KENYATTA UNIVERSITY, NAIROBI, KENYA

BIODIVERSITY OF WILD SILKMOTHS (LEPIDOPTERA) AND THEIR POTENTIAL FOR SILK PRODUCTION IN EAST AFRICA

BY

ESTHER N. KIOKO

B. Ed. (Sc.) (Hons), M. Sc (Entomology), Kenyatta Univ.

THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF
THE DEGREE OF DOCTOR OF PHILOSOPHY (Ph. D)
IN ENTOMOLOGY

JUNE, 1998.

DECLARATION BY CANDIDATE

This thesis is my original work and has not been presented for a degree in any other University

Signature Kioko. Date 11TH JUNE 1998.

Esther N. Kioko

DECLARATION BY SUPERVISORS

This thesis has been submitted for examination with our approval as supervisors

Prof. Jones M. Mueke
Department of Zoology
Kenyatta University
P. O. Box 43844
Nairobi, Kenya.

Signature Jones M. Mueke Date 16-6-98

J. M. Mueke.

Dr. Suresh K. Raina
Commercial Insects Project,
The International Centre of Insect
Physiology and Ecology (ICIPE)
P. O. Box 30772
Nairobi, Kenya.

Signature Date 17.06.'98

S. K. Raina.

DEDICATION

This thesis is dedicated to my husband Joel, and children Ndinda, Mueni and Yula.

ACKNOWLEDGEMENTS

My sincere thanks are due to Prof. Jones M. Mueke, my University supervisor, whose keen supervision was the key force behind the completion of this thesis. His contribution ranged from tireless visits to review the research progress, useful suggestions and discussions throughout the study period to positive critical review of the thesis drafts.

Many sincere thanks are due to Dr. Suresh K. Raina my ICIPE supervisor who introduced me to this very interesting research on wild silkmoths, provided me with a wealth of literature and made many suggestions that shaped the research methodologies. His support and keen supervision throughout the study period gave me a lot of inspiration.

I highly appreciate and acknowledge the financial support (scholarship) for this study from the International Fund for Agricultural Development (IFAD), Rome, Italy through the Commercial insects project, ICIPE. It is my pleasure to thank Dr. H. Herren, the Director General, ICIPE and Dr. S. Raina, the Mega Project Leader, Commercial Insects, for all the research facilities and provisions that I enjoyed during the course of this study. Thanks are also due to Dr. M. Isahakia, the Director General, National Museums of Kenya for granting me study leave to undertake these studies.

I wish to express my sincere gratitude to Miss Florence Kiilu and Mr. Vincent Shitakule for the technical assistance in the field and laboratory work. I am also thankful to Mr David Kimbu, a colleague, for his assistance and especially in formating the final draft of this thesis. I also wish to record my gratitude to all my other colleagues in the Commercial insects project and especially to Mr H. Muiru, Mr D. Ogola and Mr G. Owino for their assistance during the fixing of cages in the field. I am thankful to the many farmers that I met during this study for the many fruitful discussions and for all the information that they provided. Among them, I express special thanks to Mrs Anna Kakiti, Mr. Syethoka and Mr. Muiu for allowing me to put up cages in their farms.

I thank Dr. S. Kimani-Njogu for her assistance with the parasite identifications, Mr. M. Chemtawi for his assistance in the electron microscopy work and Dr. V. Adolkar for his many suggestions and encouragement in the course of this study. Appreciation is extended to Dr. V. Musewe, the ARPPIS Co-ordinator, my fellow ARPPIS Scholars, friends and family members who in diverse ways encouraged me during this study.

Special thanks and appreciations are to my husband Joel, and children, Ndinda, Mueni and Yula for their love, patience, support and understanding which enabled me to complete this study successfully.

GLORY TO THE ALMIGHTY GOD FOR HIS EVER ABUNDANT GRACE.

Table of contents Page

List of figures

List of tables

List of plates

ABSTRACT

Wild silk production is a unique eco-friendly agro-practice with the potential for environmental amelioration, employment and incomegeneration. The present utilisation of wild silkmoths hardly accounts for 5% of the rich potential and most of the production is from the far east countries. The steadily growing demand for silk in all silk consuming countries provides excellent opportunities for any country to venture into wild silk production. In East Africa, wild silk production would be ideal for generation of supplementary income to resource-poor farmers, reducing the destruction of their hostplants, promoting conservation of the silkmoths and at the same time permitting positive utilisation of these biological resources by the local community.

In Kenya, Uganda and Tanzania, 58 wild silkmoth species of three Lepidoptera families, Saturniidae, Lasiocampidae and Thaumetopoeidae were recorded. The species diversity varied in these three families. In family Saturniidae, 19 species were recorded in 6 genera, 33 species in 17 genera in the family Lasiocampidae and 6 species in one genus in family Thaumetopoeidae. Two case studies carried out on the distribution of *Bridelia micrantha* (Hochst) Baill (Euphorbiaceae) the hostplant of the wild silkmoth *Anaphe panda* (Boisduval) (Thaumetopoeidae) and *Sclerocarya birrea*, (A. Rich.) Hochst. (Anacardiaceae) the host plant of the silkmoth *Argema mimosae* (Boisduval) (Saturniidae) revealed that the hostplants are widely distributed in the three East African countries. In

western Kenya, a ground survey confirmed the availability of *B. micrantha* with 84 % of the farmers having it in varying numbers in their land. A questionnaire distributed to 50 local farmers near the Kakamega forest responded positively (98 %) to the potential of initiating wild silk farming as an extra source of income.

Further phenological studies on selected species, *Gonometa* sp. (Lasiocampidae) at Nguni, Mwingi and *A. mimosae* at Sultan Hamud, Makueni, Kenya showed that these silkmoths have two generations each year. The adult moth emergence synchronised with the hostplant state which was also influenced by weather conditions. A high larval mortality of the silkworms of both species was observed in the field. The overall mortality from the first instar to the onset of cocoon spinning for *Gonometa* sp. reared on caged *Acacia elatior* Brenan was 82.9 % during the short rains of 1996 and 78.9 % during the short rains of 1997. In *A. mimosae*, reared on the hostplant *Sclerocarya birrea*, 80.6 % larval mortality was recorded during the short rains of 1997. Rearing the *Gonometa* sp. silkworms in net sleeves tied to the hostplant branches reduced the mortality to 23.9 %.

In both species, the pupal stage was the longest indicating the possibility of pupal diapause. *Gonometa* sp. pupae observed in controlled environmental conditions in an incubator had a significantly shorter life span (87.2 ± 3.6 days) compared to those observed under room condition (124.0 ± 11.2 days). This is an indication that the pupal diapause in these species can be manipulated for continuous cycle of the silkmoth

generations depending on the foodplant state.

Predators attacking *Gonometa* sp. and *A. mimosae* in the field belonged to three insect ordes, Hemiptera, Orthoptera and Hymenoptera. Formicid ants were abundant. Pentatomid bugs of the sub-family Asopinae, *Maccroraphis spurcata* Walker were observed in Sultan Hamud sucking body fluids and killing larvae of *A. mimosae.*

Field collected eggs and cocoons of *Gonometa* sp. and *A. mimosae* yielded hymenopteran and dipteran parasitoids. *Mesocomys pulchriceps* Cameron and *Pediobius anastati* (Crawford) were identified from the eggs of both silkmoth species. *Telenomus* sp. and an unidentified Encyrtidae were recorded from *A. mimosae* eggs. No parasitoids were obtained from *A. mimosae* cocoons. From *Gonometa* sp. cocoons, unidentified Tachinidae together with hymenopterans *Goryphus* sp., *Eurytoma* sp and unidentified Chalcidoidea were recorded. These parasitoids from the cocoons spoilt the continuity of the silk fiber by making exit holes for the adults to emerge. Cocoons of *A. mimosae* were not reelable but those of *Gonometa* sp. gave long filaments of lustrous brown silk. Females gave longer silk thread (706.34 ± 222.4 m) compared to males (521.49 ± 204.2 m). The mean weight of silk from females was 0.43 ± 0.2 g and 0.21 ± 0.10 g from males. 2,326 to 4,762 cocoons are required to make one kilogram of *Gonometa* sp. silk.

CHAPTER ONE

GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 General Introduction.

Biodiversity is a contraction of 'biological diversity' and embraces the whole variety and range of living things. Its destruction is one of the key problems facing the world today. With this increasing concern for biodiversity, and the mounting evidence of irriversible environmental damage, there is growing need for serious steps towards conservation. There is also need to involve the local population in utilisation and conservation of their indegenous biodiversity. The fundamental goal of biodiversity conservation is to support sustainable development by protecting and using biological resources in ways that do not diminish the world's variety of genes and species or destroy habitats or ecosystems.

The economic incentives in many African countries have forced dependence on primary production, largely in agriculture, for sustaining demands for food and wealth to improve the people's living standards. The extensive agriculture and the high population growth are the main cause of the rapid dwindling of these countries' rich biodiversity. Some solution to this depletion of biodiversity lies in introducing economic incentives that

integrate conservation with economic development of the rural people (Munthali and Mughogho, 1992).

Invertebrates, and in particular insects, comprise the vast majority of life forms on earth (Holloway and Stork, 1991) and are a significant component of faunal diversity that cannot be ignored when dealing with matters of biodiversity conservation. For example, some species of the African moths produce high quality silk of commercial value (Scultze,1914; Hartland-Rowe, 1992; Chikwenhere, 1992; Peigler, 1993). These wild silkmoths sometimes called non-mulberry silkmoths are lepidopteran insects whose larvae are able to produce silk. Sericulture is the process of rearing silk producing insects in captivity or collecting their silk in the field.

Silk, because of its natural texture, strength and fineness, is one of the most ancient and preferred fibres in the world. The economic value of silk is higher than that of other natural fibres such as cotton and wool. On the international level, wild silk i.e produced by silk producing insects which are not domesticated, represents 10% of the yearly silk tonnage in the world (Schenk,1981). The present exploitation hardly accounts for 5% of the rich potential (Jolly,1981) and most of the production is from the Far East countries. The steadily growing demand for silk in all the silk consuming countries indicates excellent opportunities for any country to increase her silk production (Kumar, 1995). In Africa, silkmoth species, *Gonometa rufobrunnea* Aurivillius and *G. postica* Walker were discovered in the wild in Botswana in 1985 and attempts have been made to utilise these

species (Hartland-Rowe, 1992). In Zimbabwe, between 1986 to 1987, 430 tonnes of wild silkmoth cocoons of these species were collected by rural families and this became a source of employment in the rural areas of Matabeleland Province (Chikwenhere, 1992).

The population of wild silkmoths in Africa is declining. Like most animals on earth, wild silkmoths are also affected by man's rapid population increase and his impact on ecosystems. Agricultural development and deforestation of many habitats rob wild silkmoths their foodplants (Oberprieler, 1995). In East Africa, information on the species of wild silk moths is lacking. In this region like else where in Africa, conditions of the present human population growth and encroachment on natural habitats are also possing serious threat to the wild silkmoth habitats. Species diversity, their phenology and characteristic behaviour, their silk cocoons' structure and potential for silk production need to be investigated. This information will enhance proper planning for their utilisation as economic incentives for their conservation, that of their habitats and for the economic development of the people. This will offer a new use for the East African indegenous flora and fauna that will increase their value to the local comunities.

During this study, part of the International Centre of Insect Physiology and Ecology (ICIPE) Arthropod Divesity, Commercial Insects Project, diversity and distribution of wild silkmoth species in E. Africa was examined. Factors affecting their phenology were determined and the potential of wild sericulture evaluated focusing on rural resource poor communities. These results could be of great value to both researchers

and farmers involved in the wild silk production. It is by understanding their phenology and characteristics that we can conserve and help the society develop through the sustainable utilisation of these biological resources-wild silkmoths.The data obtained could aid in locating the best field sites for establishing wild silk farming and can be used in establishing a silk production unit for training farmers. In the long-term, these data could be used to monitor wild silkmoth species diversity and the effects of utilisation and conservation management. This study can be a reference point for wild silk production in other parts of Africa where these natural resources are underutilised.

1:2 Literature Review

1:2:1 Biology of the wild silkmoths:2:1 Biology of the wild silkmoths

Silkmoths belong to a major order of insects, the Lepidoptera. These insects have four developmental stages, the egg or ovum; the caterpillar or larva which is the principal feeding and growing stage; the chrysalis or pupa which is a transition stage and the adult or imago which is the principal dispersive and the sole reproductive stage. Silkmoths spin silken cocoons in which they pupate. The silk consists of proteins produced by modified salivary glands in the mouth of the larva and is spun from a special spinneret in the floor of the mouth.

Jolly *et al.* (1979) has published a mannual on detailed biological aspects of the

major wild silkmoths including tropical tasar, temperate tasar, muga culture, eri culture and anaphe culture. Later work includes that of Thangavelu *et al.* (1988) on muga culture, and Peigler (1989) on the giant silkmoth or atlas moth which gives fagara silk.

