INSECTS ASSOCIATED WITH FRUIT, SEED AND FOLIAGE OF *UAPACA KIRKIANA* (MUELL. ARG.) (EUPHORBIACEAE) IN MALAWI

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INSECTS ASSOCIATED WITH FRUIT, SEED AND FOLIAGE OF *UAPACA KIRKIANA* (MUELL. ARG.) (EUPHORBIACEAE) IN MALAWI

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Pectora roborant cultus recti

Thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Forestry Sciences at the University of Stellenbosch

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

13/2/98

Date

ABSTRACT

Arthropods associated with *Uapaca kirkiana* in Dedza and Zomba, Malawi, were collected during October 1996, January 1997, June 1997 and August 1997 using various collection methods including beating, sweepnets, suction using an aspirator and collection of parts of plants with endogenous arthropods or on which external sessile arthropods were attached. A total of 12,849 arthropods were collected and sorted into 10 orders, 40 families and 51 morphospecies. Arthropod diversity was high in Dedza, but the few arthropods species that occurred in Zomba had more individuals per species. More arthropods were recorded on trees growing in woodlands dominated by either large or small *Uapaca* trees. Leafchewers and sapsuckers comprised the majority of the arthropods collected. Highest arthropod counts were registered in October 1996 and lowest in June 1997.

Six arthropod morphospecies namely Phycitidae (undetermined species), white scales (undetermined species), Gelechiidae (undetermined species), Lasiocampidae (undetermined), *Bunaea alcinoe* (Saturniidae) and *Leptoglossus membraceus* (Heteroptera) were observed causing significant damage. The other species were either natural enemies or did not significantly affect *U. kirkiana* trees. Most arthropod damage was observed on individual trees on the farm and in woodlands dominated by either large or small *Uapaca* trees.

The low arthropod incidence and arthropod damage on *U. kirkiana* in mixed woodland and fire prone areas suggest that mixed woodland is the best option for managing *U. kirkiana* and that early controlled fire can also be used to minimize pests. The large number of arthropods without a direct effect on *U. kirkiana* underlines the role of this tree as an alternative or alternate host to pests of associated crops.

UITTREKSEL

Geleedpotiges geassoseer met *Uapaca kirkiana* in Dedza en Zomba, Malawi, is versamel gedurende Oktober 1996, Januarie 1997 en Augustus 1997. Verskillende versamelingsmetodes, insluitende afklop, die gebruik van sleepnette en suigwaaiers en die versameling van plantdele met endogene insekte of waaraan sittende geleedpotiges vasgeheg is, is gebruik. 'n Totaal van 12,849 geleedpotiges is versamel en gesorteer in 10 ordes, 40 families en 51 morfo-spesies. Die diversiteit van geleedpotiges was hoog in Dedza, maar die paar geleedpotige spesies wat voorgekom het in Zomba het meer individue per spesie gehad. Meer geleedpotiges is versamel op bome wat in boslande, gedomineer deur groot of klein *Uapaca* bome, groei. Blaarkouers en sapsuiers verteenwoordig die meerderheid van die geleedpotiges wat versamel is. Die hoogste geleedpotige tellings is geregistreer in Oktober 1996 en die laagste in Junie 1997.

Ses geeldpotige morfo-spesies, genaamd Phycitidae (onbepaalde spesie), wit skubbe (onbepaalde spesie), Gelechiidae (onbepaalde spesie), Lasiocampidae (onbepaalde spesie), *Bunaea alcinoe* (Saturniidae) en *Leptoglossus membraceus* (Heteroptera), wat beduidende skade aangerig het, is waargeneem. Die ander spesies was óf natuurlike vyande, óf het nie *U. kirkiana* bome beduidend geaffekteer nie. Die meeste geleedpotige skade is waargeneem op individuele bome op die plaas en in boslande wat deur groot of klein *Uapaca* bome gedomineer word.

Die lae voorkoms van geleedpotiges en geleedpotige skade op *U. kirkiana* in gemengde bosland en areas waar vure voorkom, suggereer dat gemengde bosland die beste opsie vir die bestuur van *U. kirkiana* is en dat vroeë beheerde brande gebruik kan word om peste te verminder. Die groot aantal geleedpotiges wat nie 'n direkte effek op *U. kirkiana* het nie onderstreep die rol wat die bome as 'n alternatief of alternatiewe gasheer vir peste van geassosieerde gewasse speel.

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CHAPTER ONE

1.0 INTRODUCTION

Uapaca kirkiana Muell. Arg. (Euphorbiaceae) is an important indigenous tree in the miombo ecosystem in Central Africa. The importance of the tree is obvious from the role it plays as a pioneer species in restoration of woodlands and from its fruits which are widely appreciated and consumed by societies that live in the miombo areas (Hans, 1980). In attempts to contribute to the understanding of the structure and functioning of the tree, many scientists have intensively studied various aspects of the genus *Uapaca*. These include the ecology and distribution (Ngulube, 1996), germination and nursery studies (Maghembe, Kwesiga, Ngulube, Prins & Malaya, 1994; Mwabumba & Sitaubi, 1995), genetic variation (Mwamba, 1995; Ngulube, 1996), nutritional value of the fruit (Saka & Msonthi, 1994), silvicultural practices (Mwamba, 1995; Maghembe *et al.*, 1994) and phenology (Ngulube, 1996). None of these studies has seriously focused on the interaction between *Uapaca* and insects.

Published information on insects associated with *Uapaca kirkiana* is scanty. Ngulube (1996) lists some insects collected near *U. kirkiana* flowers and gives an overview of some insect families associated with *U. kirkiana.* His report only covers insects documented in Lee (1971), Parker (1978) and Makuku (1993) and a few flower visiting insect collected during his ecology studies. Museum records and some detailed works of Pinhey (1975) and Ben-Dov (1993) have not been covered by him. His review also does not give the relative abundance and activity as well as the role of the collected insects on *U. kirkiana*. Parker (1978) provides a list of some insects found attacking foliage and fruit of *U. kirkiana* in one forest area in Zambia. His report is mainly descriptive and does not indicate how the damage figures were arrived at and gives no indication of the relative abundance of the insects. Although the Forestry Research Institute of Malawi houses the most comprehensive collection of insects associated with *U. kirkiana*, it also lacks records of the relative abundance and detailed information on activity and relative damage caused to the tree by phytophagous insects. Given the desirable properties of the tree, enhancement of this agroforestry crop is envisaged either by their planting in plantation formation, as woodlots, or as individual trees. For management purposes, as far as the potential threat exerted by insects is concerned, the following information is required: the problematic insects species associated with *Uapaca* and determination of their relative abundance and plant defensive mechanisms, followed by biological studies to develop effective pest management strategies.

U. kirkiana is reported to be resistant to insect pest damage (Ngulube, Hall & Maghembe, 1995). This has resulted in a low priority rating for studies of insects associated with this indigenous fruit tree. Where insect studies have been conducted, they are casual and limited to seedling or sapling pests (Mchowa & Ngugi, 1994). As is the case with most indigenous plants, this notion may be untrue. Underrating of insect pest damage on *U. kirkiana* may be explained by the small number of entomologists interested in studying the insects generally associated with indigenous trees. Most workers in this field are preoccupied with agricultural and exotic tree pests. The local villagers collect from a large natural forest resource, discarding insect-damaged fruit without realising the level of pest infestation. The proportion of insect damaged fruits may be quite extensive. As the crop is a natural resource, the villagers are not obliged to report pest problems affecting *U. kirkiana* to forestry or agricultural extension staff. Even if they were to report excessive damage, there is little chance that they will be taken seriously by officials having different priorities.

If the low level of pest incidence reported on *U. kirkiana* is real, it may well be due to the fact that the pest-predator and parasitoid complex is well balanced, such that the insects attacking various parts of the plant are kept under natural control, maintaining a continual balance below the economic threshold level. This situation, however, may change under intensive cultivation, either in monoculture or in combination with other crops. Future management may also make *U. kirkiana* more attractive or vulnerable to pest attack. *U. kirkiana* mixed with crop plants can act as an alternative or alternate host to crop pests, the trees may out compete crops, or other fruit trees grown along with them for pollinators, resulting in low fruit set of the associate crop (Fægri & van der Pijl, 1979), or the trees may stress adjoining crops, making them susceptible to pest attack.

Study objectives

In view of the foregoing, this study of insects associated with *U. kirkiana* has the following objectives:

a. to assemble and integrate existing information on insects associated with *U. kirkiana* from literature and insect museum records in Malawi.
b. to investigate insects associated with *U. kirkiana* in Malawi.
c. to investigate damage inflicted on the tree by biotic and abiotic factors with major emphasis on damage caused by insects.

CHAPTER TWO

2.0 LITERATURE REVIEW

In this chapter relevant information on *Uapaca kirkiana*, as a background for the entomological investigations, is presented. The information given includes notes on the taxonomy and systematics, description, phenology, distribution and growth conditions of the tree, on other trees and fauna associated with *U. kirkiana*, as well as implications of the tree's management and impact on pest status of the associated insects.

2.1 Taxonomic position of *Uapaca kirkiana*

Detailed accounts of the taxonomy and description of *U. kirkiana* have been provided by Palgrave (1981) Webster (1987), Ngulube (1996) and Seyani (1996). *U. kirkiana* is a member of the family Euphorbiaceae, subfamily Phyllanthoideae in the tribe Antidesmeae and is the sole representative of the subtribe Uapacinae. The genus *Uapaca* contains 60 species; of these *U. kirkiana* Muell. Arg., *U. sansibarica* Muell. Arg. and *U. nitida* Muell. Arg. are the most widely distributed in tropical central Africa and found in the following countries: Angola, Zambia, Zimbabwe, Malawi, Tanzania, Mozambique as well as in Madagascar (Fig. 1).

2.2 Description of arboreal plant parts

U. kirkiana is a small to medium evergreen or semi-deciduous tree, with the height of mature trees ranging from 4 to 15 m (Plate 1). The bark on the stem is grey or grey brown, thick, and deeply fissured in mature individuals (Palgrave, 1981; Ngulube, 1996). Mature trees can reach a diameter in excess of 40 cm. The mature tree is heavily branched with a spreading dense-round crown. The branchlets are short and stout with prominent leaf scars (Palgrave, 1981; Anon., 1983) (Plate 2). The leaves are alternate, simple and leathery, and are usually crowded near the tips of branchlets (Plate 2). The individual leaf shape ranges from ovate to obovate to elliptic to oblong-elliptic. The leaves are hairy on the underside and the upper side is dark-shiny green. Each leaf has an entire margin and the midrib is prominent. Dimensions of the leaves vary, but most fall within the range 12-36 cm for length and 8-24 cm for width (Palgrave, 1981; Ngulube, 1996; Seyani, 1996).

U. kirkiana is dioecious, and the unisexual inflorescences originate from axillary positions among the leaves or, more often, lower down on the second or third season wood of the branchlets (Plate 2). Male flowers occur in a dense head of four to eight fascicles with peduncles up to 10 cm long. Each male flower is covered with five to seven triangular laciniate calyx lobes and without petals. The stamens are cream-coloured and pollen is yellow. The female bracts are often tinged pink, but otherwise resemble those of the male flowers. Within the bracts, the female flowers are solitary, with a shallowy cupular five to eight-lobed calyx. The ovary is ovoid-subglobose, with three or four locules, three to four mm long and wide, and densely fulvous-tomentose. The number of styles match the number of locules. Each style is flabelliform and about four millimetre long, ending in a truncate and laciniate apex (Palgrave, 1981; Anon., 1983; Seyani, 1996).

The loquat-like fruits (hence the vernacular name African loquat) are spherical, rusty-yellow, 2 to 4 cm in diameter, fleshy, with a hard skin surrounding the sweet edible flesh (Plate 2) (Palgrave, 1981). The mass of individual mature fruits may range between 10 to 27 g when fresh and occupy a volume of 27 cm^3 (almost the size of a table tennis ball) although this may vary with site (Mwamba, 1989). The fruit contains from three to five seeds which are whitish, cordate, carinate, and apiculate, with a tough fibrous sclerotesta enclosing a small seedling-like entity (Ngulube, 1996).

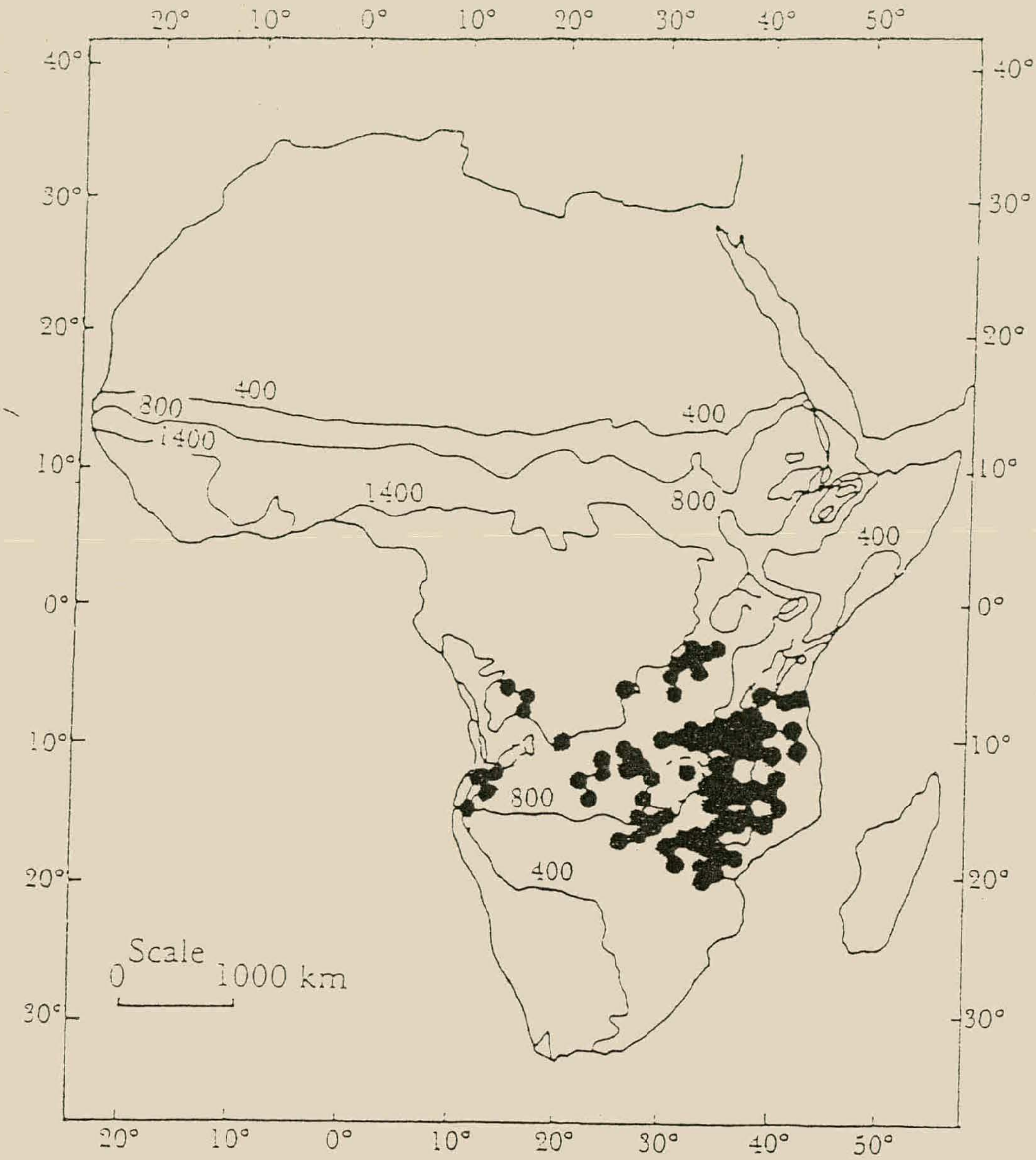

Fig. 1 Distribution of *U. kirkiana* in relation to rainfall (400, 800 and 1400 mm isohyets shown) in Africa. Source: Ngulube (1996).

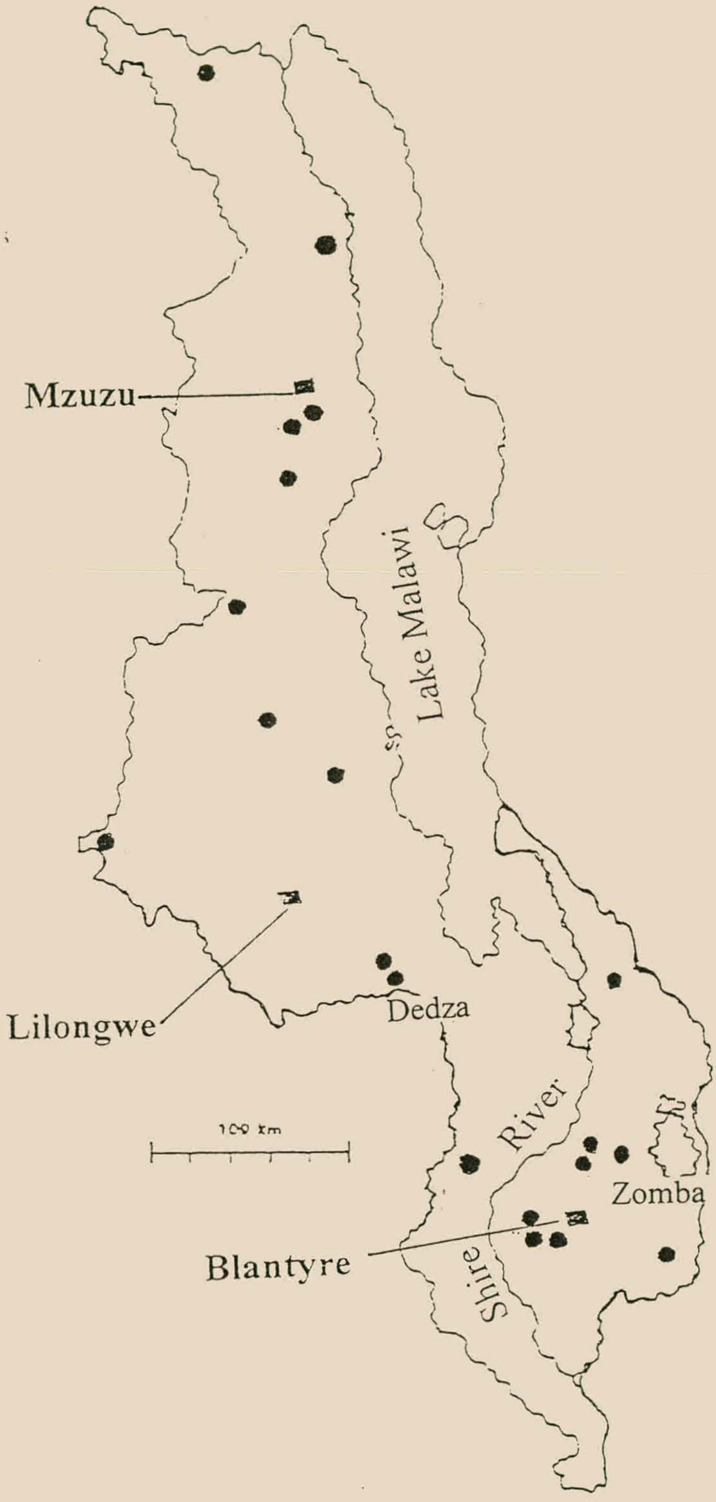

Fig. 2 Distribution of *U. kirkiana* in Malawi. Adapted from Seyani (1996) and Ngulube (1996).

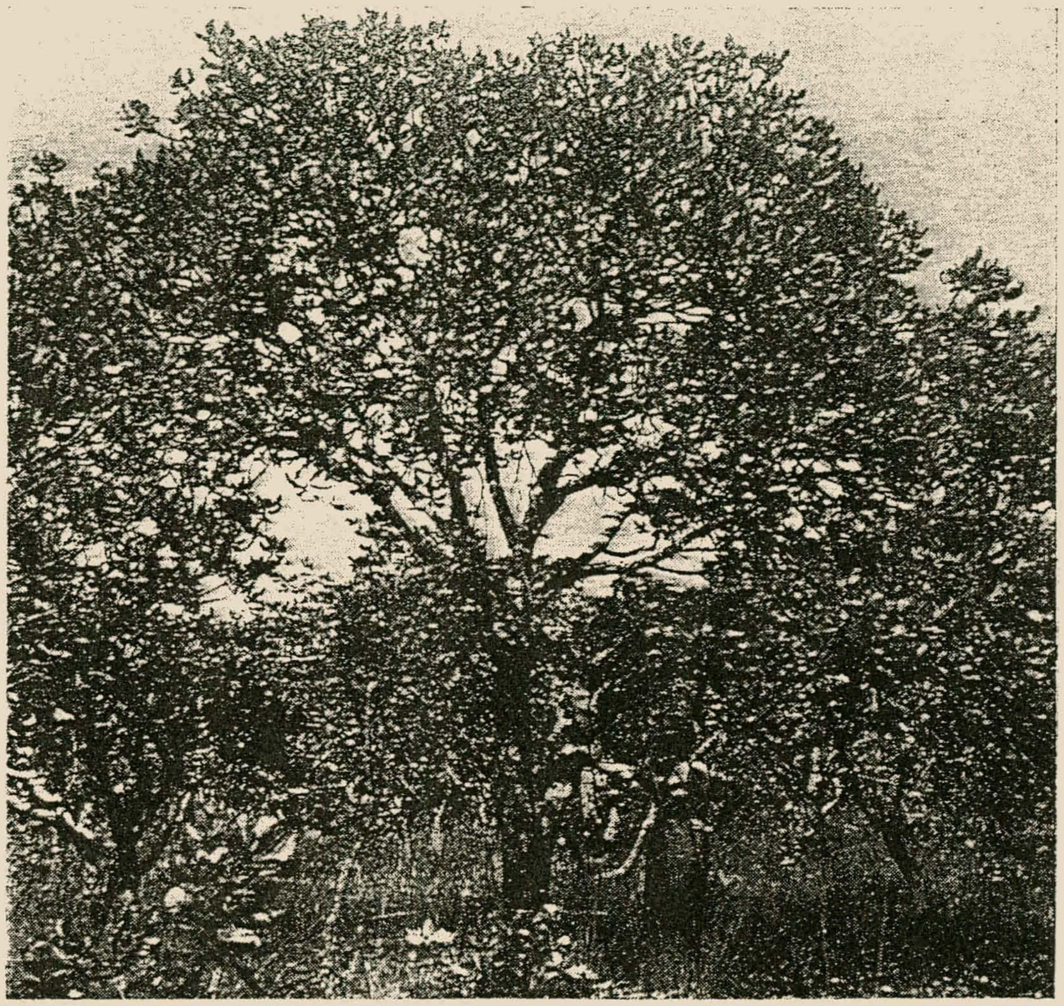

Plate 1. Mature *U. kirkiana* trees in a *Uapaca* dominated woodland. Reproduced from Pardy (1951).

