	.012	.005
B16	140	50	.015	.039	.058	.011	.021	.008	.034	.024	.016
B16	140	100	.021	.020	.016	.009	.019	.005	.019	.013	.013
B16	140	150	.029	.038	.020	.018	.032	.005	.013	.013	.018
B16	140	200	.019	.038	.027	.014	.015	.006	.012	.010	.015
B16	140	250	.025	.023	.038	.022	.031	.009	.015	.022	.022
B17	140	0	.011	.086	.043	.022		.016		.029	.025
B17	140	50	.021	.042	.035	.011		.007		.030	.019
B17	140	100	.011	.029	.017	.007		.004		.019	.014
B17	140	150	.014	.015	.026	.007		.010		.023	.019
B17	140	200	.015	.018	.013	.010		.002		.011	.014
B17	140	250	.023	.018	.009	.011		.005		.019	.012

Blanks indicates no data collected.