On the African wild silk species, Gowdey (1953), outlined the biology of *Anaphe infracta* Walsingham in Uganda giving the duration of each stage and the seasonal cycles. In Nigeria, Ashiru (1988), observed seven instars of a closely related species *Anaphe venata* Butler. There is only one other species of the African wild silkmoths which has been recently studied to some extend by Hartland-Rowe (1992) in northern Botswana. He has outlined the life-cycle of *Gonometa rufobrunnea* Aurivillius feeding on mopane. From specimen labels at the museums and from literature (Aurivillius, 1927; Gowdey, 1953; Pinhey, 1956; Pinhey, 1975; Oberprieler, 1995), some of the wild silkmoths occurring in E. Africa include the Genera *Gonometa, Argema, Anaphe* and *Epiphora*. Lack of literature on the diversity and biology of these species limits proper planning for their utilisation as beneficial insects, capable of generating income through silk production and the other by-products.

1:2:2 World diversity of wild silkmoths

The distribution of some of the world wild silk fauna has been outlined by both Jolly *et al.* (1979) and Peigler (1993). He has listed about 25 species of wild silkmoths that have been exploited for wild silk production. This exploitation has been mainly by tribal communities as reflected in some of the names of the silks.

1:2:2:1 Tasar silk

Tasar silkworms are reared in tropical and temperate zones under the names tropical tasar and temperate tasar respectively (Jolly *et al.*, 1979). The word tasar is probably derived from the Sanskrit word 'trasara' or 'tassara' meaning a shuttle, and this silk culture is said to date back to 1590 B. C. in India (Peigler, 1993). The tropical tasar silk in India is based on *Antheraea paphia* (L.) (Saturniidae), commonly referred to in literature by the junior synonym *A. mylitta* (Drury). The tropical tasar belt extends along the humid dense tropical forests of the Central and Southern plateaus in India From Bihar down through to Karnataka and Tamil Nadu. There are more than 25 eco-races in cultivation in various districts on various host plants (Nayak *et al.*, 1994). Some of the main hostplants used are *Terminalia tomentosa* Wight & Arn. (Combretaceae) and *T. arjuna* Wight & Arn., *Shorea robusta* Roxb. (Dipterocarpaceae) and *Lagerstroemia indica* L. (Lythraceae). Up to the beginning of this century, most cocoons were collected from the wild but today many cultures are 'seeded' on trees outdoors by placing eggs secured from captive moths. Larvae are given some protection by detering predaceous birds and other predators (Reddy *et al.*, 1995). India's foreign exchange earnings for exporting tasar to other countries particularly the United states, Germany and Japan since the 1960's, total hundreds of thousand dollars annually (Kumar, 1995). These exports are mainly finished products such as saris, scarves, neckties and other clothing.

The temperate tasar silk is based on *A. proylei* Jolly in India, *A. pernyi* (Guerin-Meneville) in China (called Chinese tussah) and the U.S.S.R. and *A. yamamai* (Guerin-Meneville) in Japan. These temperate tasar silkworms are reared on oak (*Quercus*, Fagaceae). *A. proylei* is a hybrid between the Indian *A. roylei* Moore and the Chinese *A. pernyi* that was developed in the 1960s and is widely introduced and exploited. It has created a new opportunity for many tribes to be involved in sericulture, making use of the natural abundance oaks and has favourably impacted the national economy of India (Peigler, 1993).

Antheraea pernyi is the chinese oak silk moth producing the chinese tussah (also spelled tussser) which is derived from tasar. Peigler (1993) noted that thousands of acres of oak *(Quercus)* are under cultivation all over China for tussah production and that chinese tussah often appears in international trade, offered for sale in Europe and the United States as finished garments such as underwear, skirts and formal wear and as cloth in fabric shops or as 'bricks' of tussah silk sold in yarn shops for spinning.

Antheraea yamamai is the Japanese oak silkmoth. The name comes from the Japanese word 'yama' meaning forests or mountains and 'mayu' meaning cocoons, roughly translating to wild silkmoth. The moth flies throughout Japan but unlike India, today wild sericulture is not a cottage industry among the Japanese people though it was in former times (Nakajima, 1981). The higher cost of labour as compared with other Asian countries and much greater demand than supply have allowed this silk to command exorbitantly high

prices. The silk has great and ritualistic significance and items produced include small tablecloths, neckties, belts, clothes for Buddhist altars and family crests in frames (Peigler, 1993). These items fetch a lot of money as shown by Peigler (1993) in a tie which has only thin lines of the oak silk (the main portion being of mulberry silk) retailed for $110!.

1:2:2:2 Muga Silk

This silk is produced by *A. assamensis* (Westwood). Thangavelu *et al.*, (1988) gives a detailed account of this silk culture, whose name is derived from a Sanskrit word meaning amber as the silk is golden brown or amber - coloured. This silk is only produced in the Assam region of North Eastern India by tribal communities. The silkworms feed on plants in the family Lauraceae such as *Machilus bombycina* King, *Litsaea polyantha* Juss., *L. citrata* Bl., *Cinnamomum obtusifolium* Nees and also on certain Magnoliaceae like *Magnolia pterocarpa* Roxb. During the nineteenth century and before, muga silk was generally used for clothing by the middle class of Assam, but in recent times, it has been priced so high that it is out of reach to the average person. All muga silk is used locally in Assam. In recent decades, there has been a decline in mugaculture due to a combination of factors such as floods, drought and the indiscriminant felling of the hostplant trees. Currently, the Indian government is actively promoting the development of muga culture, with research programs aimed at developing cultivated varieties more suited for indoor rearing and yielding larger cocoons to save muga silk whose cloth has been referred to as 'the pride of India'.

1:2:2:3 Eri silk

Eri silk is from the ailanthus silkmoth, commonly called the cynthia moth, *Samia cynthia* (Drury) of the family Saturniidae. This genus is reported to comprise of only this species and sixteen races (Crotch, 1956). These are found in the palaearctic and Indo-Australian biogeographical regions. Although the cynthia moth feeds on the tree-of-heaven, *Ailanthus altissima* (Miller) (Simarroubaceae), eri silkworms are usually raised on the palmate leaves of castor oil plants, *Ricinus communis* L. (Euphorbiaceae). The eri silkmoth has been domesticated for centuries in India, China and Japan and was introduced in America and Europe in the middle of the nineteenth century but could not be established (Jolly *et al.*, 1979). Cocoons of this species cannot be reeled and are spun into thread like cotton and this weaving is a cottage industry in Assam. Currently, the government of India is attempting to expand eri culture to other states where castor can be grown in stressed ecosystems, providing leaves for the silkworms and beans for castor oil.

1:2:2:4 Fagara silk

Fagara silk is obtained from the giant silkmoth or atlas moth *Attacus atlas* (L.) (Saturniidae) and a few other races inhabiting the Indo-Australian biogeographical region and China. Jolly *et al.* (1979) mentioned a species, *Attacus gladiator* Fruhstas occurring in Sudan. The cocoons, like those of eri silk have to be made into floss-silk and spun silk

yarn unlike the reeling of the long continous threads of *Bombyx mori* and *Antheraea*. It is likely that *A. atlas* has had occassional significance in certain South Eastern Asian countries through the centuries but minimal usage of the silk from this species occurs today (Peigler, 1993; Jolly *et al.*, 1979).

1:2:2:5 Anaphe silk

This is silk of Southern and Central Africa produced by silkworms of the Genus *Anaphe* (Thaumetopoidae). The species in the genus include *A. moloneyi* Druce, *A. panda* Boisduval, *A. reticulata* Walker (= *A. ambrizia* Butler), *A. carteli* Walsingham, *A. venata* Butler and *A.infracta* Walsingham (Gowdey, 1953). The silkworms of these species spin communal silk nests, which the local people collect from the wild and spin into raw silk that is soft and lustrous (Akerele, 1970). In Nigeria, the silk obtained from *A. infracta* is locally known as 'boko' and that from *A. moleneyi* as 'tissnian-tsamia' and 'koko' (Akerele, 1970). The 'Sanyan' cloth from Nigeria, mentioned by Peigler (1993) is a combination of cotton and Anaphe silk. Jolly *et al.* (1979), recorded that fabrics of Anaphe silk are stronger and more elastic than mulberry silk and have been used in velvet, plush fabrics, neckties, umbrellas and even ballons. In Nigeria, garments made from Anaphe silk are worn in social ceremonies. Reports by Peigler (1993) indicate that Anaphe silk garments are now getting out of reach for the ordinary person as the price has become expensive with a gown costing up to US $ 300.

1:2:2:6 Gonometa Silk

Silk from the *Gonometa postica* Walker (Lasiocampidae) has been reported to occur on the African savanna with larvae feeding on mopane tree, *Colophospermum mopane* Kirk ex J. Leo (Caesalpiniaceae) a resiniferous tree (Hartland-Rowe, 1992). The cocoons are collected in the wild and give silk of soft texture and beige colour (Peigler, 1993). In Botswana, a study by Hartland-Rowe (1992) indicated that collecting and processing of this silk may offer a viable source of employment and income to people in the villages. In Zimbabwe, Chikwenhere (1992), reported that from 1986 to 1987, 430 tonnes of wild cocoons where collected by rural families and this became a source of employment in the rural areas.

In the high plateaus of Central Madagascar, *Borocera cajani* Vinson (Lasiocampidae) and allied species are moths closely related to the *Gonometa* on mainland Africa. These have been utilised in wild sericulture by the Betsileo and Merina tribes (Peigler, 1993). The caterpillars feed on resiniferous plants including *Cajanus indicus* Spreng. (Leguminosae), *Dodonaea madagascariensis* Radlk. (Sapindaceae), *Uapaca bojeri* Baill. (Euphorbiaceae) and mango *Mangifera indica* L. (Anacardiaceae). It is recorded that indeed there is a factory of this silk in operation in Madagascar (Peigler, 1993).

1:3 Beneficial attributes of silkmoths

1:3:1 Silk fibre

Mulberry silk is used as a raw material not only for precious fabrics but also for making parachutes, tyre linings, electrical insulation materials, artificial blood vessels and surgical sutures. The wild silk is recently attracting the world markets and is equally good.

1:3:2 Food

About 500 insect species are known to be consumed worldwide (GBSELR, 1992). Most popular are species of the family Saturniidae (silkmoths or emperor moths). Oliveira *et al.* (1976) recorded that one hundred grams of caterpillars provide 76% of the individual daily protein requirements and more than 100% of the daily requirements of many of the vitamins and minerals. Nutritionally, silkmoths compare well with other animal products; for example the percentage protein in 100g of moths/pupa/larvae amounts to 23.1 % as compared to beef (18%), lamb (15.5%) and chicken (22%) (Vane-Wright, 1991). In Nigeria, Ashiru (1988) reported that the silkworms of *Anaphe infracta* are consumed while in Asia pupae of various species of silkmoths are eaten and provide an important source of nutrient to many silk workers (Roychoundury and Joshi, 1995).

1:3:3 Pupal oil and animal feed

Pupae of sikmoths are an excellent source of proteins for animals and their oil is extracted for making soap and cosmetics (Agarwal *et al.*, 1974). In India, it has been estimated that 20,000 tonnes of de-oiled *Bombyx mori* pupae are produced annually and much of it is fed to hens. The silkworm feaces are rich in protein and are good feeds for fish, pigs and are a superb organic manure. In tasar silkmoth, dead pupae which remain after reeling are very rich in protein (63 - 65 %), oil (20 - 25 %), carbohydrates (10 %) and minerals (7 - 8 %). The oil extracted from these pupae is used as an ingredient in soap because of its good cleansing power and the remaining powder is used in the baking industry for the preparation of protein-rich biscuits (Agarwal *et al.*, 1974)

1:3:4 Conservation

Mulberry (*Morus alba)* the foodplant for *Bombyx mori* is a multi use agroforestry species especially suitable for growth even in semi-arid lands. The tree gives fine wood and the leaves are high quality fodder. The fruit is used to make jam and wine. Wild silkmoths on the other hand can be used as ecological indicators of environmental change (Oberplieler, 1995). This is because they often have a restricted distribution and foodplant range. The decline in numbers of a silkmoth species in an area may be the first sign of degradation of the environment, whether by pollution, denudation of the natural

vegetation, invasion of alien plants or other causes. Similarly, an increase in numbers may also be a signal of change in the environment for example the introduction of a palatable exotic species or an increase of the natural foodplants. Before the wild silkmoth species of East Africa can be used to identify areas and ecosystems in need of conservation, and also to monitor such areas for possible decline and change in terms of species composition, detailed bioecological studies must be undertaken. Once thorough knowledge is gained on their life cycles and distribution, then these species will play a role in the future formulation of research and conservation strategies in this region.

1:4 Diapause in wild silkmoths

When the caterpillar of silkmoth or the silkworm is fully grown, it prepares to change into an immobile pupa, in which the final transformation to the moth takes place. It is the pupal stage that bridges the inhospitable drought season, lying dormant for months or even years until conditions are right for the moth to emerge. Denlinger (1986) presented evidence for the widespread existence of diapause among tropical insect species. Diapause enables insects to settle in geographical regions with temporary unfavourable environmental conditions.