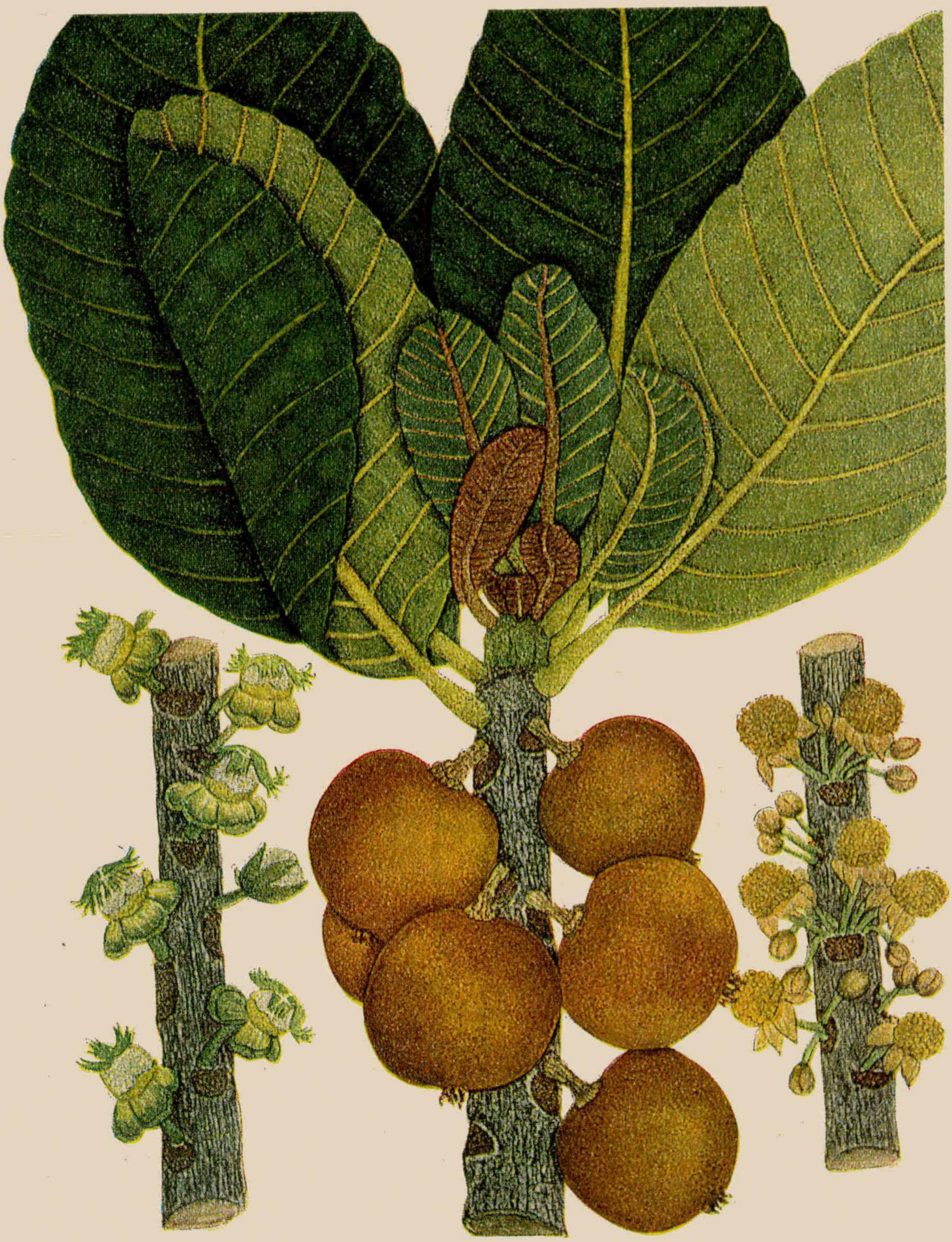

Plate 2. Female (left) and male (extreme right) inflorescences, and in the centre mature leaves and fruits of *U. kirkiana*. Reproduced from Palgrave, 1981.

2.3 Phenology of *U. kirkiana*

Although *U. kirkiana* is referred to as a semi-deciduous miombo tree, information on leaf and shoot flush is lacking (Ngulube, 1996). Casual observations in the field revealed that leaf and shoot flushes are seasonal. New leaves were observed to form toward the start of the rainy season, but the trees remain foliated throughout the year, foliage replacement taking place gradually as old leaves fall off.

Flowering and fruiting phenology of *U. kirkiana* is extensively reported in the literature. Ngulube (1996) provides a comprehensive review of the flowering and fruiting phenology of the tree. In most places in Malawi (Fig. 2) *U. kirkiana* flowers from January to May with a peak in February and March (the rainy season) (Seyani, 1996). Ngulube (1996, pers. comm.) noted that the flowering season varies from year to year. With late rains, the flowering season is advanced; he also observed a varying rate of flowering incidence from year to year. A heavy fruiting year is normally followed by a light fruiting year. Some researchers have reported two flowering periods: one main flowering period during the normal rainy season and the second flowering season occurring between September and November. The latter is referred to as a casual flowering season (Storrs, 1979). Normally few fruits develop from the flowers that develop outside the rainy season. Fruiting occurs from March to October, fruit ripening starting from October onwards soon after the start of the first rains (Seyani, 1996).

2.4 Economic importance of *U. kirkiana*

U. kirkiana is of great economic importance in Malawi, mainly because of the nutritional value of the pulp from the fruit (Saka & Msonthi, 1994; Seyani, 1996). The ripe fruit is eaten by villagers as a food supplement during months of periodic food shortage (December to February). The pulp is also used for making jam, carbonated soft drinks or wine (Mwamba, 1992; Ngulube *et al.*, 1995). Some villagers sell the fruit at the roadside or at the local markets or to the Mulunguzi winery, to supplement their income (Coote, Luhanga & Lowore, 1993). The winery, therefore, provides a lucrative market for fruit collectors and jobs for local people. Some of this wine is exported and earns foreign currency. No definite monetary values are given in the reports on the contributions made by the sale of products of *U. kirkiana* towards income and foreign exchange earnings in Malawi.

The wood is used in the furniture industry, for fuelwood and charcoal, and for making posts and agricultural implements (Goldsmith & Carter, 1981). The wood is durable and can be worked to a smooth finish. The roots and the bark are used by some societies as medicine for a variety of ailments and for making dye (Palgrave, 1981; Seyani, 1996). Some societies in Malawi use the leaves to make containers for dried vegetables (Ngulube, 1996).

2.5 Distribution of *U. kirkiana*

The distribution of *U. kirkiana* in its ecological zones in Africa and Malawi is provided by Ngulube *et al.*, (1995) and Seyani (1996), respectively. The species is widely distributed in tropical Africa (Angola, Zambia, Zimbabwe, Malawi, Tanzania and Mozambique) (Fig. 1). The geographical distribution of the species in Malawi is given in Fig. 2. *U. kirkiana* occurs in areas with an unimodal rainfall regime with a summer range of 500 to 1400 mm per annum and a mean temperature range of 18^0C to 29^0C in the hot summer season and 12^0C to 24^0C in winter. The tree favours well drained escarpments with sandy or gravely acidic soils in the altitude range of 500 to 2000 m above sea level.

2.6 Relation with other trees

Uapaca species are associated with several woody tree species in its areas of occurrence. Some of these species are: *Albizia* spp., *Anisophyllea* spp., *Brachystegia* spp., *Burkea* spp., *Isoberlinia* spp., *Julbernandia* spp., *Monotes* spp., *Parinari* spp., *Protea* spp., *Pericopsis* spp., *Pterocarpus* spp., and *Ochna* spp. (Ngulube, Hall & Maghembe, 1996). A comprehensive review of the tree species associated with *U. kirkiana* is provided by Ngulube (1996).

2.7 Insects associated with *U. kirkiana*

From museum records and a few reports, *U. kirkiana* hosts a wide range of insects (Parker, 1978; Ngulube, 1996). However, most of these insects were collected casually and in one season. Although not specifically dealing with Lepidoptera associated with *U. kirkiana*, records on moths and butterflies on this tree are provided by Pinhey (1975). Insects associated with *U. kirkiana* as reported in the literature are grouped according to their orders and parts of the plant they were collected from, and are presented in Tables 1 to 4.

2.7.1 Defoliators and their effect on fruit production and tree growth

Despite the fact that the leaves of *U. kirkiana* are hairy and leathery, it is host to many phytophagous insects which can significantly reduce the leaf photosynthetic area. In some cases, the insects are reported to cause more than 60 % leaf defoliation (Parker, 1978). Insects found feeding or resting on *U. kirkiana* leaves as listed from museum and published records are given in Table 1.

When leaf defoliators reduce the photosynthetic area, food for growth and reproduction of the plant is reduced. The wounds created from feeding can also serve as entry sites for pathogens (Dent, 1991). The effect on yield or plant growth by defoliation may be modified by several factors such as the extent of defoliation caused, the stage of plant growth at which defoliation has occurred and the physiological state of the plant. Panda & Khush (1995) reported that for seasonal leaf defoliators on evergreen plants, the feeding can be compensated for by subsequent growth in the later seasons, without reduction on growth or yield. In cases where the plant produces excessive foliage, leaf defoliation by phytophagous insects is known to reduce use of photosynthetic assimilates by parasitic leaves (non-photosynthesising leaves that are inside the canopy shaded from the sun), followed by an improved deposition of the assimilates to plant parts of economic importance to man, such as fruits (Dent, 1991). This type of feeding would be considered a normal pruning process applied to most trees to improve on assimilate allocation. Excessive defoliation at the time of flowering or fruit-filling results in excessive fruit abortion (especially fruits from late flowers) or production of small poor quality fruits (Dent, 1991; Niesenbaum, 1996; Bardner & Fletcher, 1974). Of great importance towards sustainable *U. kirkiana* management would be those defoliators that a) attack the plant at a younger age, b) those that attack the plant when it is filling the fruit and c) those that completely defoliate the plant.

2.7.2 Sapsuckers and their effect on tree growth and fruit production

Assimilate sapsuckers (along with other insects associated with foliage) associated with *U. kirkiana,* recorded from literature and insect museums, are summarized in Table 1.

The effect of feeding of plant sapsuckers on *U. kirkiana* growth and fruit production is not documented in literature. However, the effect of sapsuckers is well documented in other agricultural plants and plantation trees (Dent, 1991; Panda & Khush, 1995). Most assimilate suckers belong to the Homoptera (aphids, psyllids, leafhoppers and scale insects) and the Heteroptera (plant bugs) and to a small extent Thysanoptera (thrips). Members belonging to the sapsuckers feed by sucking plant assimilates from various parts of the plant, thereby depriving those parts of the assimilates. Some of the sapsuckers inject saliva into the plant before sucking. In many cases the saliva is suspected to induce a reaction in the plant which can result in the death of the plant or to retard its growth. Some sapsuckers are known to transmit viral diseases (Panda & Khush, 1995). In most cases the effect of sapsuckers on production and growth of plants is exerted even before the pests reach high population levels, thereby requiring control at lower population levels which hamper the various control agents (especially chemical control) (Dent, 1991)

Table 1. Insects collected on foliage of *U. kirkiana*.

Taxon	Location, source and year documented	Remarks
ORTHOPTERA		
Eumastacidae *Clerithes* sp.	Chongoni, Malawi, 1967*	Polyphagous (Lee, 1971)
Pyrgomorphidae *Zonocerus elegans* Thunb.	A number of locations in Malawi, Lee, 1971	Occasional pests of crops and trees (Lee, 1971; Scholtz & Holm, 1985)
Tetrigidae	Mzimba, Malawi, 1967*	Some members feed on algae (Scholtz & Holm, 1985)
HETEROPTERA		
Coreidae *Anoplocnemis curvipes* F.	Bvumbwe, Malawi, 1969*	Polyphagous (Lee, 1971)
Pentatomidae *Agonoscelis versicolor* Thunb.	Chongoni, Malawi, 1967*	Pest of sorghum, beans, cotton, and many other crops (IIE)
Pentatomidae	Chongoni, Malawi, 1967*	Polyphagous (IIE)
Pentatomidae *Nezara viridula* var. *torquata* F.	Chongoni, Malawi, 1967*	Polyphagous (IIE)
Pentatomidae *Nezara viridula* var. F.	Chongoni, Malawi, 1967*	Polyphagous (IIE)
Pentatomidae	Chongoni, Malawi, 1967*	Polyphagous (IIE)
Pentatomidae *Acrosternum pallidoconspersum*	Bvumbwe, Malawi, 1969*	
Pentatomidae	Bvumbwe, Malawi, 1969*	Polyphagous (IIE)
Tessaratomidae *Encosternum delagorguei* Spin.	Mwanza, Malawi (Ngulube, 1996); Zimbabwe (Makuku, 1993)	Occurs also on *Acacia*; eaten by certain communities (Makuku, 1993)
HOMOPTERA		
Coccidae *Ceroplastes uapacae* Hall	Zambia (Parker, 1978) Zimbabwe (Hall, 1932)	Polyphagous (Ben-Dov, 1993)
Coccidae	Central and east Africa (Ben-	Polyphagous (Ben-Dov, 1993)

Ceroplastes brevicauda Hall	Dov, 1993)	
Coccidae *Ceroplastes destructor* Newstead	Central and east Africa (Ben-Dov, 1993)	Polyphagous (Ben-Dov, 1993)
Coccidae *Ceroplastes spicatus* Hall	Central and east Africa (Ben-Dov, 1993)	Polyphagous (Ben-Dov, 1993)
Coccidae *Ledaspis mashonae* Hall	Dedza, Malawi (Lee, 1971)	Polyphagous (Lee, 1971)
Coccidae *Pulvinaria psidii* Mask.	Dedza, Malawi (Lee, 1971)	Pest of coffee (Ben-Dov, 1993)
Coccidae *Pulvinaria uapacae* Hodgson	Zimbabwe (Ben-Dov, 1993)	Polyphagous (Ben-Dov, 1993)
Coccidae *Saisselia persimilis* (Newstead)	Central, east and South Africa (Ben-Dov, 1993)	Polyphagous, Ben-Dov, 1993
Coccidae *Saisselia jocunda* De Lotto	Leaves Central and east Africa (Ben-Dov, 1993).	Polyphagous (Ben-Dov, 1993)
COLEOPTERA		
Anthicidae *Formicomus rubricollis* Lak.	Dedza, Malawi 1967*	Live in litter or under bark, some species are predators of insect eggs, others are scavengers (Scholtz & Holm, 1985)
Attelabidae	Dzalanyama, Malawi, 1970*	Feed on young leaves or flower buds (Scholtz & Holm, 1985)
Chrysomelidae *Altica* sp.	Chongoni, Malawi, 1969*	Larvae feed on roots of crucifers and *Hibiscus* sp. (Scholtz & Holm, 1985)
Chrysomelidae *Microsyagrus rosae* Bry.	Zambia (Parker, 1978)	Pest of a number of cultivated crops feeds on leaves (Scholtz & Holm, 1985)
Chrysomelidae *Cryptocephalus* sp.	Chongoni, Malawi 1968*	Live on branches and leaves of host plant (Scholtz & Holm, 1985)
Chrysomelidae *Colasposoma* sp.	Dzalanyama, Malawi, 1970*	Feeds on *Ipomea* sp. (Scholtz & Holm, 1985)
Coccinellidae *Hyperaspis* sp.	Flowers Zomba, Malawi, 1995*	Feeds on coccids (Scholtz & Holm, 1985)
Coccinellidae *Cheilomenes lunata* F.	Flowers Zomba, Malawi, 1995*	Feeds on *Toxoptera* sp. (Scholtz & Holm, 1985)
Coccinellidae *Epilachna dregei* Muls.	Chongoni, Malawi, 1967 & 1969*	Sporadic pest of solanaceous plants (Scholtz & Holm, 1985)
Curculionidae *Apion angulicolle* Gyll.	Chongoni, Malawi, 1967*	Feeds on leaves, some species transmit viral diseases (Scholtz & Holm, 1985)
Curculionidae *Cossonus* sp.	Chongoni, Malawi, 1967*	Burrow in live and dead wood (Scholtz & Holm, 1985)
Curculionidae	Dedza, Malawi, 1967*	Weevils, cosmopolitan pests (Lee, 1971)
Curculionidae	Livingstonia, Malawi, 1967*	Feeds on leaves (Scholtz & Holm, 1985)
Curculionidae	Mzimba, Malawi, 1968*	Weevils, cosmopolitan pests (Lee, 1971)
Curculionidae	Bvumbwe, Malawi, 1968*	Weevils, cosmopolitan pests (Lee,

Amphitmetus sp.		1971)
Curculionidae	Chongoni, Malawi, 1969*	Weevils, cosmopolitan pests (Lee, 1971)
Lagriidae *Chrysolagria* sp.	Livingstonia, Malawi, 1967*	Cosmopolitan, but of less significance (Lee, 1971)
Lagriidae	Dedza, Malawi, 1967*	Cosmopolitan, but of less significance (Lee, 1971)
LEPIDOPTERA		
Hesperiidae *Abantis arctomarginata* Lathy	Zimbabwe and Mozambique. (Henning, Pringle & Ball, 1994).	Larvae: *Uapaca* species only; adults on high canopies. Larvae preyed and parasitised by spiders and tachinid flies respectively (Henning *et al.*, 1994).
Lasiocampidae *Pachypasa sericeofasciata* Aur.	Malawi (Majawa, 1980)	Polyphagous (Pinhey, 1975)
Limacodidae *Taeda aetitis* Walleng.	Central Africa (Pinhey, 1975)	Polyphagous especially tree shrubs (Lee, 1971)
Limacodidae *Latoia urda* Druce	Central Africa (Pinhey, 1975)	Polyphagous especially tree shrubs (Lee, 1971)
Nymphalidae *Charaxes nichetes leoninus* Butler	Zimbabwe, Mozambique (Henning, 1989)	Adults have a diversity of food, but the larvae have only been collected on *Uapaca* sp. (Henning, 1988)
Nymphalidae *Charaxes nichetes veronicae* Plantrou	Zimbabwe, Mozambique (Henning, 1989).	Adults have a diversity of food, but the larvae have only been collected on *Uapaca* sp. (Henning, 1988)
Saturniidae *Ludia delegorguei* Boisd.	Namibia, Mozambique, Zimbabwe, Kenya (Pinhey, 1975)	Polyphagous (Lee, 1971)
Saturniidae *Bunaea angasana* Westw.	Zimbabwe (O'Neil, 1919)	Polyphagous (Lee, 1971)
Saturniidae *Holocerina agomensis* Karsch	Angola, Central and West Africa (Pinhey, 1975)	Polyphagous (Lee, 1971)
Saturniidae Three specimens	Chongoni, Malawi, 1967*	Feeds on leaves (Scholtz & Holm, 1985)

- * FRIM (Forestry Research Institute of Malawi) museum specimen, and the year indicates when the specimen was collected
- IIE = International Institute of Entomology identifications notes accompanying the identified specimen

2.7.3 Fruit pests and their effect on fruit production

Few insects attacking *U. kirkiana* fruit are documented (Parker, 1978; Ngulube *et al.*, 1996) (Table 2). Insect collections in most museums in Malawi concentrated on collecting adult stages of insects present at the time of collection, thereby excluding immature stages in the fruit and other plant parts.

The magnitude of pest damage to *U. kirkiana* and the effect on fruit production of pest attack is not well understood. However, the general pattern of the effect of fruit pests on crop plants is well documented (Annecke & Moran, 1982). Most fruit borers belong to the orders Lepidoptera, Diptera and Coleoptera. In most cases attacked fruits respond by early ripening followed by abortion, or the fruit can produce sap which drowns the pest (Annecke & Moran, 1982). In *U. kirkiana* small fruits are aborted, and most of such fruits have insect entry or exit holes with reddish fluid oozing from the fruit (suspected to be) prior to abscission (Ngulube, 1996). It is not known whether the aborted fruits are due to insect attack or to natural abortion to insure adequate resources for the survival of the few remaining fruits, or that the insects attack the already dying fruits. A mere count of dropped fruits or fruits with exit holes in the natural environment does not give an indication of the economic effect of fruit borers on fruit production. However, in macadamia nuts, feeding on the fruit by *Nezara viridula* is suspected to cause premature drop of fruits, and the mature fruits that are fed on by the bug develop marks which reduce the quality of the nuts (Jones & Caprio, 1994). Surface scarring on the fruit by beetles and moth larvae can provide egg laying sites to fruit detrivores such as *Drosophila* spp. and the Mediterranean fruit fly and induce fungal growth which, in turn, may drastically reduce fruit quality (Annecke & Moran, 1982).

Table 2. Insects associated with fruits of *U. kirkiana*.

Taxon	Location, year and source of record	Remarks
COLEOPTERA		
Nitidulidae *Carpophilus fumatus* Boh.	Immature fruit Zambia (Parker, 1978)	Cause damage to drying maize cobs, some species live under bark (IIE)
DIPTERA		
Drosophilidae *Drosophila ananasse* Dol.	Ripe fruit Zambia (Parker, 1978)	Occurs on fermenting fruits- feeds on micro-organisms (IIE)
Otitidae *Bromophila caffra* Rtl.	Fruits Chongoni, Malawi (Lee, 1971)	Saprophytic, but can attack living plant tissue (Lee, 1971)
Tephritidae *Ceratitis cosyrae* Wlk.	Ripe fruits Zambia (Parker, 1978)	Adults on flowers or vegetation, larvae: pest of fruits, seed, stem, gall induction (Scholtz & Holm, 1985)
Lepidoptera		
Lycaenidae *Deudorix magda* Gifford	Fruit and seed Malawi (Henning *et al.*, 1994)	Larval specimen only isolated from *Uapaca* fruits, adults are polyphagous
Lycaenidae *Deudorix* sp.	Larvae invade fruits Zambia (Parker, 1978)	Larvae associated with ants. Feeds on terminal of foliage, flowers, fruits; some members are predators of aphids and coccids (Pinhey, 1975)

- IIE = International Institute of Entomology identifications notes accompanying the identified specimen

2.7.4 Wood borers and their effect on the quality and strength of *Uapaca* wood

Although *U. kirkiana* wood is reported to be pest resistant (Palgrave, 1981), several borers have been collected from the wood or on the surface of the wood (Table 3). In the field termites have been observed attacking dead *U. kirkiana* wood.

The effect of wood borers on *U. kirkiana* wood has not been studied, partly because *U. kirkiana* wood is not widely used for timber and also due to the belief that it is pest resistant. Generally attack by wood borers is known to weaken the strength of timber, in most cases, susceptible timber requiring pretreatment before use to ensure its longevity and quality (Esbjerg, 1976).