In the family Lasiocampidae to which the *Gonometa* wild silkmoths belong, Pinhey (1975) noted that some of these moths spend years in the cocoon state before emerging, awaiting a favourable season to burst out. In Japan, Masaki (1980) reported that

lasiocampid moths enter summer diapause as pupae and winter diapause as eggs. In the wild silkmoths of the family Saturniidae, pupal diapause has been recorded in *A. yamamai* (Kato and Sakate, 1981) and in *A. mylitta* (Nayak and Dash, 1991). Egg diapause is recorded in many insects including *Bombyx mori* and *Antheraea yamamai* (Behrens,1984). To be able to forecast accurately on the utilisation of the subject species, there is need to investigate the possibility of pupal diapause and understand some of the factors regulating its maintainance and termination. This will provide useful information because for a successful establishment of silk production, methods should be devised to avoid prolonged diapause at any one of the developmental stages.

1:5 Parasitoids and predators of wild silkmoths

The relationship between entomophagus insects and their hosts requires the employment of certain terms to designate specific relationships (Clausen, 1940). In this study, the relationship between the wild silkmoths and their natural enemies is broadly divided into two, the predators and the parasitoids.

1:5:1 Predators

Many vertebrate and invertebrate predators have been reported preying on wild silkmoths. In Botswana, Hartland-Rowe (1992) reported that up to 70% larvae of *G. rufobrunea* are eaten by predacious insects. These predators include, reduviid bugs

Callilestes gracilis Miller and *Cosmolestes pictus* Klug. He also suspected predation from three species of birds, two roller species,*Corcacias caudata* and *C. garrulus* and one hornbill species, *Tockus erythrorhynchus.* Other vertebrates suspected to prey on cocoons included monitor lizards and crows.

In tasar silkworms, wasps are serious predators during the early stages up to third instar, causing severe loss resulting in partial failure or at times, total loss of silkworm crop (Reddy *et al.*, 1995). They mainly identified two wasp species, *Vespa orientalis* and *Polystes hebracus* as the most serious predators recorded. Jolly *et al.* (1979) recorded the *Canthecona* bug as a serious predator of tasar silkworms. It lives on the haemolymph of the host, which it sucks by piercing the larval body. A single bug can kill 130 to 220 first to third instar larvae in its life span. Non-insect predators of tasar include spiders, lizards, birds, snakes and a thread worm (*Hexamermis* sp.) (Jolly *et al.*, 1979).

1:5:2 Parasitoids

Peigler (1994) listed about 350 species of parasitoids recorded from about 175 saturniid species. Although he attempted to catalog all known parasitoids of Saturniidae of the world, he only listed a few African species mainly from southern Africa. This implies that few records are available from African species. But even in places like North America where a lot of work has been done on wild silkmoths (Tuskes *et al.*, 1996), recent studies reveal that new parasitoid species await discovery (Coffelt and Schultz, 1992, 1993a, b).

A complex of parasitoids of eggs, larvae and pupae have been found to be important in determining population abundance of the different wild silkmoth species (Gowdey,1953; Jolly *et al.*, 1979; Peigler, 1989; Hartland-Rowe, 1992). However, information on the natural enemies of the different species of silk moths occurring in East Africa is lacking. The current study looks at the composition of parasitoids attacking the different developmental stages of selected species of wild silkmoths in E. Africa.

1:6 Species diversity of East African wild silkmoths

Since the colonial days, national research institutions have been building up natural history collections. Unfortunately, most of these collections are not cataloged or recorded in any database form and as such most of the information is inaccessible. Most of the data or information is only available on the specimens as labels. Furthermore, during the colonial period, a lot of the natural history collections were deposited in collections in Europe and America (Van Someren,1988) and there is need to retrieve these information for national and regional use.

A synthesis of information on East African wild silkmoth species into a widely disseminated and easily retrievable computerised database would make it possible to identify the distribution of these species. This would make it easier to study their distributions relative to other environmental factors. The database lists the species name

for each specimen, where and when it was collected and the number of specimens that are from particular geographic areas. Such relational database has already been developed at the Centre for Biodiversity, National Museums of Kenya (Criel *et al.*, 1995). A pilot database and mapping of the East African fauna of hoverflies has been succesfully accomplished (De Meyer *et al.*, 1995).

Geographic Information System (GIS) is a recent computer-based innovation for automating, manipulating and displaying geographic distribution information. Spatial and temporal data are projected in the form of maps. The computerised maps are intended to let researchers identify past and current species ranges, study the spread of exotic species over time, and to determine which areas should be protected (Cohn, 1995). A wide variety of biotic and abiotic coverages (rainfall, elevation, vegetation, temperature, soil type) can be overlayed in the maps. Correlations between the abiotic data and distribution patterns can be done. For example, GIS has been used to study the correlation between the distribution of *Rhipicephalus appendiculatus* in Africa (Perry *et al.*, 1990).

To retrieve some information on the occurrence and diversity of the wild silkmoths so far collected from Kenya, Uganda and Tanzania, it requires one to visit insect collections in these countries and elsewhere. It is also important to do some ground survey and see how many of those collected in the past are still existing. During this study, different insect collections were visited to retrieve some information on the diversity and distribution of the different species of wild silkmoths in the region.

1:7 Foodplants for wild silkmoths

Food plants play an important role in wild silk production. Oberprieler (1987) observed that larval foodplants play an important role in the life of lepidopterans and have a role to play in their conservation. Most non-mulberry silkworms are polyphagous (Jolly *et al.*, 1979). Foodplants of different wild silkmoths have been studied. For tropical tasar silkmoth, eight primary and more than two dozen secondary food plants have been reported (Jolly *et al.*, 1968; Nguyon-cong-Huan, 1974). However very limited literature is available on the hostplants of african silkmoth species (Oberprieler, 1987). The hostplants recorded for *A. venata* in Nigeria by Ashiru (1988) include the Obeche tree, *Triplochiton scleroxylon* K., *Cassia sieberiana* D. C. and *Casuarina equisetifolia* L.. In Uganda, Gowdey (1953) recorded foodplants for *Anaphe infracta* as *Bridelia micrantha* (Luganda, 'Katasemite'), *Cynometra alexandri* (Luganda, 'Nongo') and *Triumfetta macrophylla* (Luganda, 'Beinsamwe'). *Bridelia* was however invariably eaten in preference to the others.

1:8 Justification

Sustainable conservation of biodiversity calls for the involvement of local population in its utilisation and conservation. The african wild silkmoths can be utilised for economic incentive for their conservation because their caterpillars yield silk of commercial value which can be sold for income generation. Silk, the queen of textiles, has

an ever increasing demand all over the world because of its elegance and lustre. Therefore, there are excellent opportunities for any country to increase silk production. Schenk (1981) stressed the need for expansion of silk production to be much more geographically spread, especially in Africa. Wild silk production needs to be introduced in East Africa as a unique eco-friendly agro-practice with the potentials for environmental amelioration, employment generation and export earnings. These can be ideal community based activities practised by rural people on plants adjoining their homesteads.

Very little research however has been done on the African wild silkmoths (Chikwenhere, 1992). Virtually, no results have been reported on the diversity and distribution of silk cocoon forming species, their hostplants, phenology and even their natural enemies. Hence the need to collect some of this information which will provide basis for wild silk farming establishment.

1:9 Objectives

1:9:1 General Objective

The general objective of this work was to study the diversity, distribution of wild silkmoths in East Africa including the phenology of selected species for establishing wild silk production as a unique eco-friendly agro-practice for environmental conservation and income generation.

1:9:2 Specific objectives

1. Determine the diversity and distribution of wild silkmoth species and their foodplants in East Africa.

2. Assess community awereness on the occurrence and economic importance of wild silkmoth species.

3. Study the phenology and characteristics of the different developmental stages of two species, *Gonometa* sp. (Lasiocampidae) at Nguni, Mwingi District and *Argema mimosae* Boisduval (Saturniidae) at Sultan Hamud, Makueni District.

4. Study the post harvest cocoon structure of two species, *Argema mimosae* and *Gonometa* sp. and evaluate them for silk production.

CHAPTER TWO

GENERAL MATERIALS AND METHODS

2:1 Distribution and mapping of wild silkmoths and their hostplants

2:1:1: Wild silkmoth species diversity information

Most records came from natural history collection specimens. The East African wild silkmoth specimens of the following collections were included in the study:

(i) National Museums of Kenya (Nairobi): this collection includes the holdings of the former Corydon Museum and it includes East African as well as non-East Africa materials.

(ii) Natural History Museum (London,UK). Some of the major holdings in the collection are the specimens collected during the colonial days and include that of Van Someren handed over to the institute by him in 1957 (Van Someren, 1988).

(iii) Entomological collections in Uganda and Tanzania. Contacts were made with research institutes in these two countries to determine the existence of entomological collections that include wild silkmoth species. These contacts were made through the recently formed East Africa-Net part of the BioNet-International which is a new initiative to mobolise and pool the world's biosystematic resources to support developing country programmes for sustainable agricultural development and the conservation and wise use of the environment and biodiversity. In Uganda, information was collected from specimens housed at the

Insect Museum, Kawanda Research Institute, Kampala and from the Forest Reaearch Department, Nakawa, Kampala.

2:1:2 Hostplant data

Plants on which cocoons or larvae were collected were identified at the East Africa herbarium housed at the National Museums of Kenya. Two case studies were carried out for *Bridelia micrantha*, the hostplant for the wild silkmoth *Anaphe panda* and *Sclerocarya birrea* the host plant for the wild silkmoth *Argema mimosae*.

2:2 Field study sites

Initial survey and collection of wild silkmoths were carried out around Sultan Hamud (2° 1'S, 37° 22'E) and Wote (1° 47', 37° 38' E) both in Makueni District; around Nguni (2° 12' S, 38° 16'E) in Mwingi District ; around Kamaguti (0° 40' N, 35°12' E) in Uasin Gishu District and around Kakamega Forest (0° 16' N 34° 53' E) in Western province of Kenya (Fig.3.1). Cage experiments were carried out at two of these sites, Nguni and Sultan Hamud. These study areas were chosen on the basis of the availability of foodplants for the wild silkmoth species and accessibility. For example Nguni is about 200 km from Nairobi, has unreliable rainfall but the indegenous fauna and flora are still quite intact and the *Acacia* trees on which *Gonometa* sp. feeds are abundant (Coe and Beentje, 1991). This site is very suitable as according to Chikwenhere (1992), the African silkmoth,

Gonometa rufobrunnea is predominantly a dry-season insect, further more the human population of this area hardly gets any sufficient food crop due to persistent drought. They are a deserving community for the wild silkmoth project.

2:3 Phenology studies in the field

Selected hostplants were eclosed with a metal-wire cage (Plate 3.1). The caged tree was seeded with first instar larvae obtained from net sleeves tied on adjacent trees with cocoons from whose moths eggs were obtained. These larvae were observed untill the spinning of cocoons was completed. During their growth, number of larvae dying during each instar were recorded. The cocoons were marked, showing the date of spinning and then harvested after a minimum of seven days and taken to ICIPE, Nairobi for further observations that are outlined in the specific chapters. Harvest was done after the minimum of seven days so as to allow the enclosed larva to complete pupation. The study covered twenty four months starting from January 1996 to December 1997. During these months, meteorological parameters *viz* temperature, relative humidity and rainfall were recorded.

2:4 Studies in the laboratory

2:4:1 Pupal duration

Cocoons were collected from the hostplants and from the caged hostplants in the field and brought to ICIPE laboratories at Duduville, Nairobi. Cocoons collected from the cages had the date of spinning marked on them using a permanent ink pen (plate 3.2). Some of the cocoons were observed in the laboratory at controlled temperature of 28° C, 60-70 % relative humidity and a photophase of 12 : 12 (L:D). The others were observed under room temperature. Emerging parasitoids were collected, pinned and identified. The cocoons which were not parasitised were observed until moth emergence. The date of moth emergence was recorded and weights of the cocoon shell and moth taken.

2:4:2 Egg parasitoids

Data on egg parasitoids was also obtained from eggs collected from the field sites and brought to the laboratory for observations. The eggs were kept in glass vials under room conditions. The vials were closed with cotton wool which was kept moist by applying a few drops of water. Collection site and initial number of eggs was written on the vial label. The emerging parasitoids were pinned and identified.

2:4:3 Adult life span

The life span was recorded for any adults that emerged. The fecudity of females was determined by counting the number of eggs laid during the entire life span. In the case of emerging adults, a male and female were placed together in a well ventilated insect rearing cage to ensure that the female mated. In case the male died ealier, it was replaced immediately to ensure that the female mated.

2:5 Data analysis

The data was analysed according to species and sex. For the eggs, percentage parasitism by each species of the parasitoid was calculated. Larval, pupal and adult life span were compared between species, and where possible sexes within species, using analysis of variance (PROC GLM, SAS Institute, 1988). In each experiment, at least fifty observations were considered for analyses. The means in each of the analyses were separated using the Student-Newman-Keuls (SNK) procedure (SAS Institute, 1988). The relationship between female moth weight and number of eggs laid was studied using the Pearson's correlation (Elhance, 1977). During reeling of silk from the *Gonometa* sp. cocoons, filament length, fibre weight, floss weight, pupa weight, number of breaks, continous non-breakable length, raw silk percentage means were compared among males and females using the t-test procedure (SAS Institute, 1988).

Figure 2.1: Map of Kenya showing field study sites

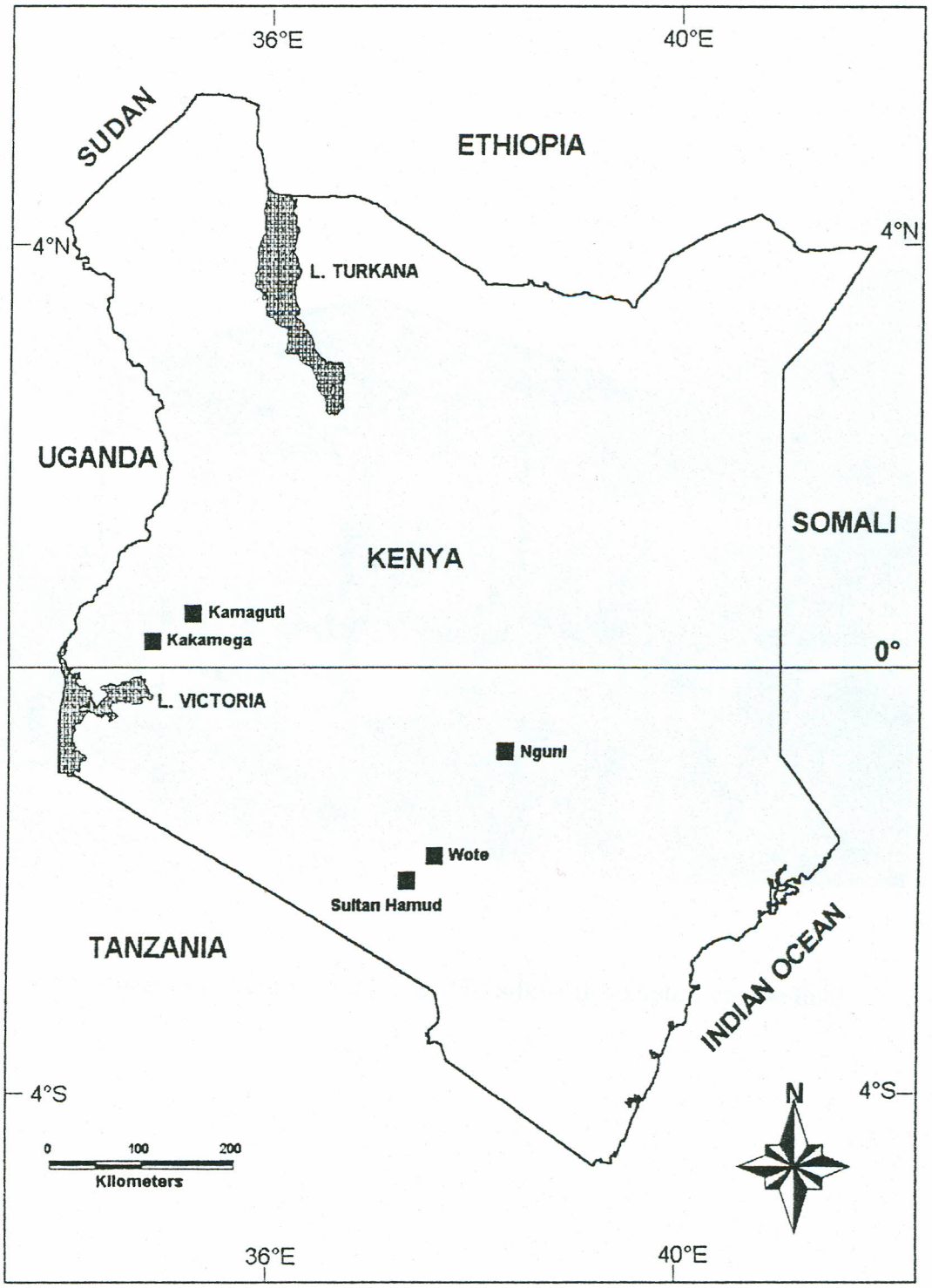


Plate 2.1: Metal – wire cage used for enclosing wild silkmoth hostplants in the field.

Plate 2.2: *Argema mimosae* cocoon with a mark showing the date (14th May 1997) it was spun in the field.

CHAPTER THREE

WILD SILKMOTH DIVERSITY, HOSTPLANT DISTRIBUTION AND COMMUNITY AWARENESS

3:1 INTRODUCTION

The real threat to the African flora and fauna is the rapid human population growth which has led to increased demand for agricultural land and fuel wood. To save the declining biodiversity, there is need to provide economic incentives to the rural communities for conservation. Recent studies in different African countries suggest that the economic incentives for biodiversity conservation carry an additional advantage of leading to voluntary changes in behaviour rather than forced changes (Munthali and Mughogho, 1992; Mkanda, 1992; Child, 1988; Frost, 1991).

This study was designed to investigate some aspects of wild silkmoth species in East Africa with the aim of providing some insight into the possibility of establishing wild silk production for income generation in this region. Wild silk production is an eco-friendly, agro-based venture with a great potential for environmental amelioration, employment generation, artisans development and export earnings. The specific objectives were to study the diversity of silk cocoon forming moth species, the occurrence and distribution of the hostplants and the community's awareness towards these species. Such

information is required to develop management plans for the conservation and sustainable utilisation of these indigenous biological resources for income generation. By understanding the wild silkmoth diversity, it can be conserved, and the society may be helped to utilise it. Understanding comes about through finding out what is already known about these species and investigating what is unknown. Utilisation comes about by disseminating this information to the many potential users, many of whom do not as yet even know their importance.

3:2 MATERIALS AND METHODS

3:2:1 Survey for the wild silkmoth species

Initially, insect collections at the National Museums of Kenya in Nairobi , Kenya; Kawanda Agricultural Research Institute in Kampala, Uganda; the Forest Research Institute at Nakawa in Kampala, Uganda and the Natural History Museum in London, United Kingdom, were used to assess the historical occurrence of the wild silkmoth species in East Africa. All the silk cocoon forming species in three lepidopteran families Lasiocampidae, Saturniidae and Thaumatopoeidae were recorded. The cocoon structure, size and colour were noted. The sizes of the cocoons were loosely classified on the basis of length as follows: small, less than 3 cm; medium, 3 - 5 cm; large, 5 - 8 cm and huge, more than 8 cm. The date collected, collector, locality collected from, hostplant information and other African distribution were also recorded. These three moth families

were selected for this study because majority of the wild silkmoths so far utilised in different parts of the world belong to these families (Peigler, 1993).

Field trips were made to various localities in Kenya (Fig.2.1) and cocoons, and silkworms were randomly sampled and silkmoths trapped with light. Collected cocoons and mature larvae were separately placed in well-ventilated insect rearing cages and observed in the laboratory in Nairobi till moth emergence. Emerging moths were then identified using keys and museum reference collections.

3:2:2 Foodplant distribution for the silkmoth species

During the retrieval of information from wild silkmoth specimens in insect collections, any record on the hostplant was recorded. This was also done for specimens collected during the field survey for which specimens of their hostplants were brought to Nairobi and identified at the East Africa Herbarium. Two case studies for the distribution of *Bridelia micrantha* and *Sclerocarya birrea* the hostplants for two of the wild silkmoth species *Anaphe panda* Walker and *Argema mimosae* Boisduval respectively were done. In addition to localities recorded from the survey, more records on the distribution for these hostplants were obtained from the plant collection at the herbarium and plotted on maps.

3:2:3 Community awareness

3:2:3:1 Questionaire

A questionaire was distributed to the community in two villages, Ikuywa and Muhudu near the Kakamega forest (Fig. 3.1). This site was chosen for this survey because Kakamega forest provides a rich and diverse habitat for many plants and animals (Khamala, 1984) and has been found to fall within one of the areas of high faunal diversity in Kenya, especially for butterflies (Larsen, 1991) which fall in the same insect order with silkmoths. The questionaire focused on: community awareness/opinion of wild silkmoths production , availability of hostplants in their farms and current income source. From the two villages, fifty people (26-80 years) were randomly chosen for the survey.

3:2:3:2 Farmers' demonstration and training

Between April 1996 and December 1997, a total of 886 farmers from different localities in Kenya, Uganda and Tanzania were involved in ICIPE's sericulture demonstration and training activities and a discussion was held with each group. An introduction about silk and wild silkmoths was done and possible economical and environmental benefits outlined to them. They were then shown different developmental stages of the silkmoths and the reeling of silk fibres from cocoons (Plate 3.4). The farmers

were then asked about their previous knowledge about the cocoons and their opinion on being involved in wild silk production as an additional income generating activity.

3:3 RESULTS

3:3:1 Wild silkmoth species diversity

A total of 58 species of wild silkmoths were recorded occurring within 170 localities in the three countries namely Kenya, Uganda and Tanzania (Appendix 1). Uganda had 36 of the species in 68 localities, Kenya 32 species in 73 localities and Tanzania 21 species in 29 localities. The number of species in each family for the three countries were: Kenya, 17 species in family Lasiocampidae, 13 in Saturniidae and 2 Thaumetopoeidae; Uganda, 21 in Lasiocampidae, 9 in Saturniidae and 6 Thaumetopoeidae; Tanzania, 11 Lasiocampids, 8 Saturniids and 2 Thaumetopoeidae. The species diversity in the three families also varied with family Thaumetopoeidae, recording six species in one genus, Lasiocampidae 33 species in 17 genera and 19 species in family Saturniidae in 6 genera (Tables 3.1 & 3.2). Although the number of cocoon forming species was high, the majority had small and loosely spun cocoons. The dates of collection are quite historical, the majority being more than thirty years ago. Assessing from the collector's names, most of them are foreign with only a few indigenous ones.

The diversity of the species collected during the field survey is shown in Table 3.3 and Plates 3.1 - 3.3. Seven species were recorded, four lasiocampids, two saturniids and one thaumetopoidae. In the Genus *Gonometa*, the moths collected were not like any that have been so far identified in this genus and were thus designated *Gonometa* sp.

3:3:2 Distribution of hostplant

Only a very small proportion of the available species of silkmoths had hostplant data. The case study on *Bridelia micrantha* showed that it has been recorded in 103 localities (Appendix 2) and is widely distributed in the three countries (Fig. 3.2). The tree is found in homes adjacent to Kakamega forest and 84 % of the questionaire respondents had the tree in varying numbers in their land (Table 3.5) and all of them had seen it in the forest. The community valued the tree and used it for housing, fencing and as a charcoal source. The study on *Sclerocarya birrea*, the hostplant for *Argema mimosae* was also widely spread in the three countries (Fig. 3.3) and has been recorded in 78 localities (Appendix 2).

3:3:3 Awareness and community's opinion towards wild silk production

All the questionaire respondents and all farmers participating in the demonstrations had seen wild silkmoth cocoons and confirmed their unawareness as to their potential as a source of silk (Tables 3.4 and 3.5). On wild sericulture as an extra source of income, it

was favoured by the majority (98 %) of the questionaire respondents who confirmed that they would pursue it in addition to their normal activities.

3:3:4 Community's income

The major sources of income to the questionaire respondents are shown in figure 3.5. The majority obtained income from farming (86%), others depended upon both farming and from the official employment (8%), running small businesses (4%) and from other activities (2%).

3:4 DISCUSSION

The diversity of wild silkmoths species is high and the distribution is widespread in the three East African countries. These results give a good indication of high potential for wild silk production in East African countries. However, a number of the cocoons were too loosely spun and may not be economical in silk production. There were however some genera like *Gonometa, Argema* and *Anaphe* which had characteristics similar to those of the cocoons that have been used in Nigeria (Ashiru, 1988) and Asian countries (Jolly *et al.*, 1979).

Lack of very recent collection dates and mostly lack of many indigenous names under the collector's column indicates that most of the collectors in East Africa were

foreigners during the colonial and post colonial era. These observations are in line with those of Oberprieler (1995) who reported that sericulture has never been a major industry in Africa but only a few european sericulturists in the past made some attempts on the wild sericulture in Africa.