Table 3. Insects associated with the stems and logs of *U. kirkiana.*

Taxon	Location, year and source of record	Remarks
ISOPTERA		
Termitidae *Nasutitermes usambarensis* Sjöst.	Nests on trunks & log Malawi, (Sands & Wilkinson, 1954)	Feed on wood (Lee, 1971)
HETEROPTERA		
Coreidae *Anoplocnemis curvipes* F.	Branches and stem Bvumbwe, Malawi, 1969*	Twig wilter (Scholtz & Holm, 1985).
Lygaeidae *Oxycarenus albidipennis* Stål.	Log, Chongoni, Malawi, 1967*	Pest of cotton (Malvaceae) (IIE)
Pentatomidae *Aspavia* sp.	Log, Chongoni, Malawi, 1967*	Polyphagous (Lee, 1971)
COLEOPTERA		
Anthribidae	Log, Mulanje, Malawi, 1938*	Fungus weevils (Lee, 1971)
Bostrichidae *Xylion adustus* Fhs.	Seasoned log Dedza, Malawi, 1967*	Woodborers, some species infested stored root products (Scholtz & Holm, 1985)
Buprestidae *Anthaxia* sp.	Log, Dedza, Malawi, 1967*	Visit flowers, larvae bore into wood (Lee, 1971; Scholtz & Holm, 1985)
Buprestidae *Megactenodes reticulatus* Klug	Log, Chongoni, Malawi, 1967*	Most larvae are woodborers, some leaf miners, root feeders, threat to moribund wood (Scholtz & Holm, 1985)
Buprestidae *Psiloptera* sp.	Log Chongoni, Malawi, (Lee, 1971)	Common in savannah Verde, on wood (Scholtz & Holm, 1985)
Buprestidae (Larvae)	Log, Dedza, Malawi, 1967*	Larvae are wood borers (Lee, 1971)
Cerambycidae *Amphidesmus analis* Ol.	Log, Dedza, Malawi, 1967*	Larvae damage wood (Lee, 1971; Scholtz & Holm, 1985)
Cerambycidae *Tragocephala mima* Thoms.	Log, Dedza, Malawi, 1967*	Girdle stem to oviposit eggs above the girdled part. Larvae burrow into moribund wood (Scholtz & Holm, 1985)
Cerambycidae *Zamium incultum* Pascol.	Log, Chongoni, Malawi, 1967*	Larvae feed on wood (Lee, 1971)
Cerambycidae *Zographus aulicus* Bertol.	Log, Chongoni, Malawi, 1970*	Larvae are wood borer (Lee, 1971)
Chrysomelidae *Megaleruca geniculata* Har.	Log, Chongoni, Malawi, 1967*	Some species live in large numbers defoliating and skeletonizing leaves (Scholtz & Holm, 1985)
Chrysomelidae *Diacantha* sp.	Log, Chongoni, Malawi, 1969*	Pest of Cucurbitaceae (Scholtz & Holm, 1985)
Chrysomelidae	Log, Dedza, Malawi, 1967*	Larvae live in the stem, causing swelling of the stem (Scholtz & Holm, 1985)
Cucujidae *Silvanus fairmairei* Grouv.	Log, Chongoni, Malawi, 1967*	Occur under bark predaceous on other small anthropods. Pest of some stored

		foods (Scholtz & Holm, 1985)
Curculionidae *Cossonus* sp.	Under bark, Chongoni, Malawi, 1967*	Burrow in live and dead wood (Scholtz & Holm, 1985)
Lyctidae *Lyctus* sp.	Log, Dedza, Malawi, 1967*	Adults and larvae feed on wood, finally reducing it to fine powder (powder post beetles) (Scholtz & Holm, 1985)
Lyctidae *Premnobius carpinnia*	Stem, Chongoni, Malawi, 1967*	Adults and larvae feed on wood, finally reducing it to fine powder (powder post beetles) (Scholtz & Holm, 1985)
Scolytidae *Glostatus* sp.	Log, Chongoni, Malawi, 1967*	Wood-borer (Scholtz & Holm, 1985)
Tenebrionidae *Catamerus rugosus* Gah.	Stem, Dedza, 1967* Mangochi, Malawi, 1976*	Feed on dead wood and fungi growing on dead wood (Lee, 1971; Scholtz & Holm, 1985)
Tenebrionidae *Ceropria romandi* Cast.	Stem, Chongoni, Malawi, 1967*	Polyphagous (Lee, 1971)
Tenebrionidae *Corticeus* sp.	Stem, Chongoni, Malawi, 1967*	Polyphagous (Lee, 1971)

- * FRIM museum specimen, and the year indicates when the specimen was collected
- IIE = International Institute of Entomology identifications notes accompanying the identified specimen

2.7.5 Insects associated with *U. kirkiana* flowers and their role

Although *U. kirkiana* is referred to as predominantly insect pollinated, its flowers are not very conspicuous, do not produce nectar nor do they produce scent (Storrs, 1979). In this regard the only obvious insect attractant is pollen. Some workers have referred to the pollen as being sticky, but personal observation in the field shows that shaking the male flowers on a dry day releases a dust of single pollen grains, suggesting that wind pollination may play a major role in fertilisation. The female flowers have their stigma exposed and extended to catch the floating pollen grains. The sex ratio reported in the literature of one male to one female tree and the closeness of the male and female trees to each other in natural populations make the acceptance of wind pollination more plausible. Table 4 gives insects associated with flowers of *U. kirkiana*.

Table 4. Insect flower visitors of *U. kirkiana*

Taxon	Male flower	Female Flower
HOMOPTERA		
Cicadellidae	*	
COLEOPTERA		
Carabidae	*	*
Chrysomelidae		*
Coccinellidae	*	
Elateridae	*	*
Lagriidae	*	*
Lycidae	*	
Scarabaeidae	*	*
Paussidae	*	*
Scarabaeidae		*
Staphylinidae	*	
Lampyridae	*	
DIPTERA		
Syrphidae	*	*
LEPIDOPTERA		
Arctiidae		*
Gelechiidae	*	*
Pyralidae	*	*
Pyraustidae		*
Noctuidae	*	*
HYMENOPTERA		
Apidae	*	*
Formicidae	*	*
Sphecidae	*	

* indicates where the insects have been caught.
Source: Ngulube, 1996.

The role of the insects associated with *U. kirkiana* flowers is not well elaborated in literature, but, insects such as bees are suspected as pollinators (Mwamba, 1992). As the female flowers do not posses any specific attractant, the pollinators are presumed to transfer pollen to the female flower by chance. The presence of insects whose attractants are 'not presented' (most of the Lepidoptera families do not feed on pollen) may have special roles other than pollination. Some of these insects can be suspected to be flower feeders, some possibly searching for egg laying sites, some preying on other insects present, and some insects may be looking for mating partners (Dafni, 1992). In Zomba (Malawi) personal observations showed that insects readily visited flowers of *Uapaca* in the flowering season, but that there were fewer insects flying around bean flowers which were close to *U. kirkiana* flowers. Some flowers are known to present strong attractants to prospective pollinators, such that these plants out-compete those with lesser attractants, especially in cases where insect pollinators are limiting. This results in lower fruit set in exclusively insect-pollinated plants with weaker attractant due to failure of pollination (Dafni, 1992). The yield of the crop plants growing in association with *U. kirkiana* has not been evaluated to determine the effect of pollinator competition. Some of the insects associated with flowers are natural enemies of crop pests. In Table 4 the hover flies and coccinellids attracted to the flowers can feed on crop pests of the crops growing next to *U. kirkiana* flowers, or the pests of *U. kirkiana* can be controlled by these natural enemies.

2.7.6 Shelter seekers and their effect

From their physiognomy, trees are said to provide a large and complex environment for the habitation of insects and other fauna (Niesenbaum, 1996; Southwood, Moran & Kennedy, 1982b). *U. kirkiana*, being a suitable tree in this context, is expected to host a wide variety of shelter seeking insects. Information on activities of most insects collected on *U. kirkiana* plant parts in reports and museum records is lacking. However, Makuku (1993) reported the presence of a shelter seeking hemipterous bug, *Encosternum delagorguei*, on *U. kirkiana* in Zimbabwe. These insects have been observed to occur on *U. kirkiana* at certain times of the year and are eaten by certain societies in Zimbabwe.

The effect of shelter seekers on *U. kirkiana* production is not established, but contribution to the societies as a food source is reported (Makuku, 1993). However, most of the shelter seekers may have a negative or positive effect on crop plants associated with *U. kirkiana*, as pests and natural enemies of such crops.

2.7.7 Alternative or alternate crop and tree pests

Generally trees serve as alternate (or as pest reservoirs when they act as alternative hosts) hosts to crop pests, either when annual crops are harvested or by hosting some insect stages (Cromartie, 1981) (Table 5). Some crops, such as maize, serve as alternate hosts of tree pests as well (Verma & Parmar, 1988). Although the role of *U. kirkiana* as an alternative or an alternate host is not established, a literature search on some of the insects observed on the tree reveal that most of these insects are crop pests. In some instances, although not established on *Uapaca*, trees that have been planted along side crops have allelopathic effects or physically compete with crops for factors of production. In the process the crops are weakened and made vulnerable to pest attack (Vandermeer, 1989).

Table 5. Some agroforestry trees that harbour or promote crop pests.

Tree	Pest	Crop	Reference
Azanza girkiana	*Dysdercus nigrofasciatus* Stål.	*Gossypium hirsutum* (cotton)	Mchowa & Ngugi, 1994
Eucalyptus sp.	Termites	Polyphagous	Meke, 1995
Faiderbia albida, Citrus sp	*Icerya purchasi* Mask.	*Cajanus cajana* (pigeon peas)	Personal observation
Gliricidium sepium	*Aphis fabae* Scopoli	*Phaseolus vulgaris* (beans)	Personal observation
Sesbania sesban	Root knot nematode	*Nicotiana tabacum* (tobacco)	Mchowa & Ngugi, 1994
Manihot sp.	*Prostephanus truncatus* (Horn)	Stored *Zea mays* (maize)	Booth, Cox & Madge, 1990.

2.8 *U. kirkiana* pest control options

As interest to manage (and cultivate) *U. kirkiana* for fruit production develops, it is necessary to anticipate pest problems and formulate the necessary pest control measures or management options that will reduce the likelihood of pest outbreaks. Literature on pest control on miombo trees growing in their natural environment is mostly non-existent. However, pest control options for horticultural, agroforestry and plantation trees can be used to control *U. kirkiana* pests as the tree is a possible agroforestry tree candidate. Emphasis therefore will have to be placed on cheap, practical, environmental friendly, and self sustaining pest control options. Possible options include: chemical control, cultural control, biological control, physical control, and traditional control.

2.8.1 Chemical control

Chemical control has wider application in agriculture than in forestry. Long rotational periods, size of trees, environmental considerations (pollution), and the compound interest on capital investment limits the use of pesticides in forestry. In this industry the use of chemical pesticides is mostly restricted to nursery stock or only used at the time of transplanting. However, on horticultural trees, chemical pesticides find wide application (Annecke & Moran, 1982). In agroforestry (in Malawi) emphasis is on low resource endowed farmers and as such chemical pesticide use is kept to a minimum. *U. kirkiana* is being developed as an agroforestry fruit tree and at this stage the possible use of chemical pesticides receives low priority. If the wine industry encourages this tree-based incentive, chemical pesticides may well find wider application. Presently, *U. kirkiana* seeds are treated with actellic dust to control seed borers and copper oxychloride to control fungi. This treatment is the only form of chemical control practised at present against pests associated with *U. kirkiana*.

2.8.2 Biological control

Biological control is a pest control method that uses other living organisms (predators, parasites/parasitoids and pathogens) to control pests. Currently there is increased awareness for biological control as a self sustaining environmental friendly pest control option on trees. Biological control techniques involve conservation, inoculation and inundation of natural enemies.

In the context of conservation, naturally occurring predators and parasites/parasitoids are promoted by improving their living conditions. This includes the promotion of silvicultural and agronomical practices that enhance their growth, fecundity, searching efficiency and to some extend reduction of pesticide usage (van Emden, 1974). The common practices that encourage conservation include weeding, tillage and mixed cropping. Weeding is believed to improve searching ability of natural enemies. Although some researchers believe that weeds increase the population of natural enemies in the field (Cromartie, 1981), their suppressive effect on plant growth would outweigh their advantage on pest control. Tillage is believed to expose soil-inhabiting pests to predators and also to harsh weather conditions which reduces ability of pests to escape quickly from natural enemies (Dent, 1991). Most natural enemies (especially parasitoids) require pollen and nectar at some stage of their life. Crop mixtures that promote such availability of pollen and nectar will promote efficacy of natural enemies. *U. kirkiana* produces pollen only and interplanting with a crop that produces nectar could promote natural enemies that require nectar. Indiscriminate use of chemical pesticides should be avoided, as they do not only kill pests, but their natural enemies as well. After pesticide treatments, pests usually recover faster than natural enemies (van Emden, 1974). Where use of chemical pesticides can not be avoided, selective insecticides should be used to minimise the effect on natural enemies.

Inoculation involves releasing small numbers of natural enemies in the hope that they will establish themselves. This approach is, in most cases, exclusively used to control imported pests by importing natural enemies from the area of pest origin. It is normally referred to as classical biological control (Dent, 1991). On *U. kirkiana*, this biological control technique can only be used if alien pests should attack the tree; no such pests have been reported to date.

Inundation involves rearing large numbers of natural enemies in the laboratory and then liberating them on to the crops in such a manner that they are well dispersed to reach the pests before they die (van Emden, 1974). This biological control technique works on the same principles as pesticides in that the natural enemies have to be reared and released when pest control is needed. In *U. kirkiana* pest control this method can be employed, if indigenous natural enemies are identified, and the techniques of breeding them are known.

The existence of natural enemies for *U. kirkiana* pests has not been determined. Knowledge of the existence of natural enemies will assist farmers to reduce use of pesticides in favour of biological or cultural control in crop mixtures that involve *U. kirkiana*. However, to implement biological control, input is required from highly trained entomologists, a scarce resource. In most cases government assistance would be required.

2.8.3 Behavioural and genetic control technique

Behavioural control technique involves the use of chemicals that modify insect behaviour or growth patterns. This method utilizes repellents, attractants, antifeedants, pheromones and hormones (van Emden, 1974). Repellents drive pests away from the host plant, while attractants selectively lure pests to a pesticide-treated bait or trap. Pheromones can also be used to selectively attract pests to their doom. In some cases high concentrations of sex pheromones in the insect environment can inhibit mating. Growth hormones can be used to arrest certain growth stages of insects. For example the larval stage can be arrested, so that the insect dies due to dehydration (van Emden, 1974). In most cases all these control methods will find very little application in *U. kirkiana* pest control as they are expensive. Perhaps they could be employed for initial pest monitoring purposes.

Genetical control mostly involves sterilising male insects by radiation or exposure to chemosterilants (van Emden, 1974; Walter & Parry, 1994). This method would also find very little application in the control of *U. kirkiana* pests as it is expensive and results are difficult to assess.

2.8.5 Selection for host resistance

This pest control option involves selection of trees that are less attacked by insect pests or those that yield well in spite of pest attack (Dent, 1991). In the wild some *Uapaca* trees were observed to be resistant to insect damage. As part of the tree development programme, selection for pest resistance can be incorporated in such a programme. However, resistant trees may not provide the same desired products as a susceptible tree. Resistant trees may be slow growing and may give poor quality and low yield (Panda & Khush, 1995).

As trees take longer to mature, the benefits from a tree breeding programme may not be forthcoming in the short term and also it may not be easy to fix resistant genes within a short period. The farmer cannot do much about breeding for resistance apart from selecting trees with obvious pest resistant traits for propagation.

2.8.6 Cultural control

Cultural control is a pest control option that utilizes agronomical or silvicultural practices that reduce pest populations or the virulence of pests. Cultural control involves cultivation of soil, clean cultivation, removal and destruction of crop residues, improvement of soil fertility status, strip or mixed farming, crop rotation, trap crops, proper timing of planting time and harvesting practices (van Emden, 1974). Cultivation of the soil, such as tillage, increases mortality of pests by exposing them to harsh environmental conditions such as sun radiation. Clean cultivation and removal of crop residues removes insect hiding places and alternative/alternate pest host plants. Improved soil nutrition improves plant resistance to pests (Panda & Khush, 1995). Strip cropping and mixed cropping reduce pests by increasing the availability of natural enemies while crop rotation and trap crops works on the principle of pest starvation (Dent, 1991). Planting trees off site stress them and make them susceptible to pest attack. Unhealthy tree seedlings, due to moisture stress and poor selection, are also susceptible to pest attack. Pests can easily build-up in such seedlings and these seedlings can subsequently act as sources of infection (van Emden, 1974). Timely harvest of fruits reduces insect pest build-up and damage (Annecke & Moran, 1982). To maximise cultural control a thorough knowledge of the pest and crop mixtures is required. Current knowledge on silvicultural practices of *U. kirkiana* is limited consequently limiting selection of cultural pest control methods to be used.

2.8.7 Traditional pest control

Traditional pest control is a term used to refer to non-scientifically proven pest control measures that rural farmers devise and use to control pests. In most rural areas there are many pest control options employed by farmers of which scientists are unaware. Farmers in some areas use wood ash or tobacco extract to control termites (Meke, 1995) and neem (*Azadirachta indica*) seed oil extract to control defoliators (Sen-Sharma, 1987). In *U. kirkiana*, since leaf defoliation seems to be apparent, neem extracts can possibly be used to control some of the defoliators.

2.8.8 Physical control

Physical pest control is a pest control method that aims at reducing pests by physically altering their environment or killing them directly (van Emden, 1974). Large and non-irritating caterpillars can be hand-picked from the trees and then destroyed by squeezing or burning. Grasshoppers can be picked early in the morning when it is still chilly, and then destroyed. In, for example, pine trees certain pests like *Plagiotriptus pinivorus* have been controlled by placing sticky bands around the stem to trap insects climbing the trees (Esbjerg, 1976). On *U. kirkiana* plants large pests on seedlings can be controlled physically as outlined above. Where labour resources are limited, this control measure would find very little application.

In natural woodlands, early burning of the forest floor can also be employed to control *U. kirkiana* pests. In fynbos, insects abundance declines soon after fire (Schlettwein, 1984). In this case if the fire is properly managed, it can control insect pests without seriously damaging the trees.

In most cases, the most effective method of control would be to select a range of the control measures discussed above and to integrate them for optimal results, the so-called integrated pest management strategy.

2.9 Other problems associated with *Uapaca*

2.9.1 Mammal pests

Seyani (1996) and Ngulube (1996) report a wide range of mammals that feed on *U. kirkiana* fruits. Some of these animals are: baboons (*Papio cynocephallus* L.), blue monkeys (*Cercopithecus mitis* Wolff), vervet monkey (*Cercopithecus aethiops* L.), the thick tailed galago (*Galago crassicaudatus* E. Geoffroy), the lesser galago (*Galago senegalensis* E. Geoffroy), bush pigs (*Potamochoerus porcus* L.), warthogs (*Phacochoerus aethiopicus* Pallas), squirrels (*Sciurus* spp.), elephants (*Loxodonta africana* Blumenbach), elands (*Taurotragus oryx* Pallas) and zebras (*Equus burchelli* Gray). Of these, the greatest damage could be expected from the primates in terms of numbers and their ability to climb fruit trees, often causing excessive fruit drop from the shaking action as they climb and jump from one branch to another. In Malawi, primates are a major agricultural pest (Anon, 1995). The larger mammals like elephants, zebras and elands are mostly restricted to parks and game reserves.

2.9.2 Diseases

Few diseases have been reported on *U. kirkiana*, the major ones include necrosis linked with *Pestalotiopsis versicolour* Speg leaf spots caused by *Cercospora* species, mildew and sooty moulds-*Cladosporium cladosporioides* (Fresen.) (Parker, 1978). The impact of these diseases on plant growth and fruit production is not known. However, this report indicates that where observed, they have not resulted in any serious damage.

2.9.3 Fire

In *Uapaca* the effect of fire on fruit production has not been evaluated, but, casual observations reveal that trees that suffer from yearly hot fires have smaller open canopies, and the tree density also seems to be reduced. The small and open canopy can be suspected to produce fewer fruits compared to trees that do not suffer from recurrent hot fires. The solution to hot fires where they are inevitable would be early burning. An open canopy may, however, facilitate wind pollination of flowers.

2.9.4 Human damage

The most common damage inflicted on the trees by humans is debarking of the stem by stones or heavy objects used to hit the tree so as to dislodge the fruits, or breaking of branches to harvest the fruits (Ngulube, 1996) (Plates 3 and 4). This damage is more common on trees in government forests closer to villages. This damage can be reduced by teaching the rural communities the best ways of fruit harvest and by making them aware of the dangers of such destructive harvesting. These educational messages can be channelled through the already existing extension communication channels established by the ministries of Agriculture and Natural Resources.

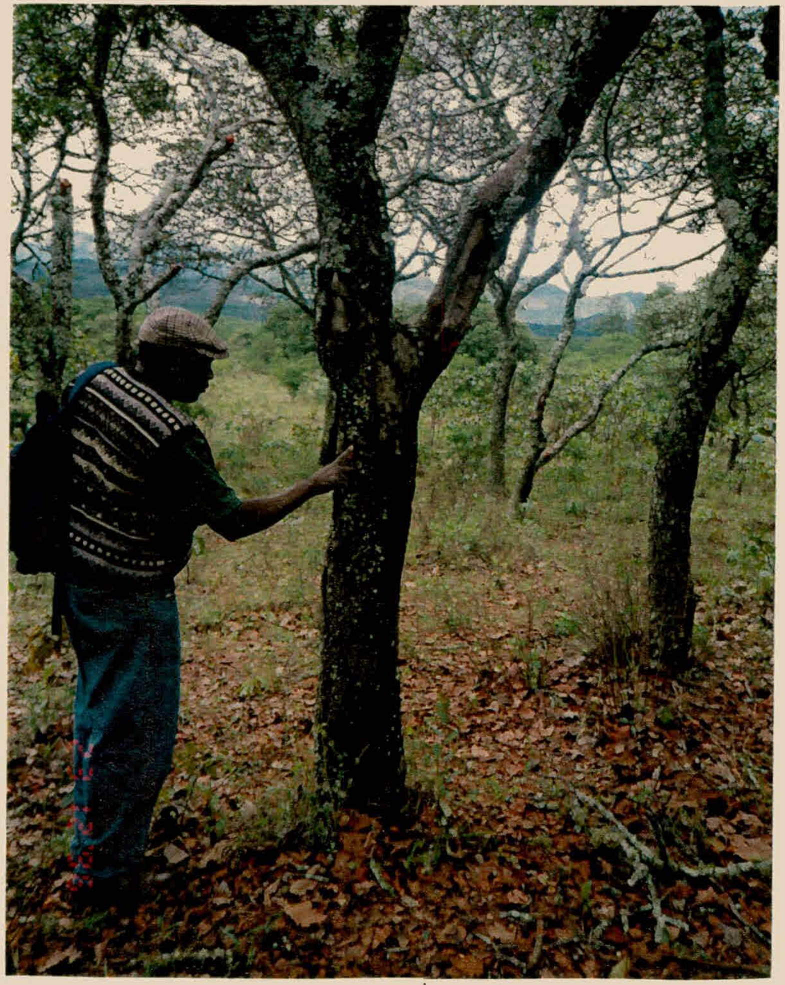

Plate 3. *Uapaca* tree with moderate old stem damage in a woodland dominated by large *Uapaca* trees.