Hostplants' data on most museum specimens was missing and this is probably because most collectors catch adult specimens with traps and may never know what the larvae, the principal feeding stage, lives on. This is in agreement with Oberprieler (1987) who noted that the importance which larval foodplants play in the life of lepidopterans and the value they have in both systematic research and conservation has received little attention. This problem can only possibly be solved through detailed observations in the field. During the field survey a lot of information on hostplants was recorded and even for some of the species like *Argema mimosae* alternative hostplants *Spirostachys venenifera* and *Lannea schweinfurthii* were recorded in addition to the main hostplant *Sclerocarya birrea* (Table 3.2). This gives a wider possibility of this species being utilised for silk production in more areas where all hostplants occur together or where just one or two occur abundantly. In places like Kakamega forest area the hostplant for *Anaphe panda* is found in majority of the farmers' homesteads and more land in the forest like the shrub areas (Fig. 3.1) could be utilised. Cultivation of *Bridelia micrantha* can be done from cuttings which according to Gowdey (1953) grow fast and are ready for silkworm rearing within a year.

It is interesting to note that most of the people were aware of the existence of the wild silkmoth cocoons but were not aware that they were made of silk. The farmers in their daily lives interact a lot with nature and this could explain their high awareness on the existence of cocoons. The lack of awareness on the economic importance of cocoons is possibly due to the fact that sericulture has never been a major industry in many countries in Africa and the only use of the cocoons has only been in traditional dances where they are filled with pebbles and used as rattles (Van Huis,1996).

The heavy reliance on subsistence farming for source of income may result in most of the farmers having quite little income and this may result in illegal over-exploitation of biological resources as reported by Khamala (1984). In Kasungu National Park in Malawi, local people have a gross income of US$ 198/ha and US$ 230/ha from tree caterpillars and beekeeping micro-enterprises respectively. These earnings are higher than the income realised by subsistence farmers from maize, beans and groundnuts (Mkanda, 1992). The introduction of wild silk farming in East Africa may offer an important economic incentive to farmers. In Nigeria, a gown of indigenous silk sells for up to 300 US$ (Peigler, 1993). Other than monetary earnings from the sale of wild silk, the enterprise will also enhance the conservation of the hostplants and the wild silkmoth species. For successful utilisation of these species of wild silkmoths, further studies on the phenology and other factors affecting the populations of some of the promising species in the field are warranted.

Table 3.1: Silk cocoon forming genera recorded in the family Lasiocampidae for the three countries, Kenya, Uganda and Tanzania.

Genus	Species per Genus	Cocoon structure	Species in Kenya	Species in Uganda	Species in Tanzania
Bombycopsis	2	small, compact	2	1	1
Ceratopacha	1	small, compact	1	-	1
Chrysopsyche	1	soft, small	-	1	-
Diapalpus	1	soft, small	-	1	-
Gonometa	7	compact, medium-large	4	4	1
Grammodora	1	soft, medium	1	-	1
Haplopacha	1	soft, small	1	-	1
Leichriolepsis	5	soft, small	1	4	1
Leipoxais	2	soft, medium	1	1	1
Mallocampa	1	compact, small	-	1	-
Mimopacha	1	soft, medium	1	1	1
Pachymeta	1	compact, large	-	1	-
Pachypasa	2	soft, large	1	1	1
Pseudometa	1	soft, small	1	-	-
Streblota	2	soft, small	-	2	-
Taragama	3	soft, small	3	2	2
Trabala	1	small, soft	-	1	-

Table: 3.2: Silk cocoon forming genera recorded in the families Saturniidae and Thaumatopoeidae in Kenya, Uganda and Tanzania.

Genus	Family	No. of species	Cocoon structure	Species in Kenya	Species in Uganda	Species in Tanzania
Antistathmoptera	Saturniidae	1	compact, medium	-	-	1
Argema	Saturniidae	2	compact, medium	2	-	-
Epiphora	Saturniidae	11	compact, small	9	6	6
Goodia	Saturniidae	2	soft, small	1	1	-
Holocera	Saturniidae	1	rough, medium	1	1	1
Ludia	Saturniidae	1	soft, small	-	1	-
Anaphe	Thaumetopoidae	6	huge,compact	2	6	2

Table 3.3: Species diversity of cocoon forming silkmoth species collected during the field surveys.

SPECIES	FAMILY	LOCALITY	HOST PLANT
Gonometa sp.	Lasiocampidae	Nguni in MwingiDistrict and Sultan Hamud in Makueni District	*Acacia elatior* *A. senegal.*
Gonometa sp.	Lasiocampidae	Kamaguti in Uasin Gishu District	*Acacia hockii* and Wattle tree
Ceratopacha sp.	Lasiocampidae	Uasin Gishu District Kamaguti	cocoons found on *Carissa edulis*
Epiphora vacuna	Saturniidae	Kakamega forest	adult caught at light trap
Anaphe panda	Thaumetopoeidae	Kakamega forest	*Bridelia macrantha*
Lechriolepsis pulchra	Lasiocampidae	Kakamega forest	unidentified shrubs
Argema mimosae	Saturniidae	Makueni District Wote & S'Hamud,	*Sclerocarya birrea, Spirostachys venenifera* and *Lannea schweinfurthii*
Philotherma sp.	Lasiocampidae	Sultan Hamud	*Sclerocarrya birrea*

Table 3.4: Farmers participating in training and demonstrations on wild silkmoth conservation and economic importance (demonstration 1,on site at farmers' locality; 2, at ICIPE).

Locality	Country	No. of farmers	Type of demonstration	% aware of cocoon existance	% aware of economic importance
Uasin Gishu	Kenya	47	1, 2	100	0
Kakamega	Kenya	85	1,2	100	0
Mwingi	Kenya	62	1,2	100	0
Siaya	Kenya	34	1,2	100	0
Homabay	Kenya	37	1,2	100	0
Sultan Hamud	Kenya	50	1	100	0
Machakos	Kenya	115	1,2	100	0
Mombasa	Kenya	105	1,2	100	0
Kajiado	Kenya	45	1,2	100	0
Kiambu	Kenya	38	1,2	100	0
Embu	Kenya	48	1,2	100	0
Thika	Kenya	47	1,2	100	0
Nyeri	Kenya	30	1,2	100	0
Laikipia	Kenya	27	1,2	100	0
Hoima	Uganda	32	2	100	0
Masindi	Uganda	10	2	100	0
Kibale	Uganda	14	2	100	0
Entebbe	Uganda	10	2	100	0
Arusha	Tanzania	50	1,2	100	0

Table 3.5: Questionaire responses from 50 respondents in two villages, Ikuywa and Muhudu in Kakamega, Kenya.

Questions	% positive response
1. Do you have *Bridelia micrantha* (Shikangania) in your land and about how many?	
Zero	16
1-5 trees	38
6-10 trees	30
more than ten	16
2. Have you seen the tree in the Kakamega forest?	100
3. Have you ever noticed on these trees	
a. cream flat eggs	16
b. large number of caterpillars with white hairs	100
c. Silk nests (as shown by interviewing person)	100
4. Are these trees used by the community for	
a. building houses and stores	98
b. poles for fencing	92
c. burning charcoal	100
d. other uses	70
5. Would you find time to produce these silk nests if they would fetch you some income and at the same time continue with your normal subsistence activities?	98
6. What is your main income source?	
a. Farming	86
b. farming and official employment	8
c. businness	4
d. others	2

Figure 3.1: Kakamega forest, study sites and vegetation zones.

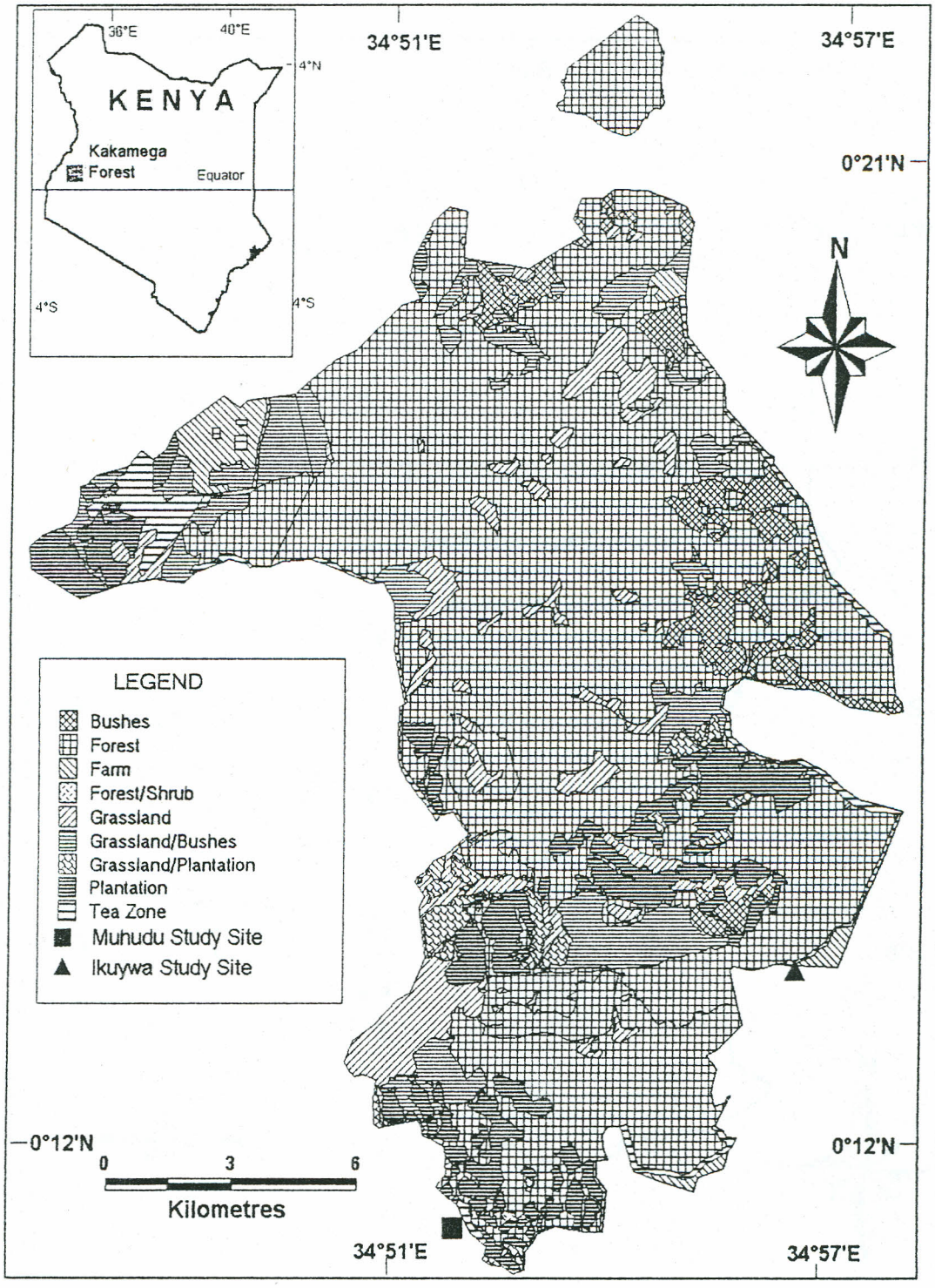


Figure 3.2: East African distribution of *Bridelia micrantha*, a foodplant for the silkworms of *Anaphe panda*.

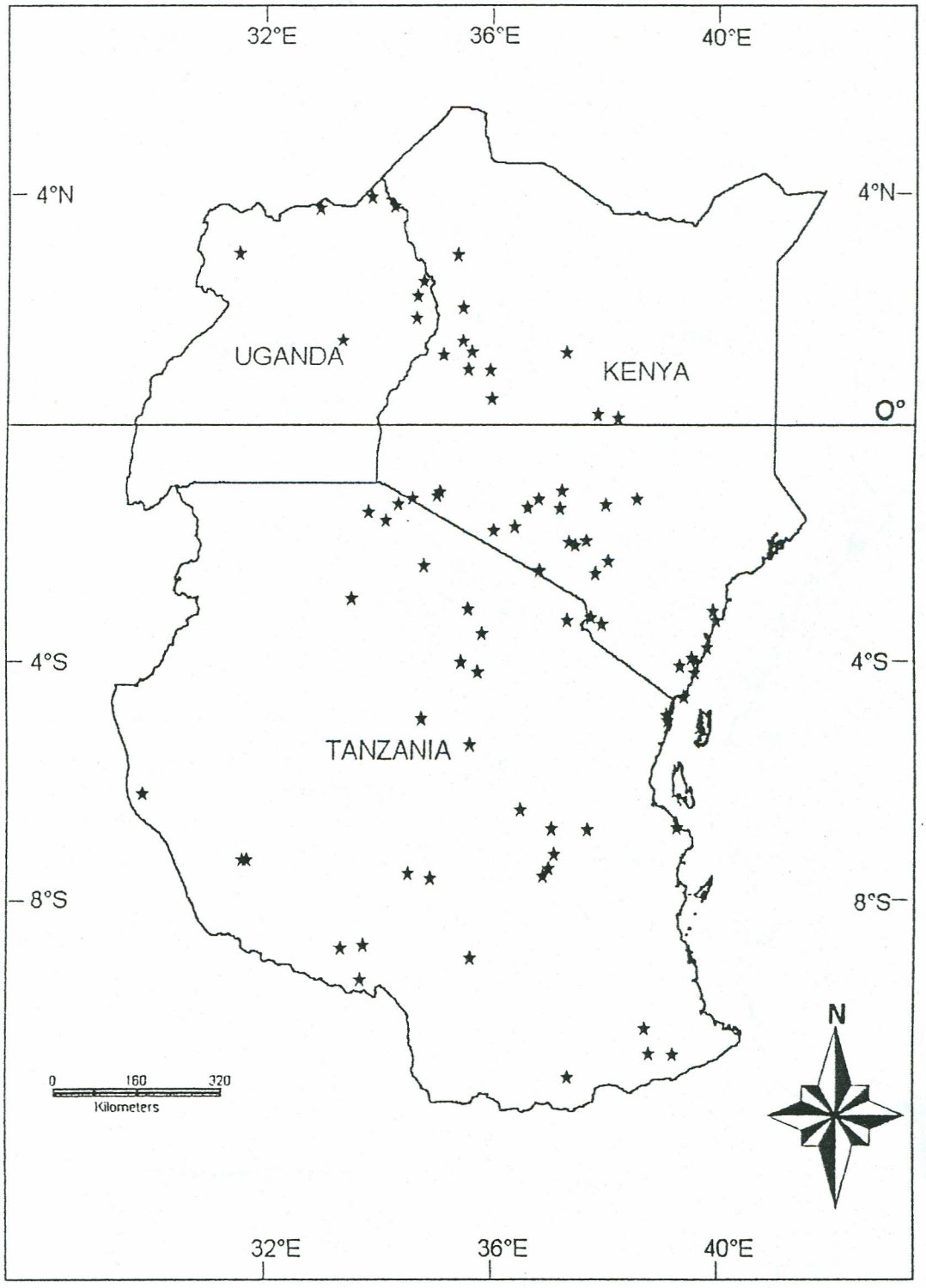


Figure 3.3: East African distribution of *Sclerocarya birrea*, a foodplant for *Argema mimosae* silkworms.

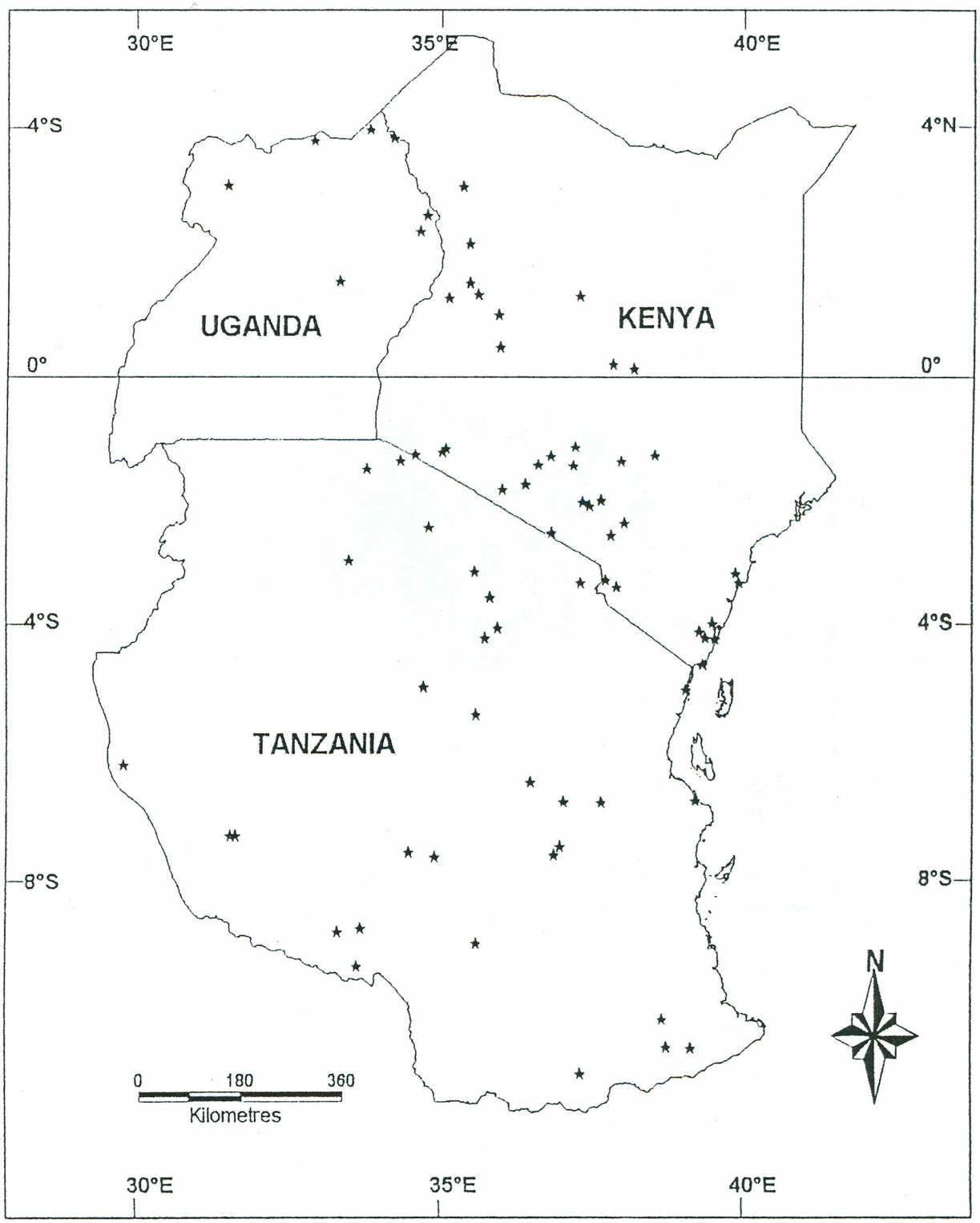


Figure 3.4: The major sources of income for questionaire respontents in Ikuywa and Muhudu villages, Kakamega, Kenya.

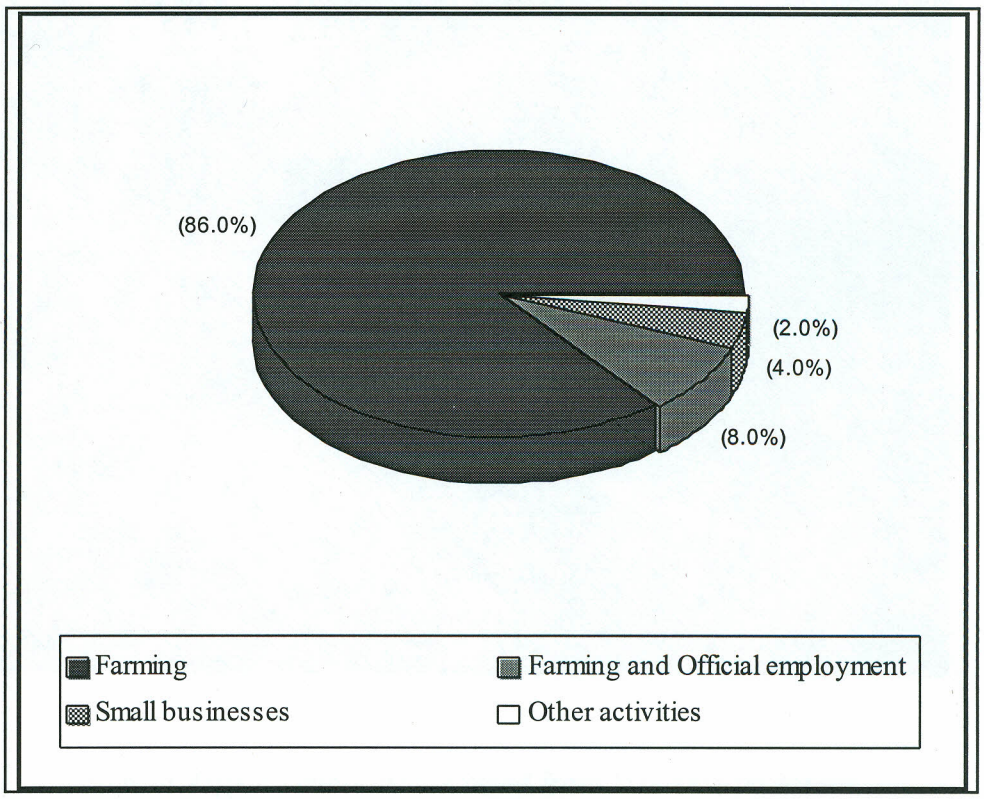


Plate 3.1: Cocoons of *Argema mimosae* collected from *Sclerocarya birrea* at Sultan Hamud, Kenya

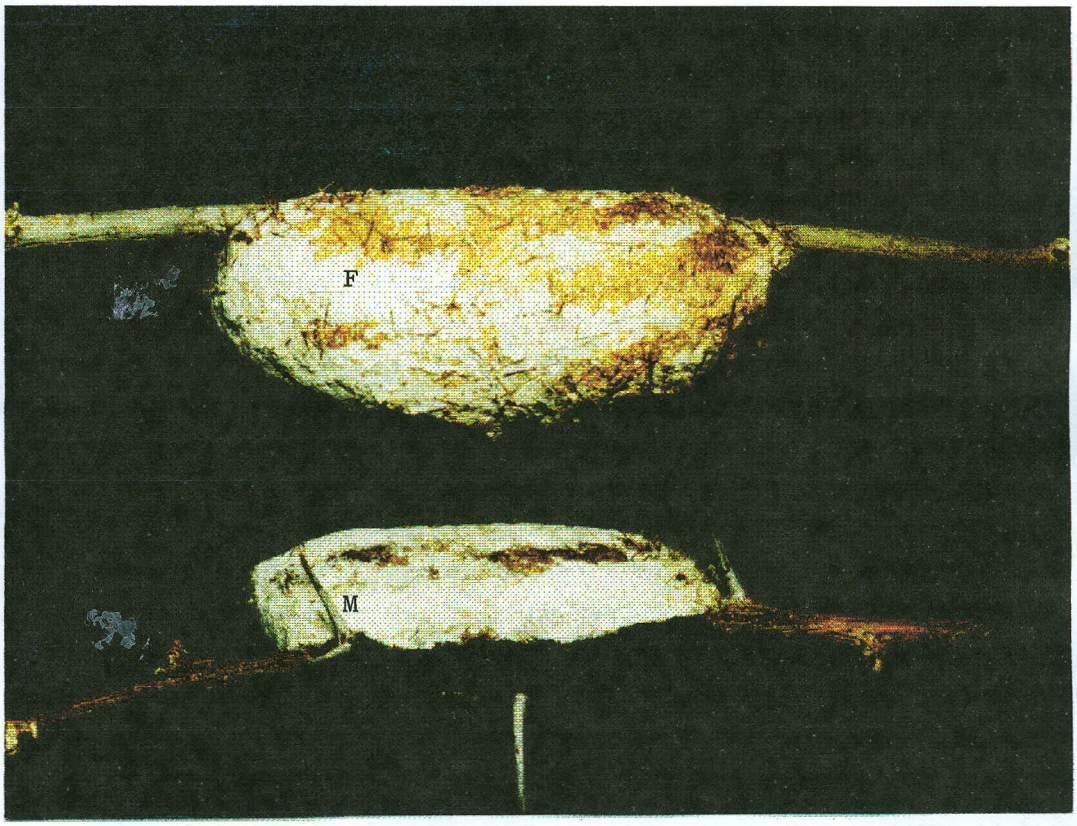


Plate 3.2: Female (F) and male (M) cocoons of *Gonometa* sp. collected from Nguni, Mwingi District, Kenya