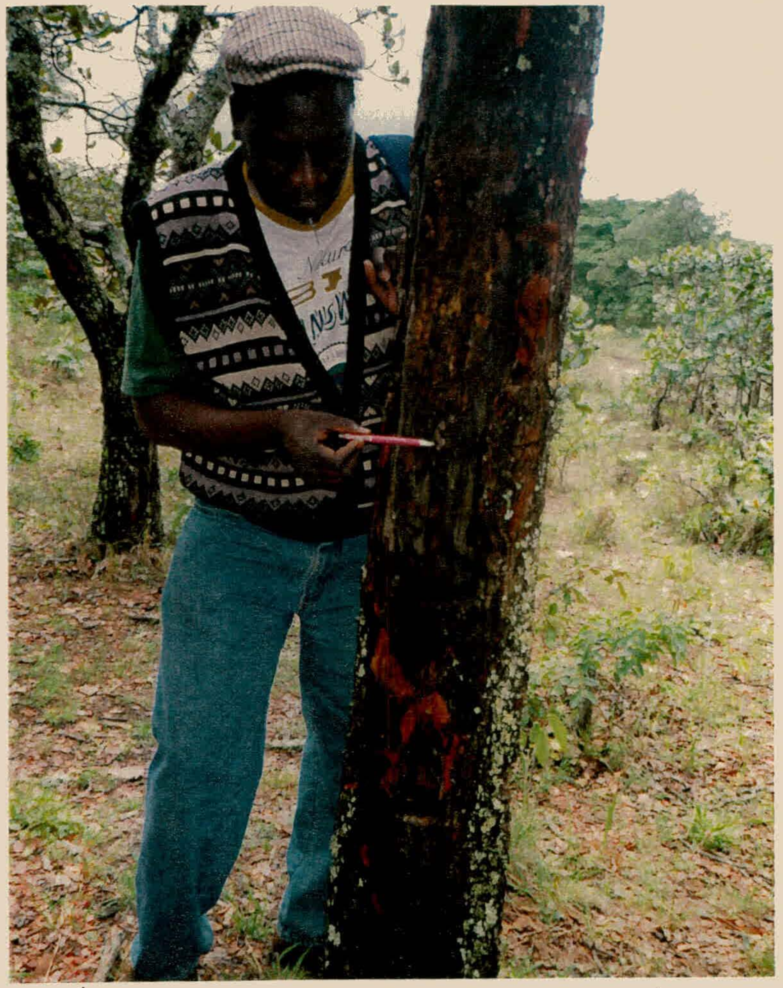

Plate 4. A heavily damaged *Uapaca* stem. The damage is inflicted when people hit the tree with heavy objects to dislodge ripe fruits. The damage consists of both fresh and old wounds and a secondary fungus infection.

CHAPTER THREE

3 INSECT STUDIES ON *UAPACA KIRKIANA*

Field work for this study was conducted from September 1996 to August 1997 with the aim to collect insects associated with *U. kirkiana*, to compile a comprehensive list of all such insects, and to compare differences in insect incidence in two separate locations and in different habitats. The survey comprised of three activities: collection of fruit pests, collection of foliage feeding or dwelling insects and quantification of insect damage to trees.

3.1 Description of the sites

3.1.1 Zomba

Zomba on the map is located at 15.23S 35.19E with an altitude of over 900 metres above sea level and has a mean annual rainfall of 1424 mm and temperature of 21.4^0 C. Here *Uapaca* woodlands are mainly found on protected areas such as: graveyards, government protected indigenous woodlands, small uncultivated areas on privately owned farms and on research plots. For the purpose of the survey, indigenous *Uapaca* woodlands were classified into: *Uapaca* woodland dominated by small *Uapaca* trees (*Uapaca* being >50 % of the tree population), *Uapaca* woodland dominated by large *Uapaca* trees (*Uapaca* trees making up more than 50 % of the tree population), and mixed woodlands (where *Uapaca* trees were less than 50 % of the tree population). On cultivated land of farmers sampling was restricted to the individual trees left on farm land or on the homestead. Four sampling sites were used in Zomba for all the *Uapaca* growing environments.

3.1.2 Dedza

Dedza is located at 14.19S 34.16E with an altitude of over 1200 metres above sea level, mean annual temperature of 17.9^0 C and a mean annual rainfall of 999 mm. *Uapaca* woodland structure in Dedza is similar to Zomba, with the exception that government woodlands near villages are used for cattle grazing. Due to limited accumulation of dead grass litter, they do not suffer from fire damage as compared to Zomba government woodland. Woodlands away from villages are pretty much the same as woodlands in Zomba in terms of fire damage risk, but one area in Dedza was singled out to have a higher fire damage risk because it had a thick grass cover. The site selection criteria in Dedza were similar to those used in Zomba although the sites were closer to villages and to the College of Forestry where the research team was based, except for one site that was classified as a fire risk area. Five sites were used for the study in Dedza.

3.2 Arthropod surveys

A sample of ten branches on thirty trees was used to study arthropods associated with *U. kirkiana* on each site for both Dedza and Zomba. Both the sample trees and the branches were selected at random in a transect on the sampling site. To avoid unnecessary loss of arthropods due to branch shaking when inspecting the branches, sampling was limited to branches within easy reach from the ground. The ten branches were inspected for presence of arthropods. Activities of the arthropods were also recorded at the time of collection. Non-sessile arthropods were dislodged onto a beating tray by beating the branch and counting them. Flying arthropods were captured using a sweepnet. The arthropods which could not readily be sorted, were all collected and kept for sorting in the laboratory. The more agile arthropods were quickly counted before they jumped off the plant. The sessile arthropods were counted on the branch. Representatives of each of the counted arthropods were killed and preserved for identification. The arthropods were killed by ethyl acetate and freezing. All the arthropods except for Lepidoptera adults and any other arthropods that could lose their colour, were kept in a 70 % ethyl alcohol preservative. Adult Lepidoptera and all the arthropods that could not be preserved in alcohol, were preserved dry. Representative plant parts (shoots, leaves, fruits and branches) with signs of endogenous arthropods were collected and placed in the insect emergence cages. Some of this plant material was dissected to remove arthropods for counting and identification. Immature arthropod stages were kept in rearing cages, so that they could develop into the adult stage for identification. However, many specimens perished before developing into adulthood.

In Zomba arthropod sampling was done in October 1996 and August 1997; and in Dedza in addition to these two months, samples were also taken in January 1997 and June 1997 providing data to compare arthropods across seasons of the year. In both places sampling was done during day time from 8:00 hrs in the morning to 17:00 hrs in the afternoon. The various arthropods collected were subsequently identified into species and morphospecies by Dr. H Geertsema and myself, by comparing them with museum material in the FRIM (Forest Research Institute of Malawi) and the University of Stellenbosch insect collection, and using identification keys where available. The specimens which could not be identified were sent to specialists of the Plant Protection Research Institute (National Collection of Insects, Pretoria) in South Africa or to the International Institute of Entomology in the United Kingdom. The identification results have not been received yet. The juvenile stages which could not be reared to the adult stage were identified up to orders and families.

3.3 Fruit damage, defoliation and dead branches

Arthropod-damaged fruits, leaves and branches were assessed in Dedza in all the five study sites in October 1996. Further fruit damage assessment was also conducted during August 1997. Arthropod damaged branches also included fire damage, human inflicted damage, and senescence. Where possible, photographs of damaged plant parts were taken. The sampling procedures were similar to the procedures for arthropod surveys, except for fruit damage, where sampling was restricted to female trees with a relatively large fruit load. Fruit damage assessment was not destructive. All the fruits on the ten assessment branches were counted and the number of dead fruits with insect holes and insect damaged fruits were noted. Fruit damage was expressed as a percentage of arthropod damaged fruits divided by the total fruit load for that particular branch multiplied by one hundred. The mean of the ten branches was determined and used as the percentage fruit damage for a tree. A total of thirty trees per site were assessed in this manner.

Leaf defoliation was defined as the area of the leaf removed by chewing arthropods. Ten leaves were removed at random from each of the ten branches used for arthropod sampling. Total leaf area and leaf area removed by chewing was estimated by use of a transparent with grids (a modification of the method used by Southwood *et al.* (1982b)). Leaf defoliation was expressed as a percentage of the leaf area removed divided by the total leaf area. The average of the ten leaves and the ten branches was used as the defoliation percentage score for the tree. Thirty trees were sampled per site.

Dead branches were visually assessed by three observers who conformed to give a mean percentage score. This approach was used because it was difficult to distinguish dead branches from senescence and human, fire or arthropod-caused death. Some trees, especially older ones, had a high canopy where assessors could not establish cause of death. In most cases they used their discretion to arrive at a dead branch score. The score was an estimation of dead branches per tree.

3.4 Nutritional status of foliage

Leaf samples consisting of young, tender leaves were collected in all the sampling sites in Dedza (except the fire prone area) for a crude Kjeldahl nitrogen analysis. The nitrogen analysis was done at the Infruitec food laboratory in Stellenbosch.

3.5 Data handling and processing

Arthropod numbers were allotted into contingency tables which were then analysed by correspondence analysis to establish the association between arthropods and tree growing conditions and arthropod seasonal distribution (Greenacre, 1984). Sørensen coefficient of similarity (Southwood, 1978), using arthropod numbers was calculated. The following formula was used:

$C_N = 2jN/(aN + bN)$; where C_N is the coefficient in question, aN = the total individuals sampled in habitat a, bN = the total individuals sampled in habitat b and jN = the sum of the lesser values for the species common to both habitats.

The arthropods were also divided into guilds (Southwood, Moran & Kennedy, 1982a) which were similarly subjected to correspondence analysis. The field observations were used to classify the arthropods as pests or as beneficial insects and into guilds. The arthropods collected in this study were combined with those arthropods documented in the literature to produce a checklist of arthropods associated with *U. kirkiana*. Notes on arthropods associated with the trees and their role on crops, where information was available, has also been added to this checklist. Graphs were drawn to show the guild distribution of arthropods across sites and seasons.

Damage (defoliation, dead fruits due to fruit borers and dead branches) data was summarized and the percentage damage was transformed into arc-sine (to normalise the data) and subjected to analyses of variance (anova).

The means were separated by Student-Newman-Keuls (SNK) procedures (Ott, 1988). Graphs were drawn to show the distribution trends of damage.

CHAPTER FOUR

4 RESULTS

4.1 Arthropod diversity, abundance and spatial distribution for Dedza and Zomba, sampling done in October 1996 and August 1997

In this study, a total of 10348 arthropods was collected. They were classified into10 orders, 40 families and 51 morphospecies. 50 species belonged to the phylum Insecta and one species to the phylum Arachnida (Table 6). The exact number of species collected was not established as sorting was based on morphospecies determinations. The actual number is expected to be much higher than 51 species, but these results will only become available after detailed identification is completed. Most of the juvenile stages collected and reared towards adulthood died in the insectary due to limited understanding of their growth requirements. The dead juvenile specimen were allocated into families represented by the adult stages. Of the 51 insect species, 43 were collected in Dedza, 35 in Zomba, 24 were restricted to one locality and 27 were found in both localities (Table 6). Arthropod material collected during this study will be deposited in the collection of the Forest Insect Collection at Zomba, Malawi.

Table 6. Arthropod species collected in October 1996 and August 1996 in Dedza and Zomba. Guild and status allocation is based on arthropod activity at the time of collection. Numbers are given in Appendix 1.

Order	Family	Morphospecies	Zomba	Dedza	Status	Guild
Aranaea	Undetermined	Spider	*	*	5	Natural enemy
Isoptera	Termitidae	*Nasutitermes usambarensis* Sjöst.		*	7	Feeding on dead wood
Blattodea	Blattidae	Undetermined		*	7	Resting
Orthoptera	Gryllidae	Undetermined	*		1	Resting under bark
Orthoptera	Tettigoniidae	Undetermined	*	*	1	Leafchewer
Orthoptera	Eumastacidae	*Clerithes* sp.	*	*	1	Leafchewer
Orthoptera	Pyrgomorphidae	*Phymateus viridipes* Stål.	*	*	2	Leafchewer
Orthoptera	Pyrgomorphidae	*Zonocerus elegans* Thunb.	*		1	Leaf grazer
Orthoptera	Acrididae	Tree locust	*	*	2	Leaf and bark chewer
Mantodea	Mantidea	Undetermined	*	*	5	Natural enemy
Heteroptera	Pyrrhocoridae	*Dysdercus nigrofasciatus* Stål.	*		1	Fruitfeeder
Heteroptera	Coreidae	*Anoplocnemis curvipes* (F.)		*	2	Sapsucker
Heteroptera	Coreidae	*Leptoglossus membraceus*	*	*	3	Sapsucker
Heteroptera	Pentatomidae	*Agonoscelis versicolor* (F.)	*	*	4	Resting
Heteroptera	Pentatomidae	*Atelocera* sp.	*	*	7	Resting
Heteroptera	Pentatomidae	*Nezara robusta* Dist.	*	*	7	Resting
Heteroptera	Scutelleridae	Undetermined		*	7	Resting
Homoptera	Cicadidae	Undetermined		*	1	Resting on stem
Homoptera	Cicadellidae	*Hilda* sp.	*		1	Sapsucker
Homoptera	Cicadellidae	Khaki leafhoppers		*	1	Sapsucker
Homoptera	Coccidae	Large green scales	*		1	Sapsucker
Homoptera	Coccidae	Mealy bugs		*	1	Sapsucker
Homoptera	Coccidae	Small green scales	*		1	Sapsucker
Homoptera	Coccidae	Small white scales	*	*	3	Sapsucker
Neuroptera	Hemerobiidae	Undetermined	*	*	5	Natural enemy
Coleoptera	Scarabaeidae	*Diplognatha gagates* (Forst.)		*	1	Fruitfeeder
Coleoptera	Coccinellidae	*Epilachna* sp.		*	1	Leafchewer
Coleoptera	Coccinellidae	*Cheilomenes* sp.		*	5	Natural enemy
Coleoptera	Coccinellidae	*Scymnus* sp.	*	*	6	Feeding on white scales
Coleoptera	Nitidulidae	*Carpophilus* sp.	*	*	4	Feeding on rotting fruit
Coleoptera	Tenebrionidae	*Catamerus rugosus* Gah.	*	*	7	Feeding on saprophytic fungi
Coleoptera	Buprestidae	*Sternocera variabilis* Klug		*	7	Resting
Diptera	Cecidomyidae	*Dasineura* sp.	*	*	1	Deformer
Diptera	Tachinidae	Undetermined	*	*	5	Natural enemy
Diptera	Syrphidae	Undetermined	*	*	5	Natural enemy
Diptera	Tephritidae	*Ceratitis* sp.	*	*	2	Fruitfeeder
Diptera	Drosophilidae	*Drosophila* sp.	*	*	1	Fruitfeeder
Lepidoptera	Psychidae	Undetermined species 1	*	*	1	Leafchewer
Lepidoptera	Psychidae	Undetermined species 2		*	1	Leafchewer
Lepidoptera	Gelechiidae	Undetermined	*	*	3	Feeding on shoot

Lepidoptera	Phycitidae	Undetermined	*	*	3	Fruit and seed feeder
Lepidoptera	Lasiocampidae	Undetermined		*	3	Leafchewer
Lepidoptera	Saturniidae	*Bunaea alcinoe* Stoll.	*	*	3	Leafchewer
Lepidoptera	Lycaenidae	*Deudorix magda* Gifford	*	*	2	Fruit and seed feeder
Lepidoptera	Geometridae	Looper	*	*	1	Leafchewer
Hymenoptera	Ichneumonidae	Undetermined		*	5	Natural enemy
Hymenoptera	Vespidae	Undetermined	*	*	5	Natural enemy
Hymenoptera	Formicidae	*Crematogaster tricolor* Gerst.	*		1	Tending scales and leafhoppers
Hymenoptera	Anthophoridae	*Xylocopa adustus* Fhs.	*		7	Resting
Hymenoptera	Undetermined	Undetermined		*	5	Natural enemy
Hymenoptera	Trichogrammatidae	Undetermined		*	6	Lepidoptera egg parasitoid

Legend: * indicates presence; 1 = causing scattered and insignificant damage; 2 = causing noticeable damage; 3 = causing serious damage; 4 = large population numbers, potential damage to other crops; 5 = natural enemy with very low population; 6 = natural enemy with high population and 7 = insignificant: occasional visitors.

Distribution of individual arthropods and arthropod species is presented in Table 7. Of the 35 insect species collected in Zomba, 41 % (seven leafchewers and nine sapsuckers) were foliage feeders, 13 % (five) fruitfeeders, 18 % (seven) natural enemies; and the remaining 28 % comprised of shootborers, tourists, saprophytic feeders and parasitic plant feeders. The order Heteroptera had the larger diversity of species, 31 %, followed by Lepidoptera (15 %) and Orthoptera (15 %). The 44 insect species recorded in Dedza consisted of foliage feeders (34 %), natural enemies (23 %), fruitfeeders (16 %), and other insect guilds such as shootborers, saprophytic feeders, parasitic plant feeders and wood-chewing insects (27 %). The majority of foliage feeding insects belonged to the orders Heteroptera (six species), Orthoptera (four species) and Lepidoptera (four species).

Table 7. Number of arthropod morphospecies collected in Zomba and Dedza in October 1996 and August 1997 arranged by guilds.

Guild	1Z	2Z	3Z	4Z	1D	2D	3D	4D	5D
Leafchewers	6 (223)*	3 (86)	3 (19)	4 (144)	3 (121)	7 (93)	6 (63)	3 (210)	2 (50)
Fruitfeeders	0	5 (196)	5 (180)	5 (162)	5 (234)	5 (207)	7 (204)	4 (237)	3 (99)
Natural enemies	5 (44)	6 (63)	3 (28)	5 (27)	8 (178)	6 (185)	8 (143)	6 (82)	3 (21)
Others	4 (525)	6 (827)	4 (644)	3 (293)	4 (512)	5 (428)	3 (200)	5 (638)	4 (92)
Stem/shootborers	1 (36)	2 (25)	1 (45)	3 (42)	2 (17)	4 (11)	6 (35)	1 (32)	2 (11)
Suckers	5 (777)	5 (416)	2 (446)	8 (138)	3 (505)	6 (235)	3 (59)	3 (52)	1 (9)
Total	21(1605)	27(1613)	18(1362)	28 (806)	25 (1567)	33 (1159)	33(704)	22(1251)	15 (281)

Legend: *The number in brackets indicates total individuals. D = Dedza; Z =Zomba; 1 = woodland dominated by small *Uapaca* trees; 2 = woodland dominated by large or old *Uapaca* trees; 3 = mixed woodland; 4 = individual *Uapaca* trees on farmland and 5 = fire prone woodland.

The total number of arthropods collected in Dedza and Zomba, separated into habitats and guilds respectively, are depicted graphically in Figs. 3 and 4. *Uapaca* woodland with small trees in Dedza and Zomba had the highest number of arthropods: 1605 and 1567 respectively, while the lowest number of arthropods was recorded in the fire prone area in Dedza (281) and on farms in Zomba (806). The highest number of individuals across guilds was recorded under the guild 'others', both in Dedza and Zomba. In Zomba the greatest contribution to this guild was from attendant ants in a habitat dominated by large *Uapaca* trees and mixed tree habitat (Appendix 1), while in Dedza the greatest contribution was by *Agonoscelis versicolor* (Heteroptera: Pentatomidae) in a mixed tree habitat. The guilds with the smallest numbers of arthropods were 'natural enemies' (162) in Zomba and leafchewers (487) in Dedza.

Of the 16 foliage feeding insects in Zomba, only two species were observed to cause noticeable damage to the foliage. These species are *Bunaea alcinoe* (Lepidoptera: Saturniidae)(see Plate 5) and *Leptoglossus membraceus* (Heteroptera: Coreidae). Larvae of *B. alcinoe* completely defoliated trees and adults and nymphs of *L. membraceus* caused branches to wilt. Five groups of *B. alcinoe* dead larvae (Plate 6) ranging from 15 to 32 individuals with natural enemy exit holes were recovered in woodland with mixed trees in Zomba. Sapsuckers in both Dedza and Zomba were dominated by scales and in Zomba leafhoppers also occurred in large numbers. Unlike in Zomba where the green scales and the big leafhopper population did not have any effect on trees, the population of white scales had a significant effect on tree in terms of leaf and shoot deformation.

In Dedza phycitid larvae were recovered from 90 % of the insect-damaged fruits while *Drosophila* sp. and *Carpophilus* sp. beetles were present in almost all the rotting fruits. In Zomba the occurrence of phycitid larvae was lower, but that of *Drosophila* sp. and *Carpophilus* sp. about the same as in Dedza.

Ten species of natural enemies, consisting of nine insects and one spider, were collected in Dedza. Of these coccinellid beetles were the most common. Small black Trichogrammatidae egg parasitoids were recovered from ten unidentified Lepidoptera egg clusters collected in Dedza. All the eggs were parasitised. In Zomba there were fewer natural enemies collected, but the higher incidence of parasitised *B. alcinoe* larvae indicates that some natural enemies may also occur in large numbers in Zomba.

Of the insects grouped under other insect guilds, *Agonoscelis versicolor* (Heteroptera: Pentatomidae) was most common and abundant and was observed resting among foliage and fruit in Dedza. In different *Uapaca* growing habitats, more insects species were encountered under exclusive woodland dominated by large *Uapaca* trees and mixed woodland, while the lowest number of species was recorded under fire prone woodland. Gall-forming insects were quite common on seedlings and saplings in Dedza. Plate 8 shows a seedling heavily infested by such a gall-forming Homoptera. In Zomba, the greatest contribution under the guild 'others' was from attendant ants.

Plate 5. Last instar larvae of *B. alcinoe* caterpillar feeding on *Uapaca* leaves in Zomba.