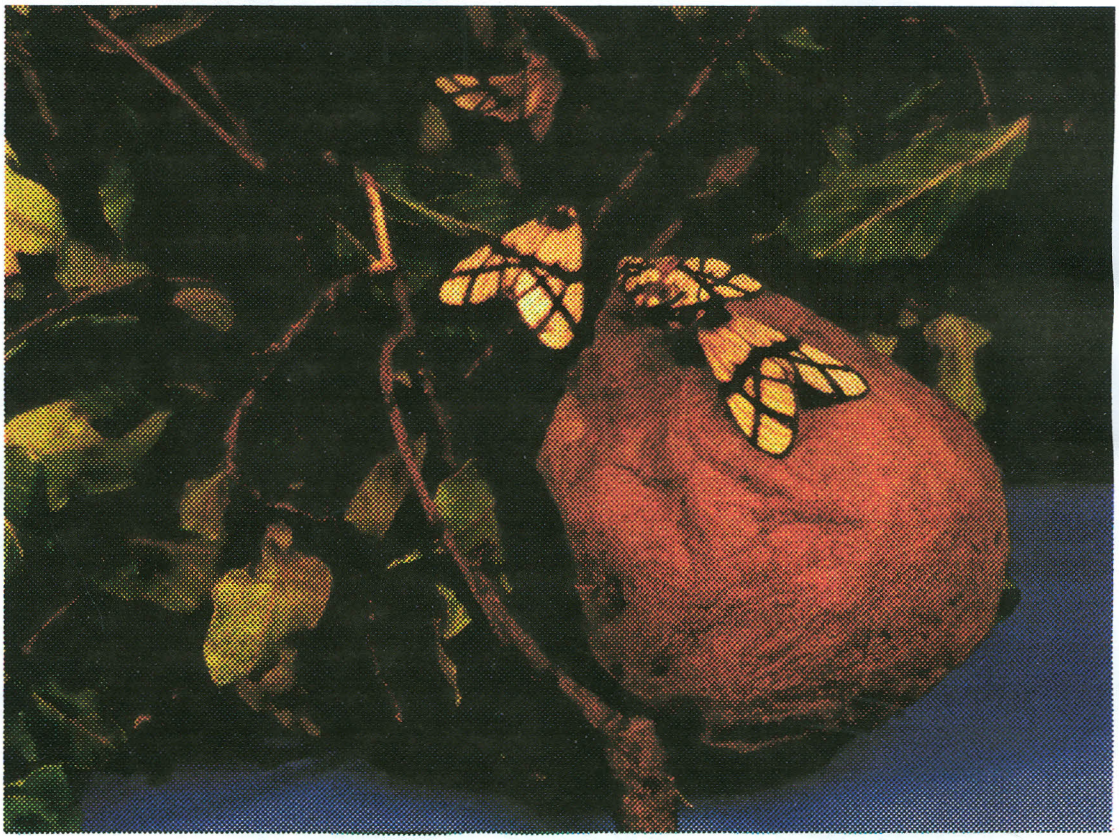


Plate 3.3: A silknest of *Anaphe panda* with the moths emerging. This silknest was collected from *Bridelia micrantha* in Kakamega forest, Kenya

Plate 3.4: Training and demonstration to farmers at the sericulture laboratories at ICIPE on the occurrence, importance and utilisation of wild silkmoth species

CHAPTER FOUR

PHENOLOGY, PREDATORS AND PARASITOIDS OF SELECTED SILKMOTH SPECIES, *GONOMETA* SP. AT NGUNI AND *ARGEMA MIMOSAE* AT SULTAN HAMUD, KENYA.

4:1 INTRODUCTION

Environmental factors including the hostplant state play an important part on the development of insects (Stamp, 1990; Sinha and Chaudhuri, 1992). It is important to understand the seasonal timing of their growth and development that is their phenology inorder to be able to utilise them. Insects are also their own worst enemies and wild silkmoths are more susceptible to economic loss from parasitism than the domestic ones as they are raised outdoors. It is important to identify these parasites so that their regulatory effects can be deliberately reduced. In Asia, parasitoids that are particularly troublesome to wild sericulture are chalcidoid wasps attacking eggs and tachinid flies attacking caterpillars (Jolly *et al.*, 1979; Thangavelu *et al.*, 1988; Peigler, 1989). Peigler (1994) listed parasitoids attacking saturniid silkmoths in the world but prominently lacking are species from Africa. However, even in places like the U.S.A., studies by Coffelt and Schultz (1992, 1993 a, b) reveal that new parasitoid records of wild silkmoth species still await discovery.

This investigation was carried out inorder to describe the characteristics and duration of the different life stages of *Argema mimosae* and *Gonometa* sp. in the field. In addition, temporal and relative importance of natural enemies, temperature, relative humidity, rainfall and host-plant state were recorded. Accurate knowledge on these factors is needed for proper development of sustainable management strategies. For example, the period an insect spends during its vulnerable life stages may affect the rates of attack by natural enemies, thereby influencing the overall population dynamics.

4:2 MATERIALS AND METHODS

4:2:1 Phenology and characteristics of adults, eggs, larvae and pupae

Observations were carried out in wire cages (5m x 5m x 5m) (Plate 2.1, see Chapter 2) and in net-sleeves in the respective sites (Plate 4:1). *Argema mimosae* studies were carried out on the host-plant *Sclerocarya birrea* (A. Rich.) Hochst. at Sultan Hamud and *Gonometa* sp. studies at Nguni on *Acacia elatior* Brenan. The form and characteristics of each stage were noted and the developmental duration of each stage in the field were recorded. Host plants at each site were searched for egg clusters to determine the oviposition pattern of these silkmoths.

Cocoons of each species were randomly sampled from the field and observed in the laboratory till moth emergence or till parasitoids emerged. To study the effect of

controlled environmental conditions, some cocoons which were formed inside the study cages were marked to indicate the date they were spun. These marked cocoons were divided into two groups, one observed under room temperature and the other in the incubator and the time taken till moth emergrnce (pupal life) was recorded. To study the correlation between female moth weight and fecudity, emerging moths were weighed individually on a digital electronic balance and total number of eggs laid by each female were recorded. The data was subjected to statistical analysis to calculate the correlation coefficient between the female moth weight and fecudity. The size of eggs of both species were measured under the light microscope. To observe the surface structure of the eggs, whole eggs were fixed in 2.5 % glutaraldehyde and dehydrated with ethanol (70-100 %). They were mounted on aluminium stubs with silver suspension, sputter coated with gold and examined and photographed under the scanning electron microscope (Joel JSM-T330A).

4:2:2 Environmental factors and hostplant state

For all the 24 months that the study was undertaken, prevailing maximum and minimum temperatures, relative humidity and rainfall were recorded for each study site. The host-plants were observed and their state classified into categories: green, shading leaves, leafless and sprouting leaves. The relationship between these hostplant states and the occurrence of the different developmental life stages of the wild silkmoths was observed.

4:2:3 Determination of parasitoids and predators

Eggs and cocoons collected from the field were kept under laboratory conditions to observe the emergence of parasitoids. This method enabled to determine the percent parasitism and identification of the parasitoids involved. In the cage all insects and other arthropods within the vicinity of the silkmoths were recorded. In the net sleeve, similar observations were made. Sampling was carried out occasionaly in the uncaged host-plants for parasitoids and predators.

4:3 RESULTS

4:3:1 Phenology, characteristics and parasitism of the silkmoth stages

4:3:1:1 Adults

The study revealed two yearly moth flight periods of *Argema mimosae* and *Gonometa* sp. The flight of the first generation was between March and April (Table 4.1) and that of the second generation was between September and November.

Gonometa sp. showed very distinct sexual dimorphism. The females were larger than the males (Plate 4.2). On the other hand, *A. mimosae* adults did not exhibit such

clear-cut sexual dimorphism. Even the antennae which are commonly used to distinguish male and female moths were comb-like in both sexes (Plate 4.3). The abdomen was used to distinguish the sexes. Females had a broad one compared to a slender one in the males (Plate 4.3).

There was no significant difference between the life span of the adults of *A. mimosae* and *Gonometa* sp. (Table 4.2). However, females of both species weighed significantly more than males. The mean weight for *A. mimosae* female was 2.7 ± 1.0 g and that of males was 1.8 ± 1.2. g while those of *Gonometa* sp. weighed 3.3 ± 2.0 g and 0.9 ± 0.5 g respectively. The mean number of eggs laid was 301 ± 114.0 for *Gonometa* sp. and 359.9 ± 71.8 for *A. mimosae*. There was a positive and highly significant correlation ($r = 0.62$, $p = 0.001$) between the female moth weight and number of eggs laid.

4:3:1:2 Eggs

There was a yearly bimodal oviposition pattern by the two species of wild silkmoths in the field during the study period. Oviposition by the moths of the first generation was observed in March/April and that of the second generation moths was observed in October/November. Observations in the field showed that eggs of *A. mimosae* were laid in smaller egg clusters than those of *Gonometa* sp consisting of 1.4 ± 0.6

to 2.3 ± 1.6 and 17.3 ± 14.3 to 34.1 ± 15.5 eggs respectively (Table 4.3). In both species, eggs were deposited on various substrates (Plate 4.4) in varying numbers as shown in Table 4.3. The eggs of *Gonometa* sp. hatched within 11.3 ± 0.1 days while those of *A. mimosae* hatched within 10.9 ± 0.3 days (Table 4.2).

The *A. mimosae* eggs were elliptic in shape, dorso-ventrally flattened and bilaterally symmetrical along the anterioposterior axis. *Gonometa* sp. eggs were oval in shape. At oviposition, eggs of both species were white and attached to the substrate with a brown gummy coating of meconium. The major and minor axis of *A. mimosae* eggs were significantly longer than those of the *Gonometa* sp. (Table 4.4). Morphological observations using scanning electron microscope (SEM) revealed that *A. mimosae* eggs had a micropyle region with a single external opening and the general chorionic pattern consisted of knobs approximately round in shape with numerous aeropyles found in between these knobs (Plate 4.5). The micropyle on the eggs of *Gonometa* sp. showed various patterns within eggs from the same female, having seven, six small and five small openings (Plate 4.6). The knobs on the chorionic surface of *Gonometa* sp. eggs consisted of raised portions with crater-like structure between which numerous aeropyles occurred (Plate 4.7).

Different species of hymenopteran egg parasitoids were observed in the laboratory from eggs collected from the field. It was interesting to note that eggs of *A. mimosae* from Sultan Hamud and those of *Gonometa* sp. from Nguni were both attacked by the same

parasitoids *Mesocomys pulchriceps* Cameron (Eupelmidae) and *Pediobius anastati* (Crawford) (Eulophidae) though in varying percentages (Fig. 4.1). During the short rains of 1997, a comparative study on percent parasitism on eggs of both species by the two parasitoids indicated that 37 % of *Gonometa* sp. eggs were parasitised by *M. pulchriceps* and 0.4 % by *P. anastati*.; in *A. mimosae*, 23 % egg parasitism was by *M. pulchriceps* and 3 % by *P. anastati* (Fig. 4.1). During this study, *Telenomus* sp. (Scelionidae) (1 %) and unidentified Encyrtidae (0.4 %) were also recorded only from eggs of *A. mimosae* (Table 4.5).

4:3:1:3 Larvae

Like the adult and egg stages, the temporal distribution of the silkmoth larvae at the two study sites was distinctily bimodal during each year of study (Table 4.1). Larvae from the first generation of moths were found in the field in March, April and May. Those from the second generation were found in October, November and December. The mean larval period from first instar to the onset of spinning was 53.5 ± 6.2 days for *Gonometa* sp. and 32.9 ± 3.8 days for *A. mimosae* (Table 4.2).

An overall mortality rate of *Gonometa* sp. larvae reared on the caged hostplant was 82.9 % during the short rains of 1996 (Table 4.6). The mortality for the same species during the short rains of 1997 was 78.9 % (Table 4.7) while that of *A. mimosae* was 80.6 % during the short rains season of 1997 (Table 4.8). Rearing *Gonometa* sp. larvae in net-

sleeves in the cage during the long rains season of 1997 reduced the larval mortality to 23.9 % (Table 4.9).

The species composition of larval predators observed in the field are presented in Table 4.10. Identification for some of the predators was only possible up to the generic level. The predators belonged to three insect orders: Hemiptera, Orthoptera and Hymenoptera. Some spiders were also observed (Plate 4.10) but could not be identified. Formicid ants were quite abundant, *Crematogaster* sp. of sub-family Myrmicinae was associated with *A. mimosae* and unidentified ants of the sub-family Formicinae attacked young larvae of the *Gonometa* sp. Pentatomid bugs of the sub-family Asopinae, *Maccroraphis spurcata* Walker were observed in Sultan Hamud sucking the body fluids of *A. mimosae* larvae. The orthopteran, *Cilnia* sp. (Family Mantidae, sub-family Mantinae) was observed feeding on the 5th instar larvae of *A. mimosae* at Sultan Hamud and was also collected in Nguni in close vicinity of the *Gonometa* sp. larvae.

Argema mimosae larvae which were solitary showed distinct form and colour changes from the first to the fourth instar. First instar larvae are black with anterior and posterior regions being orange in colour (Plate 4.8) and have six rows of tubercles. The orange/black colour of the larvae was a very close match of the colour of the hostplants' young leaves (Plate 4.8). Second instars are orange green with six rows of tubercles. Third instars are green with six rows of tubercles whose tips are orange. Fourth and fifth instars are green with only two dorsal rows of green tubercles. The green colour also

closely matched the colour of the hostplants' mature leaves (Plate 4.8). Larvae of *Gonometa* sp. were gregarious up to the end of the third instar. They showed less colour and form variations. They retained from first instar to spinning stage a mixture of white and black hairs with much longer hairs on the lateral sides (Plate 4.9). The larvae are also equipped with sharp black and brown spines which are irritating to human skin. During the day, the *Gonometa* sp. larvae remained relatively sedentary.

4:3:1:4 Pupa

The pupae of both species are enclosed in a tough silk cocoon. In *A. mimosae*, pupation is in tough, thick, silverly cocoon with some numerous irregular small holes and a prominent emergence valve at the top end; attached side-on to a twig (Plate 3.1 in chapter 3). The cocoon of *Gonometa* sp. is compact, brownish in colour and is equiped with spine irritating to the human skin (Plate 3.2). The cocoons of the first generation of moths were found in the field from May to October. Those from the second generation were found from December to March. In both species, the pupal duration was the longest compared to the other developmental stages (Table 4.2). *Gonometa* sp.cocoons collected from the cage at the end of the long rains of 1997 and observed under room and controlled conditions in the incubator indicated that those kept in the incubator had a significantly shorter pupal life span than those observed at room conditions. Cocoons in the incubator had moths emerging after 87.2 ± 3.6 days, while those under room conditions emerged after 124.0 ± 11.2 days.