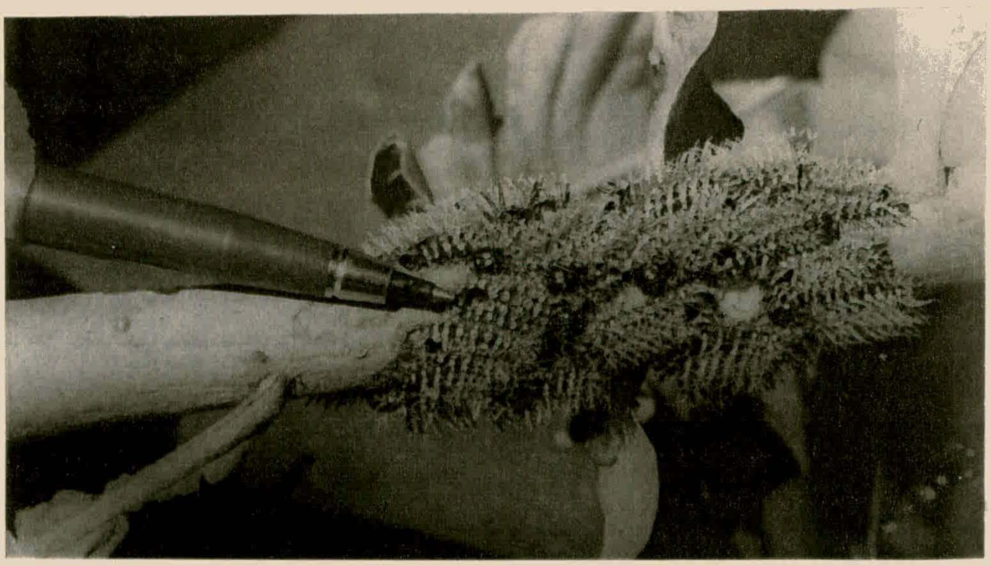

Plate 6. Mummified *B. alcinoe* caterpillars on a small *Uapaca* tree branch in Zomba. The pen is pointing at a parasitoid exit hole.

Plate 7. Large green scales with shelter-building attendant ants in Zomba. The attendant ants were also found in association with leafhoppers.

Plate 8. Leaves of a sapling with leaf galls marked by yellow spots, Dedza. The galls were underneath the leaf, almost all the galls had an exit hole with a homopteran cast skin.

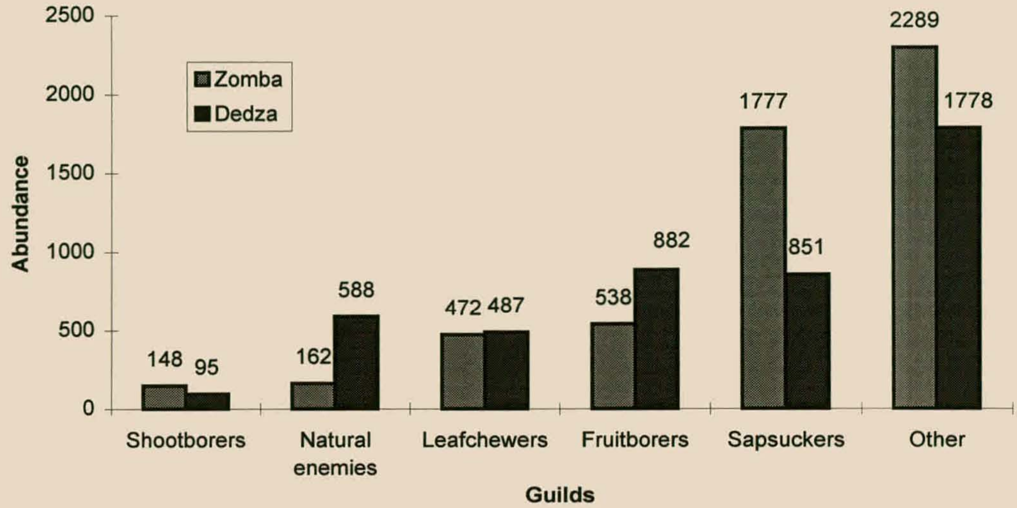

Fig 3. Guild composition of the arthropods collected in Zomba and Dedza during October 1996 and August 1997 excluding the arthropods collected in a fire prone area in Dedza.

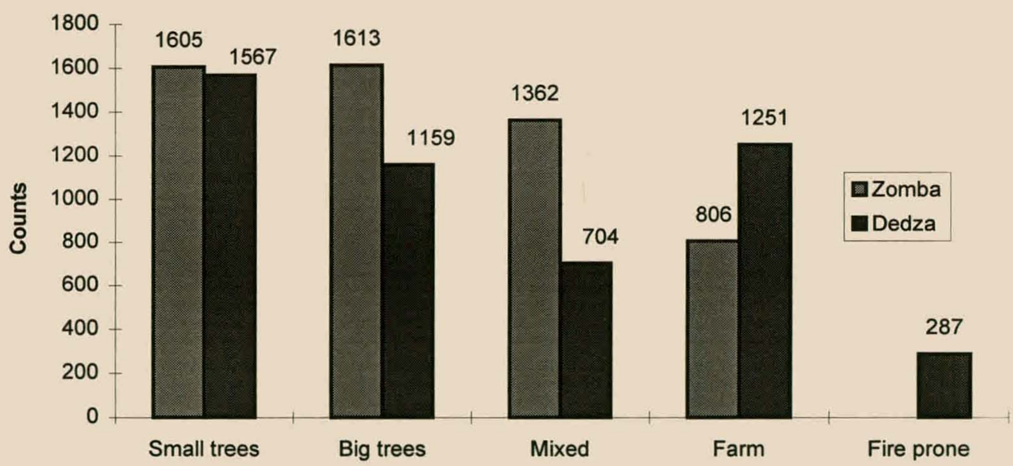

Fig 4. Total arthropod distribution across woodlands in Dedza and Zomba. Legend: small trees = woodland dominated by small or young *Uapaca* trees; big trees = woodland dominated by large *Uapaca* trees; mixed = woodland with *Uapaca* comprising of less than 50 % of the tree population; farm = individual trees growing on farm land and fire prone = fire prone *Uapaca* woodland.

The total number of arthropod species per order, collected in Dedza and Zomba during October 1996 and August 1997, are shown in Fig. 5. Except for Coleoptera species, there was general agreement in numbers of species between these two localities.

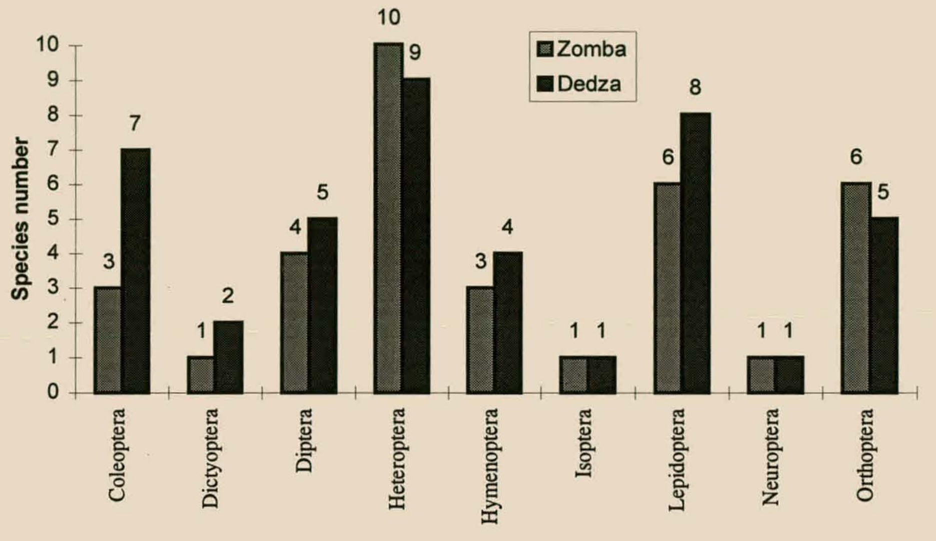

Fig. 5. Total number of arthropod morphospecies per order collected in Dedza and Zomba in October 1996 and August 1997

4.1.2 Correspondence analysis of arthropod abundance

Using the data from Appendix 1, a correspondence analysis (Fig. 6) to establish the association between species and the two locations, Zomba and Dedza, was conducted. Most of the arthropods occurred in large numbers in all the sites in Dedza and only on farm land in Zomba.

A correspondence analysis of distribution of guilds in Dedza and Zomba, based on contingency Table 7, was performed and is shown in Fig. 7. From this figure it can be seen that *Uapaca* trees on farmland in both Dedza and Zomba are associated with stemborers and leafchewers. In Dedza, woodland dominated by large *Uapaca* trees, mixed woodlands and fire prone areas are associated with fruit chewers and natural enemies. While in Zomba; mixed woodland, woodland dominated by large *Uapaca* trees and individual *Uapaca* trees on farm land (in Dedza as well) are associated with the guilds 'others' and suckers.

Various authors have used similarity indices for comparing habitats (Southwood, 1978; Moran & Southwood, 1982; Southwood *et al.*, 1982b). As this approach yields useful information, Table 8 was constructed. Of all the *Uapaca* growing environments studied, woodland dominated by large *Uapaca* trees and mixed woodland in Zomba; and then woodland dominated by small *Uapaca* trees and woodland dominated by large *Uapaca* trees in Dedza are strongly similar in terms of arthropod species composition. The rest of the woodlands joined by the positive sign (Table 8) are weakly similar.

Table 8. Similarity indices for the nine sites in Zomba and Dedza. Data used is from Appendix 1: arthropods collected in Dedza and Zomba.

	1Z	2Z	3Z	4Z	1D	2D	3D	4D	5D
1Z		+	+						
2Z	0.563		*						
3Z	0.564	0.796							
4Z	0.145	0.309	0.157			+	+	+	
1D	0.311	0.208	0.176	0.400		*		+	
2D	0.150	0.299	0.253	0.562	0.635		+	+	
3D	0.105	0.314	0.265	0.529	0.462	0.576		+	
4D	0.099	0.245	0.234	0.555	0.564	0.550	0.573		
5D	0.102	0.226	0.227	0.397	0.241	0.294	0.486	0.296	

Legend: + = habitats with similarity indices between 0.5 and 0.6, * = habitats with indices above 0.61. The first row and column represent locations of sampling sites; D = Dedza, Z =Zomba; 1 = Woodland dominated by small *Uapaca* trees; 2 = Woodland dominated by old or large *Uapaca* trees; 3 = Mixed woodland; 4 = Individual *Uapaca* trees on farmland and 5 = Fire prone woodland.

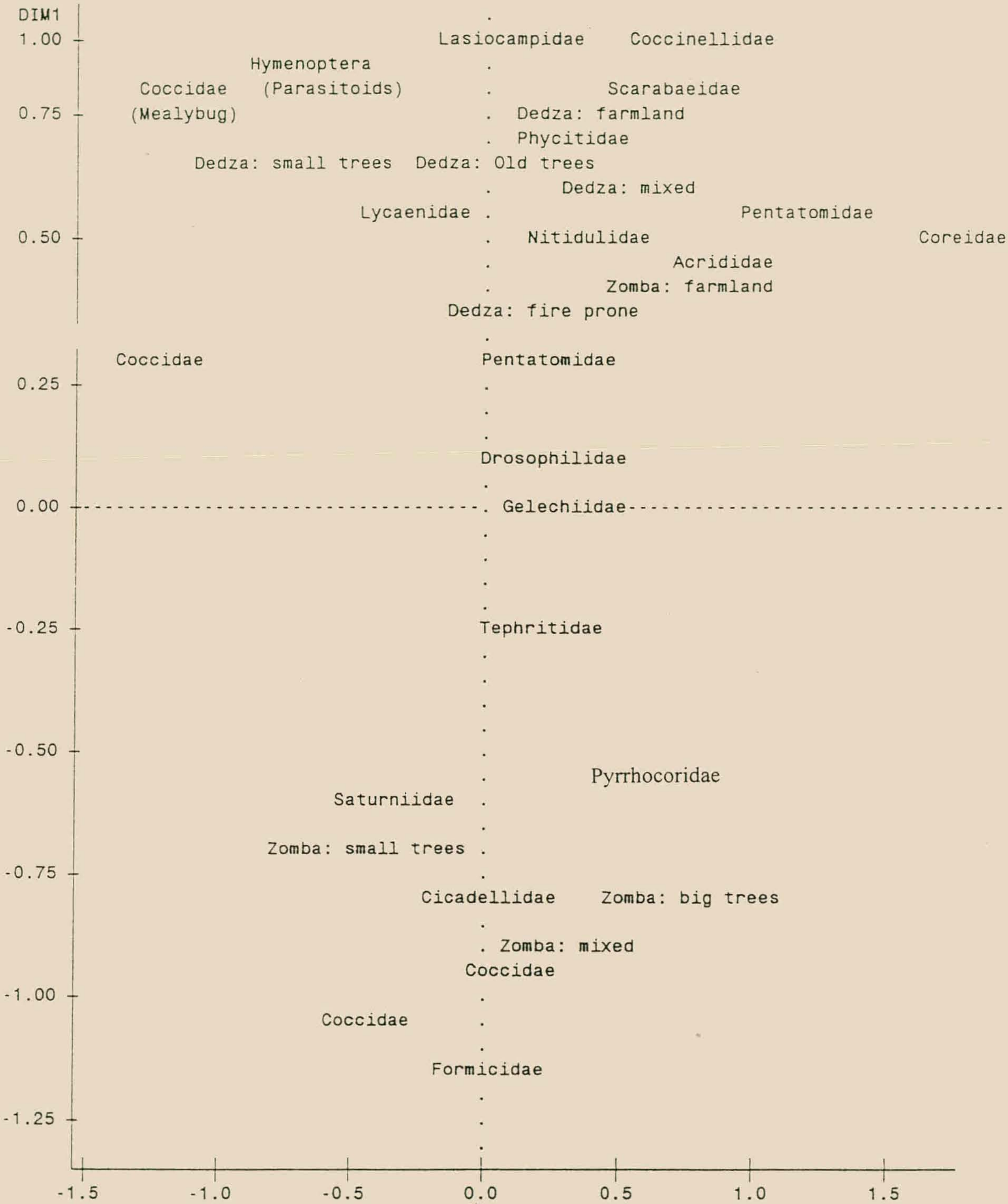

Fig. 6. Correspondence analysis of arthropods collected in Zomba and Dedza in October 1996 and August 1997. Data used is from Appendix 1, total individuals per species, and only families that are pests, natural enemies or occur in large numbers are shown.

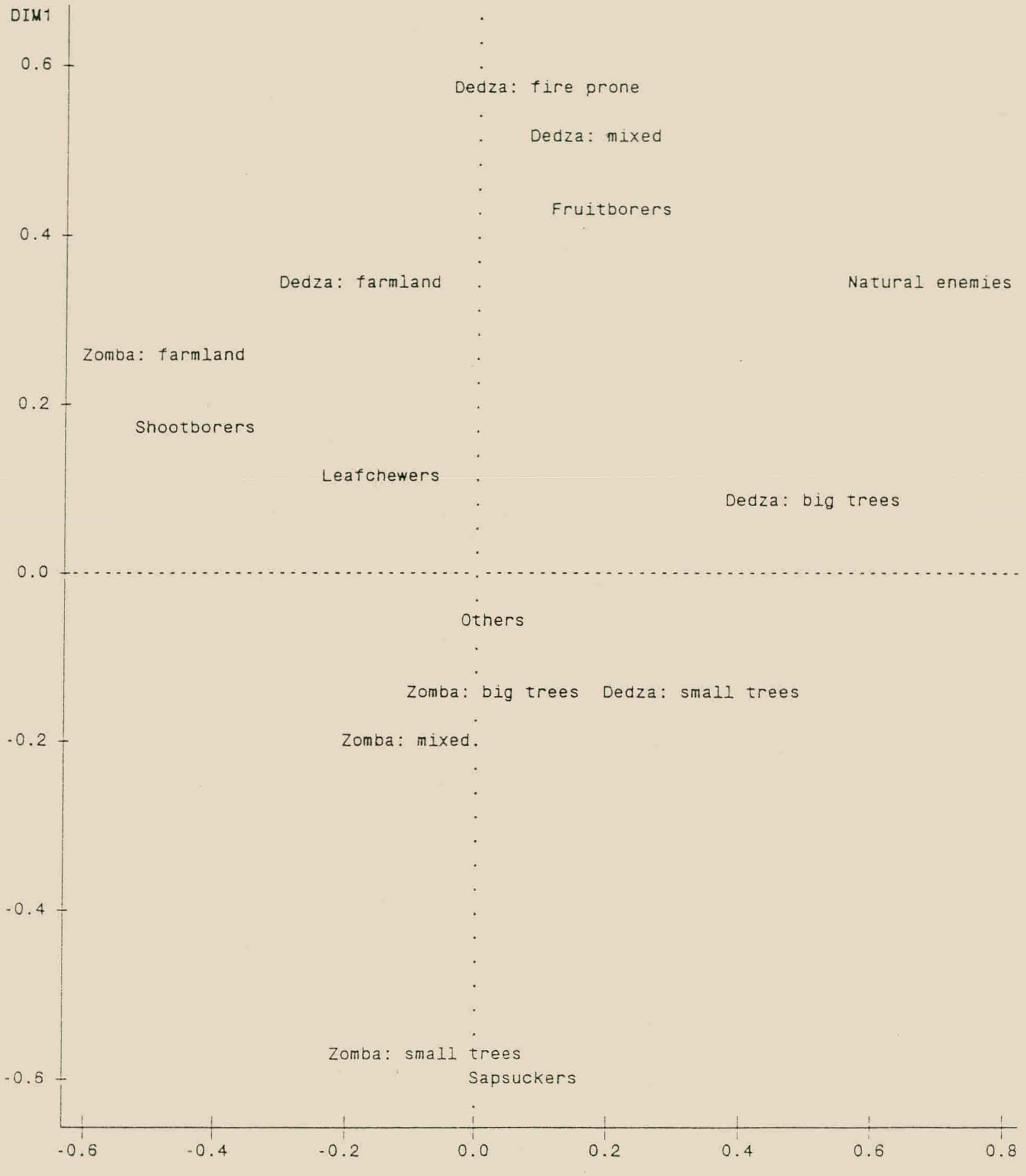

Fig. 7. Correspondence analysis of data in Table 7 showing guild distribution across different *Uapaca* habitats in Zomba and Dedza.

4.2 Seasonal abundance of arthropods in Dedza from data collected in October 1996, January 1997, June 1997 and August 1997

A total of 7463 arthropods was collected for the arthropod seasonality studies in Dedza. The October and August collections were also used in the abundance studies between Dedza and Zomba. The seasonal and site distribution of arthropod guilds numbers in Dedza are given in Table 9 and in Fig. 8. The seasons are represented by months when collection was done. January represents the wet hot season, June the cold season. August represents the end of the cold season and the beginning of the dry hot season, and October the hot dry season. The highest arthropod numbers were collected in October and the lowest in January. The arthropod guild 'others' represented the highest number of arthropods in October. Weather data is summarized and graphically presented in appendix 5.

Table 9. The number of individual arthropods, arranged by guilds, recorded in the five sites in Dedza for the four months data was collected. The other part of the table gives the number of individual arthropods recorded each of the four months

Guild	1	2	3	4	5	Guild	Oct-96	Jan-97	Jun-96	Aug-97	Total
Fruit borers	373	317	339	339	161	Fruit borers	526	100	443	460	1529
Leafchewers	139	125	93	284	71	Leafchewers	340	62	113	197	712
Natural enemies	351	303	221	197	57	Natural enemies	299	282	243	305	1129
Others	645	593	301	757	134	Others	1580	307	253	290	2430
Stem borers	31	23	73	47	17	Stem borers	64	63	23	41	191
Suckers	806	458	89	100	19	Suckers	676	408	204	184	1472
Total	2345	1819	1116	1724	459	Total	3485	1222	1279	1477	7463

Legend: * *Uapaca* growing habitat. 1 = woodland dominated by small *Uapaca* trees; 2 = woodland dominated by old or large *Uapaca* trees; 3 = mixed woodland; 4 = individual *Uapaca* trees on farmland and 5 = fire prone woodland.

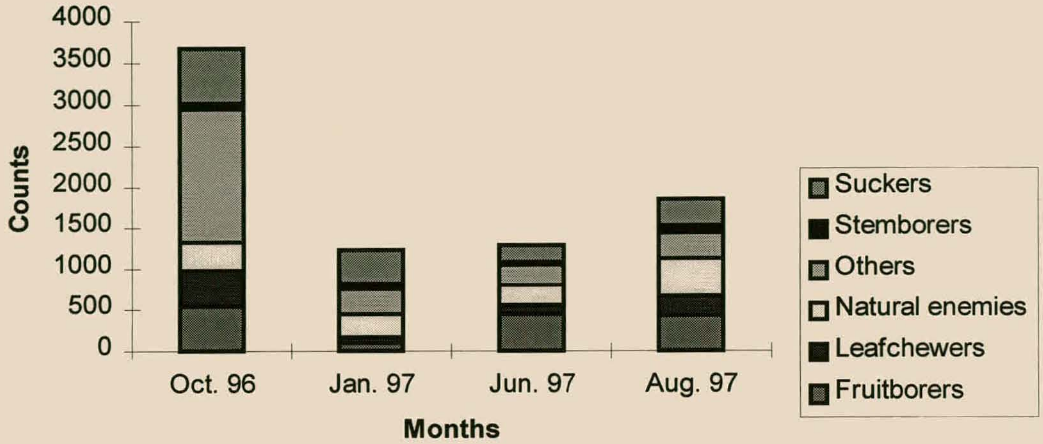

Fig. 8. Seasonal variation of arthropods collected in Dedza arranged in guilds. Seasons are represented by the four months when samples were collected.

All guilds were lowest in number in January, except for stemborers and natural enemies which were fairly consistent throughout the four sampling seasons. The overall graphical pattern of the total arthropods across sites has a similar trend as the data set for abundance comparison between Dedza and Zomba (Fig.7).

Correspondence analysis of arthropod seasonal distribution using data in Table 9 is presented in Figure 9. From the figure, the months of June and August are associated with fruit borers and natural enemies, January is associated with stem borers and suckers, while October is associated with leafchewers and the guild 'other' arthropod guilds.

Correspondence analysis of the guild distribution for the five sites used for seasonal arthropod abundance (Fig. 10) shows that farmland *Uapaca* trees are associated with leafchewers and 'other' arthropod guilds, while *Uapaca* trees in fire prone areas and in mixed woodland are associated with fruit borers and stem borers. Trees in woodlands dominated by large *Uapaca* trees are associated with sapsuckers, while small trees are associated with natural enemies and sapsuckers.

4.3 Fruit and foliage damage

4.3.1 Fruit damage

The distribution of fruit borer damage for October 1996 and June 1997 is shown in Fig. 11. Fruit damage was significantly different (α = 0.05, p > 0.001) across the five sampling sites and between the two years. The highest damage in 1996 was under large trees while in 1997 the highest fruit damage was on trees growing on farmland. The lowest fruit damage was observed on trees growing in mixed-wood habitat.

4.3.2 Defoliation and branch damage

Insect defoliation and dead branch (expressed as a percentage) distribution on the five *Uapaca* sampling sites are depicted in Fig. 12. Both defoliation and dead branches were significantly (α = 0.05, p > 0.001) different across the five sampling sites. The highest defoliation damage was observed on small trees and the lowest defoliation was observed on trees growing in a fire prone area. Arthropod leaf grazing consisted of chewing the lamina together with smaller veins, skeletonising and leaf mining. In Dedza more serious observable damage was caused by white scales (white scale damage was visually assessed without assigning any cardinal scale) on trees growing in a habitat dominated by small trees, and by lasiocampid larvae on trees growing in gardens. Other defoliation damage on trees growing in gardens (Plate 9) could not be associated with the insects collected as they were not present at the time of collection. From the appearance of the defoliation damage the insects responsible could well be either grasshoppers or leaf feeding beetles.

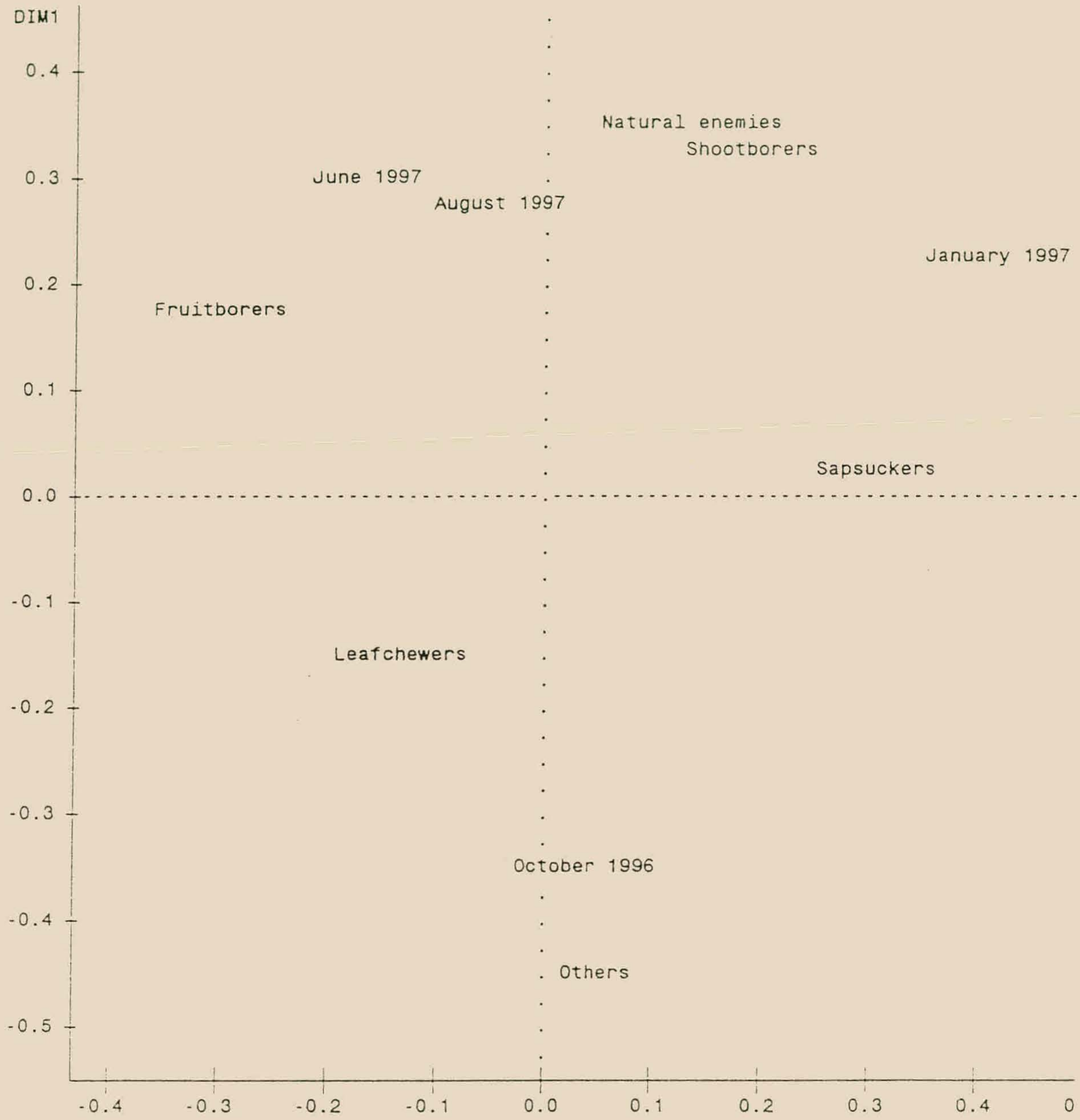

Fig. 9. Correspondence analysis of seasonal distribution of different arthropod guilds collected in Dedza. Analysis based on data from Table 9.

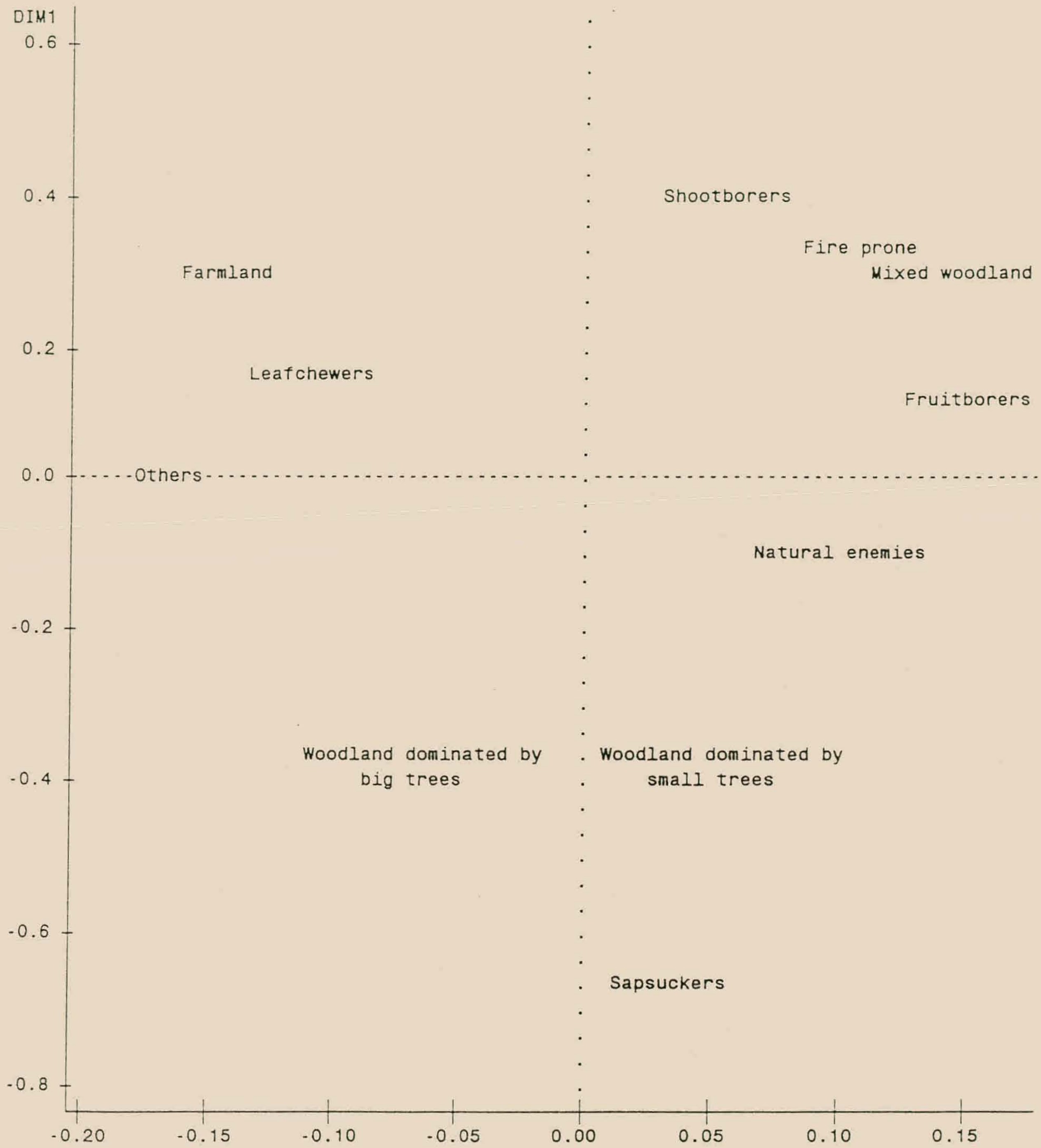

Fig. 10. Correspondence analysis of guild distribution over the five *Uapaca* growing habitats in Dedza. Data used is based on the seasonal variation studies. In this plot, the data used is from totals of four months (referred to as seasons) while in Fig. 7 the data used is from two months totals.

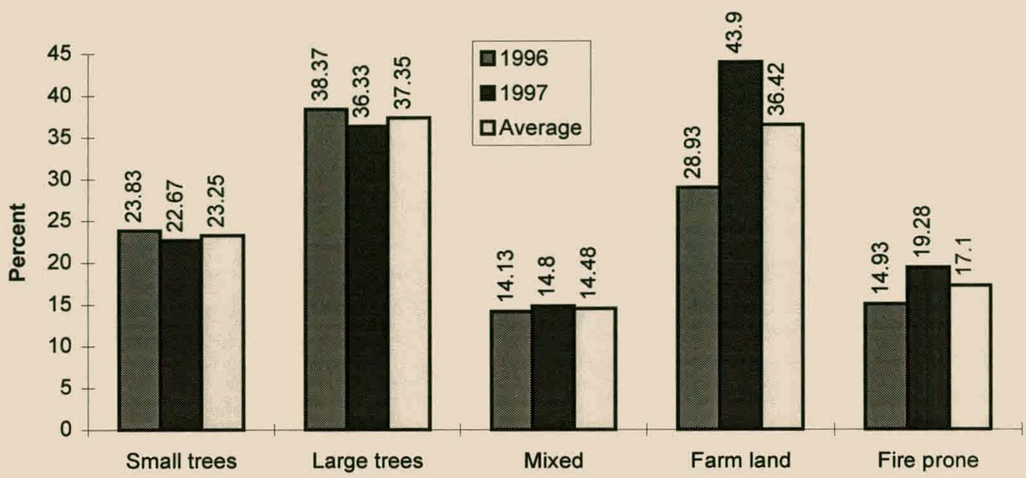

Fig. 11. Arthropod fruit damage in Dedza for October 1996 and June 1997. The vertical scale represents percent arthropod-damaged fruits. Legend: small trees = woodland dominated by small *Uapaca* trees; large trees = woodland dominated by large *Uapaca* trees; mixed = woodland with *Uapaca* comprising of less than 50 % of the tree population; farmland = individual trees growing on farm land and fire prone = fire prone *Uapaca* woodland.

The pattern of dead branch distribution across the five sampling sites was the opposite of that shown by the defoliation pattern (Figure 12). The highest number of dead branches was observed on trees growing in a fire prone area and the lowest number of dead branches was observed on small trees (See Plate 10 for fire damage). Field observations revealed that dead branches were concentrated in the bottom of the canopy. On large trees in mixed woodland and *Uapaca* dominated woodland, dead branches were more on female trees with damaged stems (Plates 3 and 4). The stems were damaged by hitting with stones and large objects to shake off ripe fruits. Collectors who were interviewed during the survey indicated that the trees with the highest damage were also the heavier fruit producers.

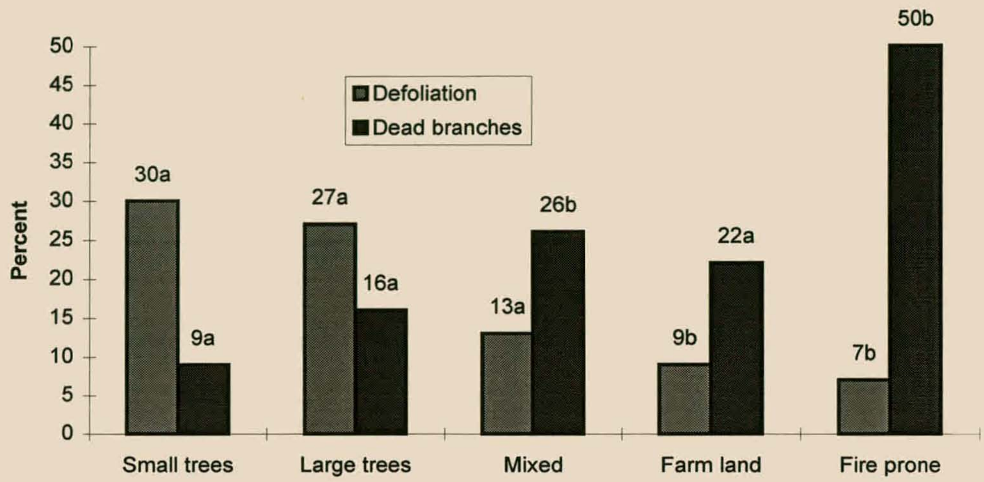

Fig. 12. Percent leaf defoliation and dead branches in Dedza assessed in August 1997. Legend as for figure 11. Figures with the same letter are not significantly different (α=0.05).

Plate 9. A heavily insect-defoliated *Uapaca* tree in a maize and bean field in Dedza. Most of the individual trees on farm land in Dedza showed this pattern of leaf damage. The damage is higher on old leaves than on young leaves.

Plate 10. A fire damaged *Uapaca* woodland in Zomba. This particular woodland was dominated by young *Uapaca* trees.

4.3.3 Other damages

Although not part of this study, it was observed that there were many parasitic plants growing on large *Uapaca* trees both in Dedza and Zomba (Plates 11 and 12). In some cases the parasitic plants had a reducing effect on fruit production, but this trend was not uniform, other parasitic-plant infested branches had more fruits than non-infested branches.

Some trees were observed dying from an unknown pathological condition. A pathologist suspected a fungal infection of *Armilaria* sp. Baboons were also observed to indiscriminately remove fruits from trees by use of excessive shaking to dislodge ripe fruits and also when they jumped from one branch to another.

4.4 Leaf nitrogen content

Total nitrogen content of leaves collected from the study sites in Dedza is presented in Table 10. Individual trees growing on farm land had higher nitrogen content followed by trees growing in woodland dominated by small *Uapaca* trees. The least nitrogen content was recorded from leaves of trees growing in a mixed woodland.

Table 10. Kjeldahl nitrogen analysis of tender *Uapaca* leaves from study sites in Dedza. Nitrogen is expressed as a percentage of the sample biomass. The leaf samples were collected in January 1997.

Tree growing habitat	Sample 1	Sample 2	Sample 3	Sample 4	Mean	Std. dev.
Woodland dominated by small trees	1.52	1.58	1.31	1.06	1.37	0.235
Woodland dominated by old trees	1.21	1.14	1.23	1.22	1.21	0.045
Mixed woodland	1.09	1.03	1.12	1.24	1.12	0.088
Individual trees on farmland	1.58	1.52	1.51	1.29	1.48	0.127

Plate 11. A parasitic plant infested branch. The parasitic plant is the dark dense foliage in the middle of the branch in the picture. Note the small number of fruits compared to a non-infected branch on the same plant. One of the fruits shown by a white arrow.

Plate 12. A nonparasitic plant infested branch on an *Uapaca* Fruits are shown by a white arrow.

CHAPTER FIVE

5 DISCUSSION

5.1 Checklist

Lack of full identification of the arthropods collected in this study limits comparison of arthropods collected with those reported in literature. However, a comparison of most of the arthropods collected with museum material in Malawi reveals that most of the insects have been collected and reported before. Present collection and museum specimen in Malawi make a comprehensive *Uapaca* insect collection, such that later collections will have to be identified using this collection. In this study all the orders are mostly underrepresented, compared to those given in the literature. This observation may be explained by several factors including the fact that this study did not cover every month of the year, the emphasis being on the seasonality of arthropod presence represented by a particular month per season. In this manner, many arthropods could have been missed. Sampling was limited to day time, and nocturnal arthropods were not observed or collected. The list compiled from literature covers a period ranging from 1918 to the present, while the present study covered only one year, and therefore unlikely to collect most of the arthropods reported in literature. Some of the arthropods may have moved to other habitats due to expansion of agriculture. However, most of the important pest species reported by Parker (1978) on *U. kirkiana*, have also been recovered in this study.

A literature survey of insects associated with *U. kirkiana* reveals that most of these insects are pests of agricultural crops and important forestry and horticultural trees. As *U. kirkiana* is semi-deciduous, one would therefore expect *U. kirkiana* to provide food for polyphagous crop pests during crop off-season periods. It was not within the scope nor purpose of this study to establish the role of *U. kirkiana* as an alternative or alternate host through sampling of insects on *U. kirkiana* and the surrounding plants.

Most of the arthropods collected in the study have a passive role or have little effect on *U. kirkiana*. Less than twenty percent of the arthropods pose a risk to *U. kirkiana* production as pests of concern and even so less than half of the twenty percent have been observed to form a serious threat to *U. kirkiana* fruit production. Of the various arthropods posing serious risk, fruit borers are the most damaging as they directly affect the fruit yield over a wide area, while the white scales causing leaf deformation were restricted to small portions of *Uapaca* woodland. The lower number of natural enemy species reported in the study is a disturbing finding in that there are good chances of other arthropods reaching high population levels without counter checks. These high population levels can then cause damage to *U. kirkiana* or surrounding trees or agricultural crops. In this study very high populations of *Agonoscelis versicolor* and of the large and small green scales were observed.

Table 11. Number of families recorded on *U. kirkiana* in literature and during the present survey.

Order	Literature survey	Field survey
Aranaea	0	1
Isoptera	1	1
Dictyoptera	0	2
Orthoptera	3	5
Hemiptera	6	7
Neuroptera	0	1
Coleoptera	24	5
Diptera	4	5
Lepidoptera	11	7
Hymenoptera	3	6
Total	52	40

Of the forty families collected in this study (Table 11), eighteen families are new additions to the literature list of arthropods associated with *U. kirkiana*. These families are: Blattidae, Gryllidae, Tettigoniidae, Acrididae, Mantidea, Pyrrhocoridae, Cicadidae, Hemerobiidae, Scarabaeidae, Cecidomyidae, Tachinidae, Phycitidae, Psychidae, Anthophoridae, Ichneumonidae, Formicidae, Trichogrammatidae and Vespidae. Out of these additions the most serious pest belongs to the Phycitidae, members of which attack fruit. Trichogrammatidae is another important addition to the list as they parasitised eggs of an unidentified Lepidoptera in a mixed woodland.

The total list of arthropods collected in this study together with the list compiled from literature and museums does not compare well with the list collected by other researchers on tree arthropods (Southwood *et al.*, 1982a; Moran & Southwood, 1982; Recher, Majer & Ganesh, 1996). These researchers report a longer list of species and thus a much higher arthropod diversity than observed in this study. However, Gander (1980) observed that savannah trees have lower arthropod diversity than temperate trees. In terms of the total arthropods collected in this study, it may appear that there are more arthropod individuals per species than have been recorded by Moran & Southwood (1982) and other researchers in temperate environments. It should be noted that the arthropod collection carried out for this study was not a continuous process as was the case with the other researches. In this study the arthropod collection methods used (emphasis was on observing activity of the arthropods), may have resulted in the escape of arthropods. If insecticide fogging or spraying was used, thereby ensuring larger catches, it may have enabled more conclusive comparisons of the trees studied in terms of arthropod fauna richness with data reported in the literature. The impact of deforestation, in this case opening up of indigenous woodlands for exotic tree species and farm lands, has resulted in creation of indigenous vegetation islands. Elsewhere creation of these islands is reported to contribute towards decline of arthropod numbers and diversity (Didham, 1997). The effect of deforestation on the low arthropod diversity recorded in this study can not therefore be ruled out.

Of the two study districts Dedza had more species than Zomba. This could be attributed (among many other factors) to higher rainfall and lower temperature in Dedza than Zomba. Recher *et al.* (1996) report that high rainfall and high soil nutrition status increases arthropod diversity. Moran & Southwood (1982) report that trees growing in temperate regions have generally more arthropods than savannah regions. If temperature is taken as a factor, then this scenario could hold for Dedza which is cooler than Zomba. The low arthropod diversity in Zomba *Uapaca* woodland could also be attributed to hot bush fires prevalent in Zomba. Schlettwein (1984) observed that arthropod population in a fire managed fynbos declined soon after fire, but, with the sprouting of new green grasses, populations soon increased exceeding the arthropod populations in areas where fire was not used as a management tool. This, however, gives a general picture but does not show the difference when only tree dwelling insects are considered. In this regard, tree arthropods may not increase in population as most small trees may be permanently damaged, thereby reducing food availability and arthropods that dwell in trees or lay eggs on foliage may be killed in the fire.

5.2 Arthropod richness across the nine sites used for sampling

In Zomba the lowest number of arthropod species on *U. kirkiana* was recorded on mixed woodland whereas in Dedza the highest number of arthropod species was recorded in this type of woodland. In Zomba *Uapaca* trees growing in a mixed woodland were shorter than their associates (mostly *Brachystegia* spp.) and most of them were shaded. In Dedza most *Uapaca* trees in mixed woodland were of the same height as the associated trees. Basset, Aberlenc & Delvare (1992) working in a Cameroon rain-forest observed the same trend where more arthropods occurred on exposed tree canopies than on shrubs growing underneath the big trees. Because of exposure to the sun, the exposed canopy is able to manufacture more food hence become more nutritious than the shaded canopy, thereby supporting a higher arthropod diversity.

Under farmland conditions, there were more arthropod species in Zomba than in Dedza. In Zomba farm trees were mixed with other trees and most farms used for the study were close to small woodlands unlike in Dedza where the trees were isolated. Zomba farm trees compared well with the trees growing in mixed woodland in Dedza. This finding therefore agrees with the findings of Moran, Hoffmann, Impson & Jenkins (1994) who observed that a forest vegetation with a high diversity of flora supports a large diversity of arthropods.

5.3 Arthropod numbers

Although Dedza has a high diversity of arthropod species, abundance of arthropods was higher in Zomba. The high number of individual arthropods in Zomba was contributed mainly by green scales, leafhoppers and attendant ants. The high population of green scales and leafhoppers may be due to the protection against natural enemies given by ants. The high numbers of the green scales and leafhoppers would have, in return, produced more honey dew providing more food for the ants who similarly respond by increasing their population. Schlettwein (1984) also observed a large population of leafhoppers associated with a large population of ants, and suggested protection offered to these insects by ants against natural enemies as being responsible for the higher populations. The high population of the green scales and leafhoppers did not have a noticeable effect on *U. kirkiana*. The attendant ants were not observed on isolated trees on the farmland which had very low populations of leafhoppers and green scales. In Dedza, however, the large number of white scales on small trees caused considerable leaf deformation and the badly damaged trees did not produce fruits at all. The damage was characteristic of vector-transmitted virus disease. It was interesting to note that none of the trees under farm land was affected by this white scale. Mchowa & Ngugi (1994) observed that different tree growing conditions affect tree arthropod populations by increasing or decreasing natural enemy availability or changing the general arthropod environment. This suggests that different management practices can be used to control certain pest arthropods on *U. kirkiana*. It was interesting to note that there was a high population of coccinellids on trees infested with white scales, and observations later on showed a decline of these scales. This study was not able to ascribe the decline to the high numbers of coccinellids, as weather changes could also have played a major role. Coccinellids are regarded as cosmopolitan natural enemies and not efficient in most cases when it comes to specific control of pests (Rodger Day, pers. comm.).

Both in Dedza and Zomba, larvae of an unidentified lasiocampid moth and of *B. alcinoe* (Saturniidae) moths respectively, although not in high numbers, were observed to cause more defoliation on *U. kirkiana* trees than the other defoliating arthropods combined. In Zomba four groups of over twenty *B. alcinoe* larvae were observed to completely defoliate *U. kirkiana* trees they occupied. However, these lepidopterous larvae were restricted to a few trees. The presence of several groups of mummified *B. alcinoe* larvae in Zomba is an indication that this insect is subject to natural enemy control. Lee (1971) also observed that the larvae of this caterpillar are subjected to heavy natural enemy control.

Fruit arthropods collected had lower numbers with the exception of *Drosophila* sp. and an unidentified moth of the family Phycitidae. Of the two insects, phycitid larvae were responsible for most of the fruit damage. The high numbers recorded in Dedza in particular were on woodland with mixed trees and individual trees growing on farms. Only two natural enemies were recovered from fruits, a hymenopteran and a tachinid fly. Both natural enemies occurred in low population numbers and had minor influence on fruit borers. The tachinid fly may actually be a secondary parasite. In this regard the fruit would require definite pest control measures to reduce attack by especially phycitid larvae on fruits.

5.4 Distribution of numbers across habitats

The high total arthropod numbers observed in the various habitats was generally as expected, except for *U. kirkiana* trees growing on farmland in Dedza. The high number of arthropods under small trees agree with the high nitrogen content in the leaves and also the dense population of the small trees (Ngulube, 1996). Recher *et al.* (1996) working in Australia observed that *Eucalyptus* species growing in fertile soils had more arthropod than those on infertile soils because the leaves had had a high nitrogen content. Moran *et al.* (1994) found that in Pondoland (South Africa) arthropod numbers increased with an increase of host density. The fire prone area, farmland and the mixed tree vegetation had the lowest *U. kirkiana* density, but also lower arthropod counts. Small trees on farmland, although with low arthropod counts, suffered the heaviest leaf defoliation. This may suggest that leaf chewing arthropods are favoured in this environment, although the arthropods responsible for the damage were not found. When farm land *U. kirkiana* arthropods from Dedza and Zomba are compared, Dedza has higher arthropod numbers. Although the density of farm trees in Dedza was lower than in Zomba, trees in Dedza had higher arthropod counts. The high number of arthropods were mainly contributed by fruit borers in Dedza which was not unexpected as Dedza *U. kirkiana* trees had higher fruit counts per branch than in Zomba (farmland average for Dedza was 83 fruits/10 branches and Zomba was 46 fruits/10 branches).

5.5 Arthropod guild numbers

The high number of individual arthropods in the arthropod guild 'others' reflects that most arthropods on *U. kirkiana* trees have a passive role. Moran & Southwood (1982), Southwood *et al.* (1982b) and Recher *et al.* (1996) observed small numbers of arthropods under the guild 'others'. This may be due to their sampling methods (pesticide fogging) which did not allow proper documentation of arthropod activity on the tree. In this regard they based their guild classification on activity of well known members of that particular group of arthropod. For example, *A. versicolor* in this study which is classified under 'others' because it was just resting on *U. kirkiana*, could have been classified under sapsuckers, using their system, because most members of this group are sapsuckers.

5.6 Seasonal arthropod variation

The study shows a high number of arthropods in October 1996 (hot dry season), then a low number in January 1997 (hot wet summer) and June, 1997 (winter), the number of arthropods starting to rise again in August 1997 (spring). This trend is in partial agreement with the trend reported by other researchers such as Southwood *et al.* (1982a), Schlettwein (1984) and Recher *et al.* (1996). These workers observed a high density of arthropods in summer and a low density in winter. In this study, the low arthropod counts in wet summer may be explained by the disappearance of large numbers of *A. versicolor*, white scales, fruit borers and leafchewers. The causes for the decline of white scales and *A. versicolor* are not clear but rain could have been a factor causing the reduction in their numbers. The decline in fruit borers in the wet summer could be associated with the disappearance of fruits as they mature and ripen. Phenology studies conducted by Ngulube (1996) show that January is the end of the fruit season and the beginning of the flower season (Fig. 13). The decline in numbers of leafchewers in January cannot easily be explained, but movement of arthropods to more nutritious plants with tender leaves could possibly play a major role as most of the plants are green at this time. Also synchronisation of life stages with particular seasons may also contribute to the low counts. Few lasiocampid larvae were recovered in the rainy season, indicating their low season. The general low count in winter could be associated with the cold weather. The high number of arthropods in hot dry weather could be attributed to the double role of shelter and food provided by *U. kirkiana. U. kirkiana* being a semi-deciduous tree retains its foliage when most of the surrounding trees have shed their foliage.

5.7 Fruit damage

Fruit damage observed in this study (Fig. 11) is quite high, ranging from 14 % to 44 %. By any standards the statement that *U. kirkiana* has less pest problems (Ngulube, 1996) stresses the lack of detailed studies to uncover the pest problems of *U. kirkiana* fruit trees. In this study low pest damage recorded under mixed vegetation and the fire prone area suggests that fire and plant diversity have a role in pest reduction. In mixed vegetation, the diversity of plants may promote the efficacy of natural enemies or hamper with host tree search on the part of the pest (Cromartie, 1981). In this regard, fire may be responsible for directly killing the pest, exposing the pests to nature enemies as they escape from fire or removing overwintering sites (Dent, 1991). The high incidence of pest damage under farmland and in woodland dominated by large trees may be explained by the fact that *U. kirkiana* trees are well exposed to the pests, hence easy location of fruits, as shown by high pest damage incidences. The slightly low pest damage incidence under woodland dominated by small trees may be explained by low fruit production which may have been difficult for the pests to locate.

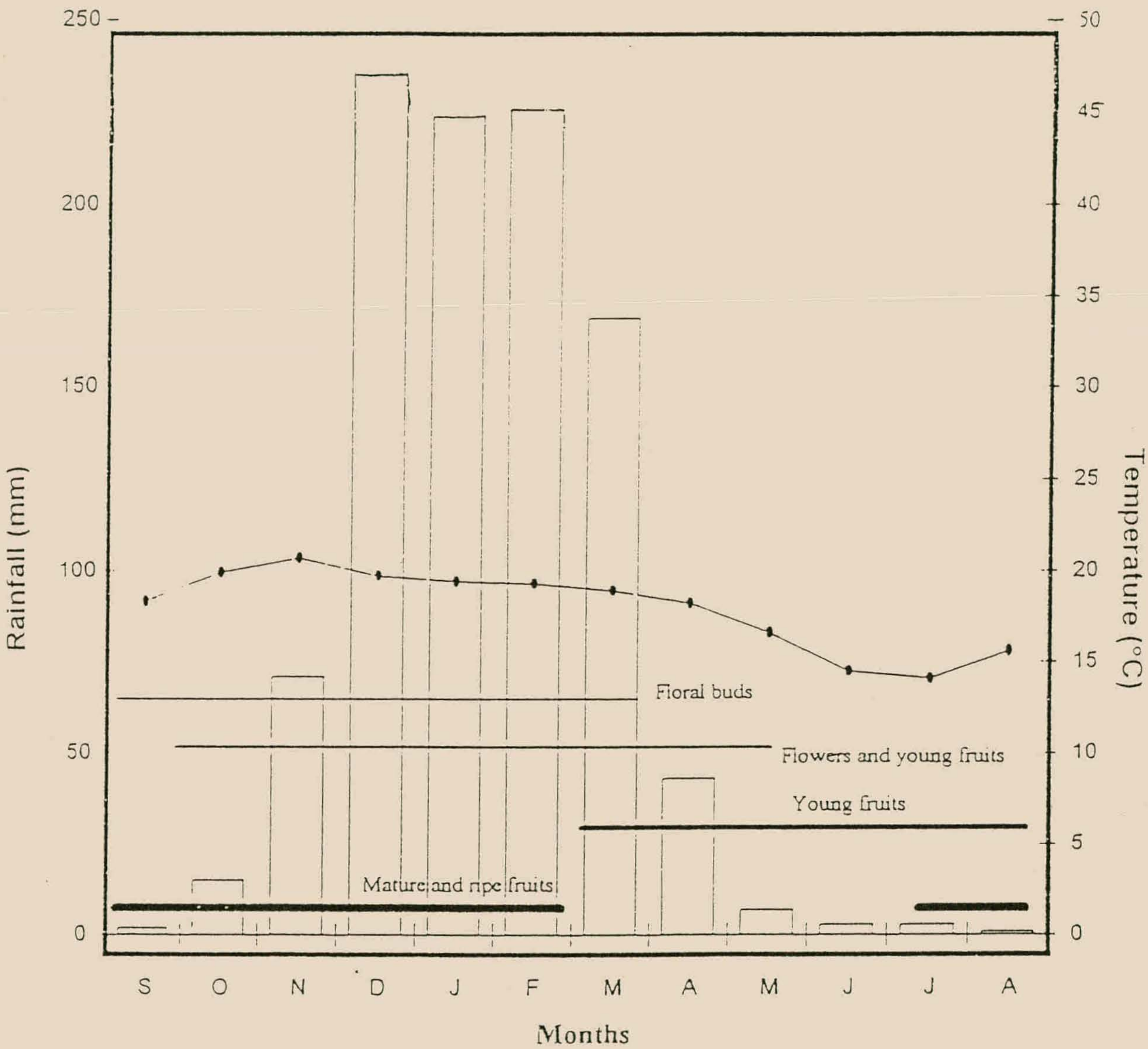

Fig. 13 Mean monthly rainfall (mm), mean temperature (^{0}C) and a summary of phenological phases of *U. kirkiana* in Chongoni Malawi. Data collected from 1994 to 1995. Source: Ngulube (1996).

Leaf defoliation has a similar pattern to fruit damage and may be explained by the same factors, such as diversity and exposure principles and the role of fire in arthropod reduction. Because of fire, numbers of dead branches are high in fire prone areas. The late fires that occur in this area kill most of the lower branches as *U. kirkiana* is known to be fire sensitive (Kikula, 1986). In mixed woodland there was a high incidence of stem damage by human activity (hitting the stem to dislodge ripe fruits). This damage resulted in the death of most of the crown of the heavily damaged trees. No effort was made to find out why there was more human damage on large trees in mixed woodland than on large trees in a woodland dominated by large *U. kirkiana* trees. However, a casual observation revealed that most trees in a mixed woodland were very tall and mostly out of reach of fruit collectors in contrast to short trees in a woodland dominated by big *U. kirkiana* trees.

CHAPTER SIX

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The following conclusions can be drawn from this study:

1. A wide variety of arthropods are associated with *U. kirkiana* as verified from the literature and from the present study. From this investigation it is clear that less than five percent of the arthropods collected are serious pests of *U. kirkiana*, and the rest are natural enemies, pests of other trees and crops and some are casual pests of *U. kirkana*. The arthropods that cause serious damage to *U. kirkiana* trees are phycitid larvae, white scales, Gelechiidae shootborers, *Bunaea alcinoe*, lasiocampid larvae and *Leptoglossus membraceus*.
2. *Uapaca* trees harboured more arthropod species in Dedza than in Zomba, but the few species present in Zomba occur in much larger numbers than in Dedza. Low temperatures and high rainfall in Dedza may play a role in the arthropod differences. In this regard if control measures are contemplated, different control measures for the two area may be employed.
3. More arthropods were observed on trees in a woodland dominated by small or young *U. kirkiana* trees followed by woodlands dominated by large *U. kirkiana* trees while the lowest numbers were reported in fire prone area and on farm land. Small trees were more nutritious than big trees, thereby attracting more arthropods. Farm land had fewer arthropods because trees did not occur in high enough densities for ease of location by associated arthropods.
4. The study established that there is a clear trend in terms of arthropod guild association with *U. kirkiana* growing habitat. Individual trees on farms and large trees in woodland dominated by large *U. kirkiana* trees in Dedza are associated with fruit borers. While small trees in woodland dominated by small *U. kirkiana* trees in Zomba are dominated

by sapsuckers, and shootborers were associated with individual trees growing on farm land in Zomba, the other habitat and guilds were not strongly associated.

5. There is more arthropod-related damage on fruit and foliage than expected, indicating that arthropods are also an important aspect in considering *U. kirkiana* tree management.
6. Most of the branch damage was related to human activity such as fire and direct hitting to collect fruits. Although arthropods played a small role in terms of branch damage, there were more shootborers in Zomba on farm land.

6.2 RECOMMENDATIONS

Based on the findings of this study the following recommendations can be made:

1. For best and high fruit productions in terms of lower pest damage, *Uapaca* trees should be managed in mixed indigenous habitats to reduced pest damage to foliage and fruits. Controlled burning can to some extent be used to reduce pest damage in *U. kirkiana* woodland management.
2. External pest intervention should be provided on farm land, if high *U. kirkiana* fruit yields without pest damage are required.
3. Trees and crops that are affected by the pests associated with the arthropods collected on *U. kirkiana* should not be mixed or grown in close association with *U. kirkiana.* Some of these crops are coffee and cotton.
4. Further arthropod surveys should be carried on *U. kirkiana* and trees or crops associated with *U. kirkiana* to establish obligate and cosmopolitan arthropods associated with *Uapaca*. This study should cover a longer period than the present one and should cover a wider geographical area.
5. A defoliation simulation study should be carried out to determine the effect of defoliation on fruit production and growth of *U. kirkiana*.

APPENDICES

Appendix 1 Total arthropod individuals collected in the abundance study in Zomba and Dedza in October 1996 and August 1997.

Order	Family	Morphospecies	1*z	2z	3z	4z	1d	2d	3d	4d	5d	Total
Aranaea	Undetermined	Undetermined	15	27	3	9	22	50	30	10	7	173
Isoptera	Termitidae	*Nasutitermes* sp.	0	0.	0	0	0	p	p	p	0	0
Blattodae	Blattidae	Undetermined	0	0	0	0	0	0	3	27	13	43
Orthoptera	Gryllidae	Undetermined	11	4	15	0	0	0	3	0	0	33
Orthoptera	Tettigonidae	Undetermined	0	21	5	0	0	21	5	0	0	52
Orthoptera	Eumastacidae	*Clerithes* sp.	19	0	0	43	5	4	0	1	0	72
Orthoptera	Pyrgomorphidae	*Phymateus viridipes*	34	2	0	0	45	27	8	0	0	116
Orthoptera	Pyrgomorphidae	*Zonocerus elegans*	9	0	0	52	0	0	0	0	0	61
Orthoptera	Acrididae	Tree locust	3	2	9	25	4	3	0	29	0	75
Mantodae	Mantidae	Undetermined	10	7	12	3	11	0	5	0	0	48
Heteroptera	Pyrrhocoridae	*Dysdercus* sp.	0	25	0	14	0	0	0	0	0	39
Heteroptera	Coreidae	*Anoplocnemis* sp.	0	0	0	0	0	37	21	0	0	58
Heteroptera	Coreidae	*Leptoglossus* sp.	0	2	0	72	0	0	0	0	0	74
Heteroptera	Pentatomidae	*Agonoscelis versicolor*	0	127	33	221	372	271	146	517	52	1739
Heteroptera	Pentatomidae	*Atelocera* sp.	2	7	11	8	8	12	14	13	9	84
Heteroptera	Pentatomidae	*Nezara* sp.	0	0	0	28	0	29	21	21	0	99
Heteroptera	Scutelleridae	Undetermined	0	0	0	9	3	12	0	30	0	54
Homoptera	Cicadidae	Undetermined	0	0	0	0	0	3	7	0	5	15
Homoptera	Cicadellidae	*Hilda* sp.	98	61	71	16	0	10	0	18	0	274
Homoptera	Cicadellidae	Khaki leafhopper	0	0	0	0	10	0	18	0	28	56
Homoptera	Coccidae	Large green scales	213	97	57	0	0	0	0	0	0	367
Homoptera	Coccidae	Mealy bugs	0	0	0	0	22	13	3	0	0	38
Homoptera	Coccidae	small green scales	173	224	307	0	0	0	0	0	0	704
Homoptera	Coccidae	Small white scales	291	0	0	0	475	134	0	0	0	900
Neuroptera	Hemerobiidae	Undetermined	5	0	0	8	28	5	0	0	0	46
Coleoptera	Scarabaeidae	*Diplognatha gagates*	0	0	0	0	0	0	5	0	0	5
Coleoptera	Coccinellidae	*Cheilomenes* sp.	0	0	0	0	23	5	30	25	9	92
Coleoptera	Coccinellidae	*Epilachna* sp.	0	0	0	0	0	6	18	38	0	62
Coleoptera	Coccinellidae	*Scymnus* sp.	14	25	13	0	64	113	52	42	5	328
Coleoptera	Nitidulidae	*Carpophilus* sp.	0	16	44	41	68	86	47	53	45	400
Coleoptera	Tenebrionidae	*Catamerus rugosus*	0	7	5	0	5	3	0	0	0	20
Coleoptera	Buprestidae	*Sternocera variabilis*	0	0	0	0	3	0	9	0	0	12
Diptera	Cecidomyidae	*Dasineura* sp.	100	36	39	63	132	142	51	64	27	654
Diptera	Tachinidae	Undetermined	0	0	0	0	0	0	5	0	0	5
Diptera	Syrphidae	Undetermined	0	p	p	p	p	p	p	p	p	p
Diptera	Tephritidae	*Ceratitis* sp.	0	20	7	5	0	5	13	0	0	50
Diptera	Drosophilidae	*Drosophila* sp.	0	144	96	71	50	88	63	71	41	634
Lepidoptera	Geometridae	Undetermined	0	6	0	0	0	4	15	0	0	25
Lepidoptera	Psychidae	Undetermined	5	0	0	0	0	0	6	15	0	21
Lepidoptera	Psychidae	Undetermined	0	7	0	3	0	8	2	0	0	25

Lepidoptera	Gelechiidae	Undetermined	25	21	29	42	14	53	18	32	5	239
Lepidoptera	Phycitidae	Undetermined	0	5	24	22	49	21	73	84	13	291
Lepidoptera	Lasiocampidae	Undetermined	0	0	0	0	67	15	9	127	0	218
Lepidoptera	Saturniidae	*Bunaea alcinoe*	153	48	5	21	0	5	0	0	50	282
Lepidoptera	Lycaenidae	*Deudorix magda*	0	11	9	23	67	7	3	29	0	149
Hymenoptera	Ichneumonidae	Undetermined	0	0	0	0	20	0	15	0	0	35
Hymenoptera	Vespidae	Undetermined	0	4	0	7	0	2	0	1	0	14
Hymenoptera	Formicidae	*Crematogaster tricolor*	425	654	567	0	0	0	0	0	0	1646
Hymenoptera	Anthophoridae	*Xylocopa* sp.	0	3	0	0	0	0	0	0	0	3
Hymenoptera	Trichogrammatidae	Egg parasitoids	0	0	0	0	10	10	6	4	0	30
Total			1605	1613	1361	806	1567	1204	706	1251	281	10404

Key: d = Dedza, z =Zomba

1 = Woodland dominated by small *Uapaca* trees

2 = Woodland dominated by old *Uapaca* trees

3 = Mixed woodland

4 = Individual *Uapaca* trees on farmland

5 = Fire prone woodland

Appendix 2. Arthropods collected in Dedza for seasonality studies. Arthropods collected in October, 1996 and August 1997 were also used in the arthropod diversity for Dedza and Zomba.

Order	Family	Morphospecies	1 Oct	2 Oct	3 Oct	4 Oct	5 Oct	1 Jan	2 Jan	3 Jan	4 Jan	5 Jan	1 Jun	2 Jun	3 Jun	4 Jun	5 Jun	1 Aug	2 Aug	3 Aug	4 Aug	5 Aug
Aranaea	Unknown	Unknown	17	36	7	5	0	12	6	12	21	0	5	14	23	5	7	5	14	23	5	7
Blattodae	Blattidae	Undetermined	0	0	3	6	0	0	0	0	0	27	0	0	3	0	0	0	0	0	21	13
Orthoptera	Gryllidae	Undetermined	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orthoptera	Tettigonidae	Undetermined	0	21	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	5	0	0
Orthoptera	Eumastacidae	*Clerithes* sp.	0	4	0	0	0	0	7	0	0	0	5	2	0	1	0	5	0	0	1	0
Orthoptera	Pyrgomorphidae	*Phymateus viridipes*	38	27	0	0	0	2	3	0	0	0	7	0	0	0	0	7	0	8	0	0
Orthoptera	Acrididae	Undetermined	2	0	0	8	0	0	2	7	0	0	2	3	0	21	0	2	3	0	21	0
Mantodae	Mantidae	Undetermined	11	0	5	0	0	5	5	7	15	2	0	0	0	0	0	0	0	0	0	0
Heteroptera	Coreidae	*Anoplocnemis*	0	37	21	0	0	0	39	14	0	0	0	0	0	0	0	0	0	0	0	0
Heteroptera	Pentatomidae	*Agonoscelis versicolor*	365	250	139	503	52	8	25	3	18	2	2	21	8	16	0	7	21	7	14	0
Heteroptera	Pentatomidae	*Atelocera* sp.	7	12	6	13	9	2	32	5	17	3	1	0	8	0	0	1	0	8	0	0
Heteroptera	Pentatomidae	*Nezara* sp.	0	29	21	18	0	0	2	0	1	7	0	0	0	3	0	0	0	0	3	0
Heteroptera	Scutelleridae	Undetermined	0	12	0	18	0	0	0	0	7	0	3	0	0	8	0	3	0	0	12	0
Homoptera	Cicadidae	Undetermined	0	3	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0
Homoptera	Cicadellidae	Undetermined	0	10	0	4	0	0	0	0	13	0	0	0	0	14	0	0	0	0	14	0
Homoptera	Coccidae	Small white scales	368	83	0	0	0	176	97	0	0	0	107	51	0	0	0	107	51	0	0	0
Homoptera	Pseudococcidae	Mealy bugs	22	13	3	0	0	0	0	0	0	0	15	2	3	0	0	0	0	0	0	0
Neuroptera	Hemerobiidae	Undetermined	12	5	0	0	0	51	5	0	7	0	16	0	0	0	0	16	0	0	0	0
Coleoptera	Scarabaeidae	*Diplognatha gagates*	0	0	5	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	Coccinellidae	*Cheilomenes* sp.	7	5	11	4	9	1	3	0	1	5	18	5	2	21	0	16	0	19	21	0
Coleoptera	Coccinellidae	*Epilachna* sp.	0	6	3	7	0	0	0	8	17	0	0	3	1	32	0	0	0	15	31	0
Coleoptera	Nitidulidae	*Carpophilus* sp.	40	34	19	27	21	3	0	0	2	1	43	52	28	14	24	28	52	28	26	24
Coleoptera	Coccinellidae	*Scymnus* sp.	27	69	22	16	2	3	19	5	3	7	37	44	26	14	3	37	44	30	26	3
Coleoptera	Tenebrionidae	*Catamerus rugosus*	5	3	0	0	0	15	8	12	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	Buprestidae	*Sternocera variabilis*	3	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
Diptera	Cecidomyidae	Undetermined	57	91	14	43	19	30	60	38	49	5	75	51	37	21	8	75	51	37	21	8
Diptera	Tachinidae	Undetermined	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Tephritidae	Undetermined	0	5	13	0	0	1	2	15	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Drosophilidae	*Drosophila* sp.	27	47	42	37	21	31	2	22	5	7	23	41	21	34	20	23	41	21	34	20
Lepidoptera	Geometridae	Undetermined	0	4	6	0	0	0	2	7	3	0	0	0	0	0	0	0	0	9	0	0

Lepidoptera	Psychidae	Undetermined	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Lepidoptera	Psychidae	Undetermined	0	0	6	15	0	0	0	0	0	0	0	3	7	0	0	0	0	0	0	0
Lepidoptera	Gelechiidae	Shootborer	6	3	10	22	5	11	5	30	10	7	3	7	8	5	0	8	5	6	10	0
Lepidoptera	Phycitidae	Undetermined	26	5	34	42	3	2	0	5	0	0	32	13	39	42	10	23	16	39	42	10
Lepidoptera	Lasiocampidae	Undetermined	39	15	9	93	0	2	0	0	0	0	0	0	0	0	0	28	0	0	34	0
Lepidoptera	Saturniidae	Undetermined	0	0	0	0	29	0	0	0	0	0	0	5	0	0	21	0	5	0	0	21
Lepidoptera	Lycaenidae	*Deudorix magda*	47	7	3	16	0	0	0	0	0	0	2	0	0	5	0	20	0	0	13	0
Hymenoptera	Ichneumonidae	Undetermined	7	0	6	0	0	0	0	0	0	0	0	0	0	0	0	13	0	9	0	0
Hymenoptera	Vespidae	Undetermined	0	0	0	0	0	13	10	5	27	12	0	2	0	1	0	0	2	0	1	0
Hymenoptera	Trichogrammatidae	Undetermined	10	0	6	0	0	12	5	3	0	0	0	0	0	0	0	0	10	0	4	0
Total			1143	844	426	897	175	382	341	198	216	85	396	319	214	257	93	424	315	278	354	106

Legend: O = October 1996, J = January 1997, J = June 1997 and A = August 1997; *1 = woodland dominated by young *Uapaca* trees; 2 = woodland dominated by old *Uapaca* trees; 3 = mixed woodland; 4 = individual *Uapaca* trees on farmland; 5 = fire prone woodland.

Appendix 3. Seasonal distribution arthropod data for Dedza arranged by guilds

	October, 1996					January, 1997					June, 1997					August, 1997				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Fruitborer	140	98	121	122	45	39	4	42	7	8	100	106	88	95	54	94	109	88	115	54
Leafchewers	79	85	24	123	29	4	16	22	20	0	14	16	8	54	21	42	8	39	87	21
Natural enemies	91	115	57	25	11	97	53	32	74	26	76	65	51	41	10	87	70	81	57	10
Others	427	356	156	570	71	53	93	53	74	34	80	72	48	45	8	85	72	44	68	21
Stemborer	9	6	17	22	10	11	5	30	10	7	3	7	8	5	0	8	5	18	10	0
Suckers	397	184	51	35	9	178	170	19	31	10	123	53	11	17	0	108	51	8	17	0
Total	1143	844	426	897	175	382	341	198	216	85	396	319	214	257	93	424	315	278	354	106

Legend

*1 = Woodland dominated by young *Uapaca* trees; 2 = woodland dominated by old *Uapaca* trees; 3 = mixed woodland; 4 = individual *Uapaca* trees on farmland; 5 = fire prone woodland.

Appendix 4 Arthropod checklist: included are arthropod from literature, insect museum and the present study. The arthropods have been grouped into foliage, stem or log, flower and fruit feeding or dwelling.

Order	Family	Morphospecies	Guild	Present study	Literature
Aranaea	Undetermined	Spider	Natural enemy	*	
Isoptera	Termitidae	*Nasutitermes usambarensis* Sjöst.	Stem/log	*	*
Blattodea	Blattidae	Undetermined	Foliage	*	
Orthoptera	Acrididae	Tree locust	Foliage	*	
Orthoptera	Eumastacidae	*Clerithes* sp.	Foliage	*	*
Orthoptera	Gryllidae	Undetermined	Stem	*	
Orthoptera	Pyrgomorphidae	*Phymateus viridipes* Stål.	Foliage	*	
Orthoptera	Pyrgomorphidae	*Zonocerus elegans* Thunb.	Foliage	*	*
Orthoptera	Tetrigidae	Unidentified (FRIM Museum)	Foliage		*
Orthoptera	Tettigoniidae	Undetermined	Foliage	*	
Mantodea	Mantidea	Undetermined	Natural enemy	*	
Heteroptera	Coreidae	*Anoplocnemis curvipes* (F.)	Foliage	*	*
Heteroptera	Coreidae	*Leptoglossus membraceus*	Foliage	*	
Heteroptera	Lygaeidae	*Oxycarenus albidipermis* Stål.	Stem/log		*
Heteroptera	Pentatomidae	*Acrosternum pallidoconspersum* Stål.	Foliage		*
Heteroptera	Pentatomidae	*Agonoscelis versicolor* Thunb.	Foliage	*	*
Heteroptera	Pentatomidae	*Aspavia* sp.	Stem/log		*
Heteroptera	Pentatomidae	*Atelocera* sp.	Foliage	*	
Heteroptera	Pentatomidae	*Nezara robusta* Dist.	Foliage	*	
Heteroptera	Pentatomidae	*Nezara viridula* var. *smaragdula* F.	Foliage		*
Heteroptera	Pentatomidae	*Nezara viridula* var. *torquata*	Foliage		*
Heteroptera	Pentatomidae	Unidentified (FRIM Museum)	Foliage		*
Heteroptera	Pentatomidae	Unidentified (FRIM Museum)	Foliage		*
Heteroptera	Pentatomidae	Unidentified (FRIM Museum)	Foliage		*
Heteroptera	Pyrrhocoridae	*Dysdercus nigrofasciatus* Stål.	Fruit	*	
Heteroptera	Scutelleridae	Undetermined	Foliage	*	
Heteroptera	Tessaratomidae	*Encosternum delagorguei* Spin.	Foliage		*
Homoptera	Cicadellidae	*Hilda* sp.	Foliage	*	
Homoptera	Cicadellidae	Khaki leafhoppers	Foliage	*	
Homoptera	Cicadellidae	Unidentified (FRIM Museum)	Flower		*
Homoptera	Cicadidae	Undetermined	Stem	*	
Homoptera	Coccidae	*Ceroplastes brevicauda* Hall	Foliage		*
Homoptera	Coccidae	*Ceroplastes destructor* Newstead	Foliage		*
Homoptera	Coccidae	*Ceroplastes spicatus* Hall	Foliage		*
Homoptera	Coccidae	*Ceroplastes uapacae* Hall	Foliage		*
Homoptera	Coccidae	Large green scales	Foliage	*	
Homoptera	Coccidae	*Ledaspis mashonae* Hall	Foliage		*
Homoptera	Coccidae	Mealy bugs	Foliage	*	
Homoptera	Coccidae	*Pulvinaria psidii* Mask.	Foliage		*
Homoptera	Coccidae	*Pulvinaria uapacae* Hodgson	Foliage		*
Homoptera	Coccidae	*Saisselia jocunda* De Lotto	Foliage		*
Homoptera	Coccidae	*Saisselia persimilis* (Newstead)	Foliage		*
Homoptera	Coccidae	Small green scales	Foliage	*	
Homoptera	Coccidae	Small white scales	Foliage	*	

Neuroptera	Hemerobiidae	Undetermined	Natural enemy	*	
Coleoptera	Chrysomelidae	*Altica* sp.	Foliage		*
Coleoptera	Anthicidae	*Formicomus rubricollis* Lak.	Foliage		*
Coleoptera	Anthribidae	Unidentified (FRIM Museum)	Stem/log		*
Coleoptera	Attelabidae	Unidentified (FRIM Museum)	Foliage		*
Coleoptera	Bostrichidae	*Xylion adustus* Fhs.	Stem/log		*
Coleoptera	Buprestidae	*Anthaxia* sp.	Stem/log		*
Coleoptera	Buprestidae	*Megactenodes reticulatus* Klug	Stem/log		*
Coleoptera	Buprestidae	*Psiloptera* sp.	Stem/log		*
Coleoptera	Buprestidae	*Sternocera variabilis* Klug	Foliage	*	
Coleoptera	Buprestidae	Unidentified (FRIM Museum)	Stem/log		*
Coleoptera	Carabidae	Unidentified (FRIM Museum)	Flower		*
Coleoptera	Cerambycidae	*Amphidesmus analis* Ol.	Stem/log		*
Coleoptera	Cerambycidae	*Tragocephala mima* Thoms.	Stem/log		*
Coleoptera	Cerambycidae	*Zamium incultum* Pascol.	Stem/log		*
Coleoptera	Cerambycidae	*Zographus aulicus* Bertol.	Stem/log		*
Coleoptera	Chrysomelidae	*Microsyagrus rosae* Bry.	Foliage		*
Coleoptera	Chrysomelidae	Unidentified (FRIM Museum)	Flower		*
Coleoptera	Coccinellidae	*Cheilomenes lunata* F.	Foliage		*
Coleoptera	Coccinellidae	*Cheilomenes* sp.	Natural enemy	*	
Coleoptera	Coccinellidae	*Epilachna dregei*	Foliage		*
Coleoptera	Coccinellidae	*Epilachna* sp.	Foliage	*	
Coleoptera	Coccinellidae	*Hyperaspis* sp.	Foliage		*
Coleoptera	Coccinellidae	*Scymnus* sp.	Leaves and shoot	*	
Coleoptera	Coccinellidae	Unidentified (FRIM Museum)	Flower		*
Coleoptera	Chrysomelidae	*Cryptocephalus* sp.	Foliage		*
Coleoptera	Cucujidae	*Silvanus fairmairei* Grouv.	Stem/log		*
Coleoptera	Curculionidae	*Amphitmetus* sp.	Foliage		*
Coleoptera	Curculionidae	*Apion angulicolle* Gyll.	Foliage		*
Coleoptera	Curculionidae	*Cossonus* sp.	Foliage		*
Coleoptera	Curculionidae	*Cossonus* sp.	Stem/log		*
Coleoptera	Curculionidae	Unidentified (FRIM Museum)	Foliage		*
Coleoptera	Curculionidae	Unidentified (FRIM Museum)	Foliage		*
Coleoptera	Curculionidae	Unidentified (FRIM Museum)	Foliage		*
Coleoptera	Curculionidae	Unidentified (FRIM Museum)	Foliage		*
Coleoptera	Elateridae	Unidentified (FRIM Museum)	Flower		*
Coleoptera	Chrysomelidae	*Colasposoma* sp.	Foliage		*
Coleoptera	Chrysomelidae	*Diacantha* sp.	Stem/log		*
Coleoptera	Chrysomelidae	*Megaleruca geniculata* Har.	Stem/log		*
Coleoptera	Lagriidae	*Chrysolagria* sp.	Foliage		*
Coleoptera	Lagriidae	Unidentified (FRIM Museum)	Foliage		*
Coleoptera	Lagriidae	Unidentified (FRIM Museum)	Flower		*
Coleoptera	Lampyridae	Unidentified (FRIM Museum)	Flower		*
Coleoptera	Lycidae	Unidentified (FRIM Museum)	Flower		*
Coleoptera	Lyctidae	*Premnobius carpinnia*	Stem/log		*
Coleoptera	Lyctidae	Unidentified (FRIM Museum)	Stem/log		*
Coleoptera	Scarabaeidae	Unidentified (FRIM Museum)	Flower		*
Coleoptera	Nitidulidae	*Carpophilus fumatus* Boh.	Fruit		*
Coleoptera	Nitidulidae	*Carpophilus* sp.	Fruit	*	
Coleoptera	Paussidae	Unidentified (FRIM Museum)	Flower		*
Coleoptera	Scarabaeidae	Unidentified (FRIM Museum)	Flower		*
Coleoptera	Chrysomelidae	*Glostatus* sp.	Stem/log		*

Coleoptera	Scarabaeidae	*Diplognatha gagates* (Forst.)	Fruit	*	
Coleoptera	Staphylinidae	Unidentified (FRIM Museum)	Flower		*
Coleoptera	Tenebrionidae	*Catamerus rugosus* Gah.	Stem	*	*
Coleoptera	Tenebrionidae	*Ceropria romandi* Cast.	Stem/log		*
Coleoptera	Tenebrionidae	*Corticeus* sp.	Stem/log		*
Diptera	Cecidomyidae	*Dasineura* sp.	Foliage	*	
Diptera	Drosophilidae	*Drosophila ananasse* Dol.	Fruit		*
Diptera	Drosophilidae	*Drosophila* sp.	Fruit	*	
Diptera	Otitidae	*Bromophila caffra* Rtl.	Fruit		*
Diptera	Syrphidae	Undetermined	Natural enemy	*	
Diptera	Syrphidae	Unidentified (FRIM Museum)	Flower		*
Diptera	Tachinidae	Undetermined	Natural enemy	*	
Diptera	Tephritidae	*Ceratitis cosyrae* Wlk.	Fruit		*
Diptera	Tephritidae	*Ceratitis* sp.	Fruit	*	
Lepidoptera	Arctiidae	Unidentified (FRIM Museum)	Flower		*
Lepidoptera	Gelechiidae	Unidentified (FRIM Museum)	Flower		*
Lepidoptera	Gelechiidae	Undetermined	Shoot	*	
Lepidoptera	Geometridae	Looper	Foliage	*	
Lepidoptera	Hespieriidae	*Abantis arctomarginata* Lathy	Foliage		*
Lepidoptera	Lasiocampidae	*Pachypasa sericeofasciata* Aur.	Foliage		*
Lepidoptera	Lasiocampidae	Undetermined	Foliage	*	
Lepidoptera	Limacodidae	*Latoia urda* Druce	Foliage		*
Lepidoptera	Limacodidae	*Taeda aetitis* Walleng.	Foliage		*
Lepidoptera	Saturniidae	*Holocerina agomensis* Karsch	Foliage		*
Lepidoptera	Saturniidae	*Ludia delegorguei* Boisd.	Foliage		*
Lepidoptera	Lycaenidae	*Deudorix magda* Gifford	Fruit	*	*
Lepidoptera	Lycaenidae	*Deudorix* sp.	Fruit		*
Lepidoptera	Noctuidae	Unidentified (FRIM Museum)	Flower		*
Lepidoptera	Nymphalidae	*Charaxes nichetes leoninus* Butler	Foliage		*
Lepidoptera	Nymphalidae	*Charaxes nichetes veronicae* Plantrou	Foliage		*
Lepidoptera	Phycitidae	Undetermined	Fruit	*	
Lepidoptera	Psychidae	Undetermined species 1	Foliage	*	
Lepidoptera	Psychidae	Undetermined species 2	Foliage	*	
Lepidoptera	Pyralidae	Unidentified (FRIM Museum)	Flower		*
Lepidoptera	Pyraustidae	Unidentified (FRIM Museum)	Flower		*
Lepidoptera	Saturniidae	*Bunaea angasana* Westw.	Foliage		*
Lepidoptera	Saturniidae	*Bunaea alcinoe* Stoll	Foliage	*	
Lepidoptera	Saturniidae	Unidentified (FRIM Museum)	Foliage		*
Lepidoptera	Saturniidae	Unidentified (FRIM Museum)	Foliage		*
Lepidoptera	Saturniidae	Unidentified (FRIM Museum)	Foliage		*
Hymenoptera	Anthophoridae	*Xylocopa adustus* Fhs.	Foliage	*	
Hymenoptera	Apidae	Unidentified (FRIM Museum)	Flower		*
Hymenoptera	Formicidae	*Crematogaster tricolor* Gerst.	Foliage	*	
Hymenoptera	Formicidae	Unidentified (FRIM Museum)	Flower		*
Hymenoptera	Ichneumonidae	Undetermined	Natural enemy	*	
Hymenoptera	Sphegidae	Unidentified (FRIM Museum)	Flower		*
Hymenoptera	Trichogrammatidae	Undetermined	Natural enemy	*	
Hymenoptera	Undetermined	Undetermined	Natural enemy	*	
Hymenoptera	Vespidae	Undetermined	Natural enemy	*	

Legend: * indicates presence

Appendix 5. Summaries of weather data for 1996 and 1997 and arthropods count for Dedza.

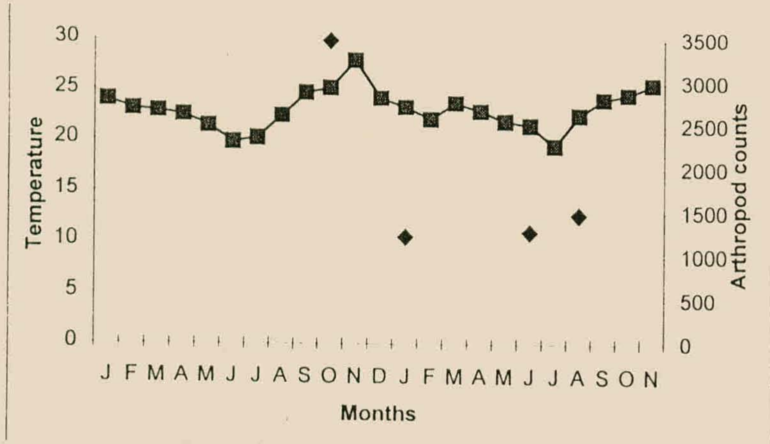

Fig. 14. Mean monthly maximum temperature and arthropod counts

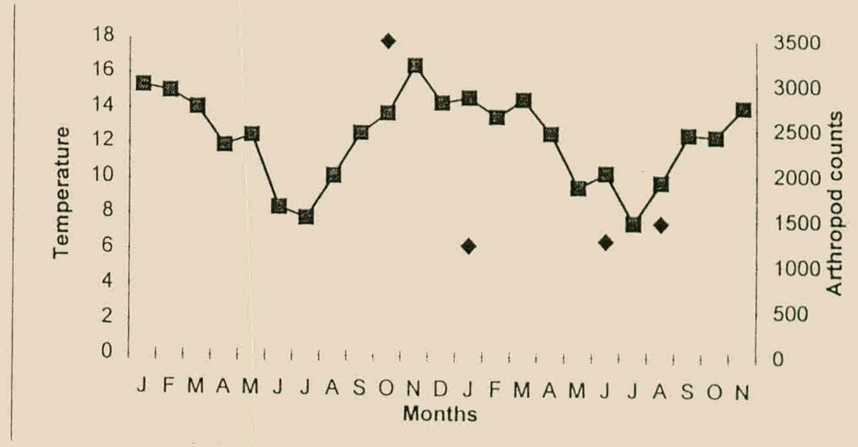

Fig. 15 Mean monthly minimum temperature and arthropod counts

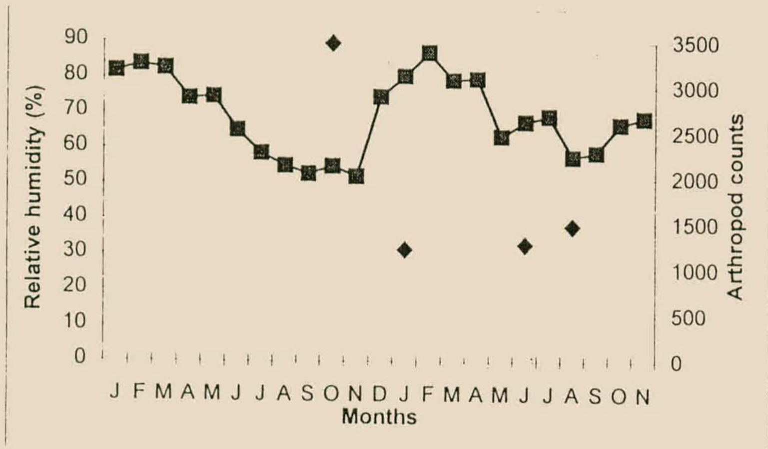

Fig. 16 Mean monthly relative humidity and arthropd counts

Fig. 17 Mean monthly wind speed and arthropod counts

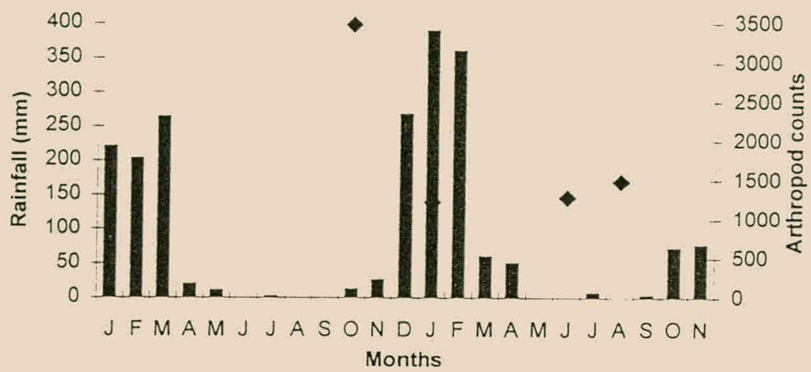

Fig. 18 Monthly rainfall totals and arthropod counts.

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