No parasitoids were encountered from *A. mimosae* cocoons during this study period. However, hymenopteran and dipteran parasitoids were recorded from *Gonometa* sp. cocoons. These parasitoids spoilt the silk fibres as they made exit holes on the cocoons to facilitate their emergence (Plate 4.11). The dipteran parasitoids were only identified as belonging to the Family Tachinidae and the hymenopteran parasites as *Goryphus* sp. (Icheumonidae), *Eurytoma* sp. (Eurytomidae) and unidentified wasps of the family Chalcidoidae. Cocoon predation was observed in both species. Predated cocoons had an opening through which the pupae had been eaten. No predator was caught in the act but increased number of lizards in the cages during the cocoon season could possibly mean that they were the attackers although this needs to be investigated further.

4:3:2 Climatic conditions and hostplant state

The prevailing ambient temperature, relative humidity and rainfall varied from season to season during the study period. Fluctuations in these environmental factors are presented month wise for the 24 months in Appendix 3 for both sites. A unique synchronization in the hostplant state and the developmental stages of the silkmoths was observed (Table 4.1).

4:4 DISCUSSION

The study of different life stages of *Argema mimosae* at Sultan Hamud and *Gonometa* sp. at Nguni has shown that two distinct generations occur each year in the field. The number of generations of wild silkmoths per year varies according to prevailing climatic conditions. For instance, Oberprieler (1995) noted that *A. mimosae* has only one generation in Namibia. In NE Botswana, Hartland-Rowe (1992) observed two generations which comprised an annual cycle for *Gonometa rufobrunnea*. In terms of wild silk production, having two generations of moths in a year is an advantage as farmers can harvest and get income twice a year.

The female population of varying moth weight was observed to determine its relation with actual fecudity by number of eggs. In other species of wild silkmoths, significant relationship between fecudity and female weight has been reported for eri silkworm, *Philosamia ricini* (Singh and Prasad, 1987; Kotikal *et al.*, 1989), *Antheraea polyphemus* (Miller *et al.*, 1982) and in *Antheraea mylitta* (Badhera, 1992). Kasule (1991) reported similar findings in bugs in his experiments with the cotton stainer bug. The fecudity observed for these two species *Gonometa* sp. and *A. mimosae* also compares well to that of other species currently utilised for wild silk production. Nayak *et al.* (1994) reported 334.64 ± 20.51 eggs per female as the maximum for *Antheraea paphia*, and 216.23 ± 12.67 as the lowest production in his experimental *A. paphia*. For *Bombyx*

mori, the domesticated silkmoth, Janarthanan *et al.* (1994) noted 486 ± 13 eggs per individual as maximum production and 419 ± 15 eggs per individual as the minimum. In this study the fecudity rates for *Gonometa* sp.was 301.7 ± 114.0 eggs per female and 359.9 ± 71.8 eggs per female of *A. mimosae*. These figures compare well with those of the Asian wild silkmoth, *A. paphia* reported by Nayak *et al.* (1994).

Mesocomys pulchriceps (Cameron) was found to be the most important parasite of the eggs of the two silk moth species in the field. This species has been found to attack other wild silkmoth species in the field. In Botswana, Hartland-Rowe (1992) found it attacking eggs of *G. rufobrunea*. In south Africa, it has been recorded attacking eggs of the edible mopane moth, *Imbrasia belina* (Westw.) (Van Den Berg, 1971, 1974) and the closely related *Imbrasia cytherea clarki* Geertsema and *I. cytherea cytherea* (Fabr.) (Geertsema, 1975). The highest percent egg parasitism recorded for the two species was 37.4 % in *Gonometa* sp.which is lower than 55 % reported by Hartland-Rowe (1992) for *G. rufobrunea* in Northern Botswana. In *A. mimosae*, an overall 27.4 % egg parasitism was recorded.

The other egg parasitoids, *Pediobius anastati, Telenomus* sp and unidentified Encyrtidae occurred in much lower percentages 3.4 %, 1 % and 0.4 %, respectively. These species have also been recorded attacking eggs of other Lepidoptera (Prinsloo, 1987; Peigler, 1994). A *Pediobius* sp. in South Africa has been observed from eggs of saturniid moths *Imbrasia cytherea* and *I. belina* (Van den Berg, 1971, 1974; Geertsema,

1975). Another species in this genus, *P. tarsalis* (Ashmead) in the USA has been recorded as a hyperparasitoid on Ichneumonidae and Tachnidae attacking Lepidoptera including the wild silkmoth, *Hyalophora cecropia* (Peck, 1963). *Ooencyrtus cirinae* Prinsloo (family Encyrtidae) has been recorded from the eggs of another saturniid moth, *Cirina forda* and is known only from the vicinity of Pretoria, Transvaal, South Africa (Prinsloo, 1987). *Telenomus* sp. parasitism on *A. mimosae* eggs was 1 %. It is likely that the numbers reported here are underestimates. Else where, like Northern Arizona, *Telenomus* sp. parasitism on eggs of *Callosamia promethea* was recorded between 4 % to 56 % (Peigler, 1994).

The occurrence of common parasitoids between *Gonometa* sp. (Lasiocampidae) and *A. mimosae* (Saturniidae) observed in this study is quite interesting. This parasitoid-host sharing seems to be more ecological than taxonomic as the two wild silkmoth species belong to different families. Peigler (1994) reported a similar observation and said a possible explanation is that the two families share ecological characters like hairy larvae feeding externally on foliage of woody plants, pupation in cocoons above ground level and living in the same or similar ecosystems.

Despite the variation in number of openings at the micropyle end of *Gonometa* sp. eggs, there was consistency in the chorionic structure of all the eggs of each species. The characteristic micropyle and chorionic structure of each species could be utilised as tools for taxonomic studies. In the Asian wild silkmoth genus *Antheraea*, the chorionic

characters are species specific and have been used for taxonomic distinction of species (Jolly, 1981). Kawaguchi *et al.* (1996) has shown specific characters in the eggs of the domesticated silkmoth *B. mori* and those of its possible ancestor *B. mandarina* both at the micropyle region and the chorionic pattern.

The mortality rate of larvae observed for *Gonometa* sp. larvae was higher than that of the *A. mimosae*. This could probably be attributed to the fact that *Gonometa* sp. larvae at the early instars were gregarious and therefore once a predator has found them, it can feed on a whole cluster. This is supported by the fact that rearing in the net sleeve reduced the mortality rate from 83 % to 24 %. In Botswana, *Gonometa rufobrunnea* larvae suffered a mortality rate of 70 % in the field (Hartland-Rowe, 1992).

The predators observed during this study were dominated by formicid ants. Formicid ants have also been observed as predators by other researchers in different parts of Africa especially in relation to tsetse fly (Fiske, 1920; Carpenter, 1920; Rogers and Randolph, 1984). A pentatomid bug, *M. spurcata,* found sucking body fluids and killing *A. mimosae* larvae belongs to the same sub-family, Asopinae, with *Podisus maculiventris* Say. In North America, the latter feeds mainly upon hairless lepidopteran larvae and one individual is recorded to have consumed 123 third and fourth instar larvae of the army worm *Laphgma exigua* Hbn. during a period of nine weeks (Wilson, 1933). Though pentatomids are mainly phytophagus, the sub-family has developed predatory habits and their salivary glands produce an alkaline secretion which is injected into the body of the

host and acts as a poisoning or paralyzing agent (Elson, 1937).

The pupal stage was the longest in both species. This indicates the possibility of the existence of pupal diapause. Some earlier researchers, like Pinhey (1975) and Hartland-Rowe (1992), had also observed extended pupal periods in species of wild silkmoths. The significantly shorter pupal period in the incubator with controlled temperature and photoperiod as compared to room conditions indicates that the pupal life can be shortened by alteration of the prevailing environmental conditions. Similar findings have been reported for the silkmoths of the genus *Antheraea* (Jolly *et al.*, 1971; Jolly *et al.*, 1979).

The parasitoids observed from *Gonometa* sp. cocoons in this study are in the same families as those recorded from *Gonometa rufobrunnea* in Botswana (Hartland-Rowe, 1992). Hartland-Rowe (1992) proposed that parasitoids lay eggs in or on the larvae and later the adult parasitoids emerge from the cocoons. Marsh (1937) observed that a few ichneumonid wasps specialize on prepupal larvae, being attracted by the smell of the freshly spun silk. They extend their ovipositors through the partially spun cocoons and lay eggs in the pre-pupal larvae. Such ichneumonid parasitoids have only a narrow window of opportunity in which to locate and oviposit on the spinning larvae as once the cocoon has hardened, the ovipositor of the parasitoid cannot penetrate it. The *Goryphus* sp. (Ichneumonidae) observed from *Gonometa* sp. was several times seen walking and probing on freshly spun cocoons. Further observations need to be made to asertain

whether this species stings the pre-pupal larva or an earlier stage.

A close relationship was observed between the sprouting of new leaves by the hostplants and the emergence of moths. By the time the hostplants were shading leaves, the silkmoths were in the pupal stage in which they remained untill the hostplants started sprouting new leaves. Sinha and Chaudhuri (1992) observed similar synchronization in broods of the tropical tasar silkmoth, *Antheraea mylitta*. There must be existing natural environmental signals that regulate the whole mechanism by which this synchrony is achieved. Further, this synchrony must be for the survival of the silkmoths through the establishment of the feeding stage, the larvae on the hostplants when they have leaves thus providing optimum life conditions for them.

Plate 4.1: Net sleeve used for enclosing specimens on branches of the hostplant in the field

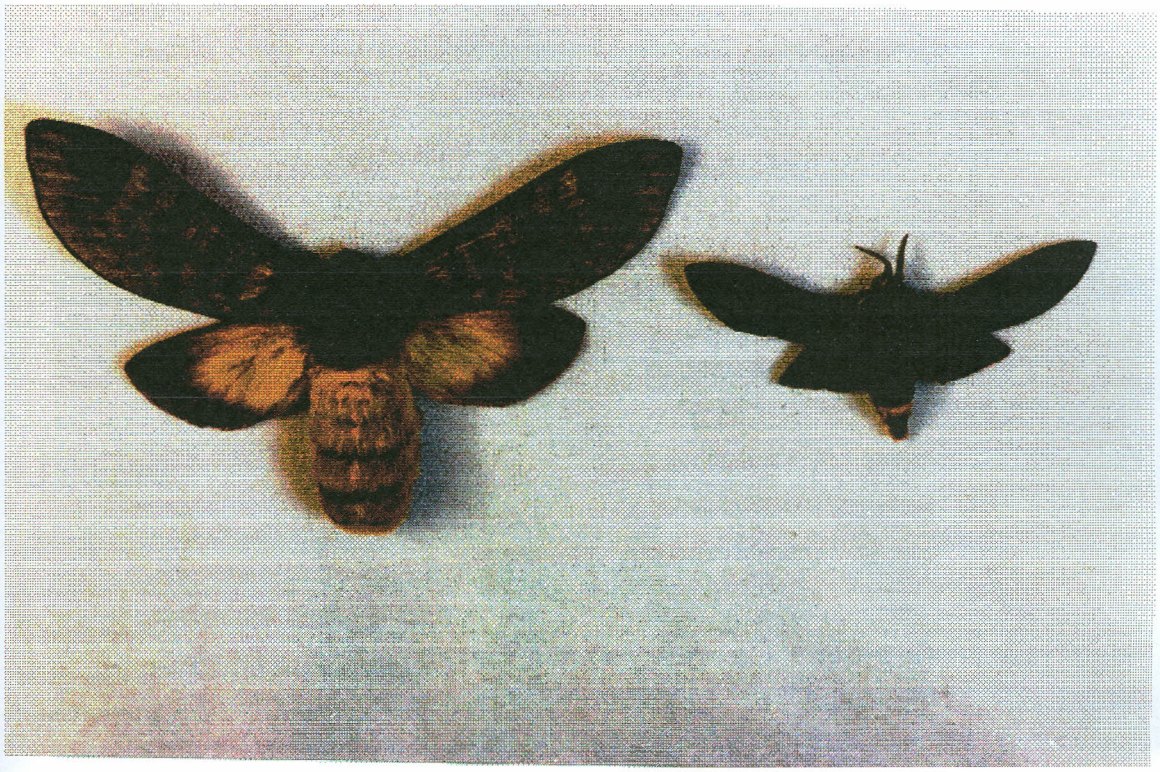


Plate 4.2: Adults of the wild silkmoth, *Gonometa* sp. female moth (left) and male moth (right)

Plate 4.3: Adults of the wild silkmoth *Argema mimosae*, female moth (left) and male moth (right)

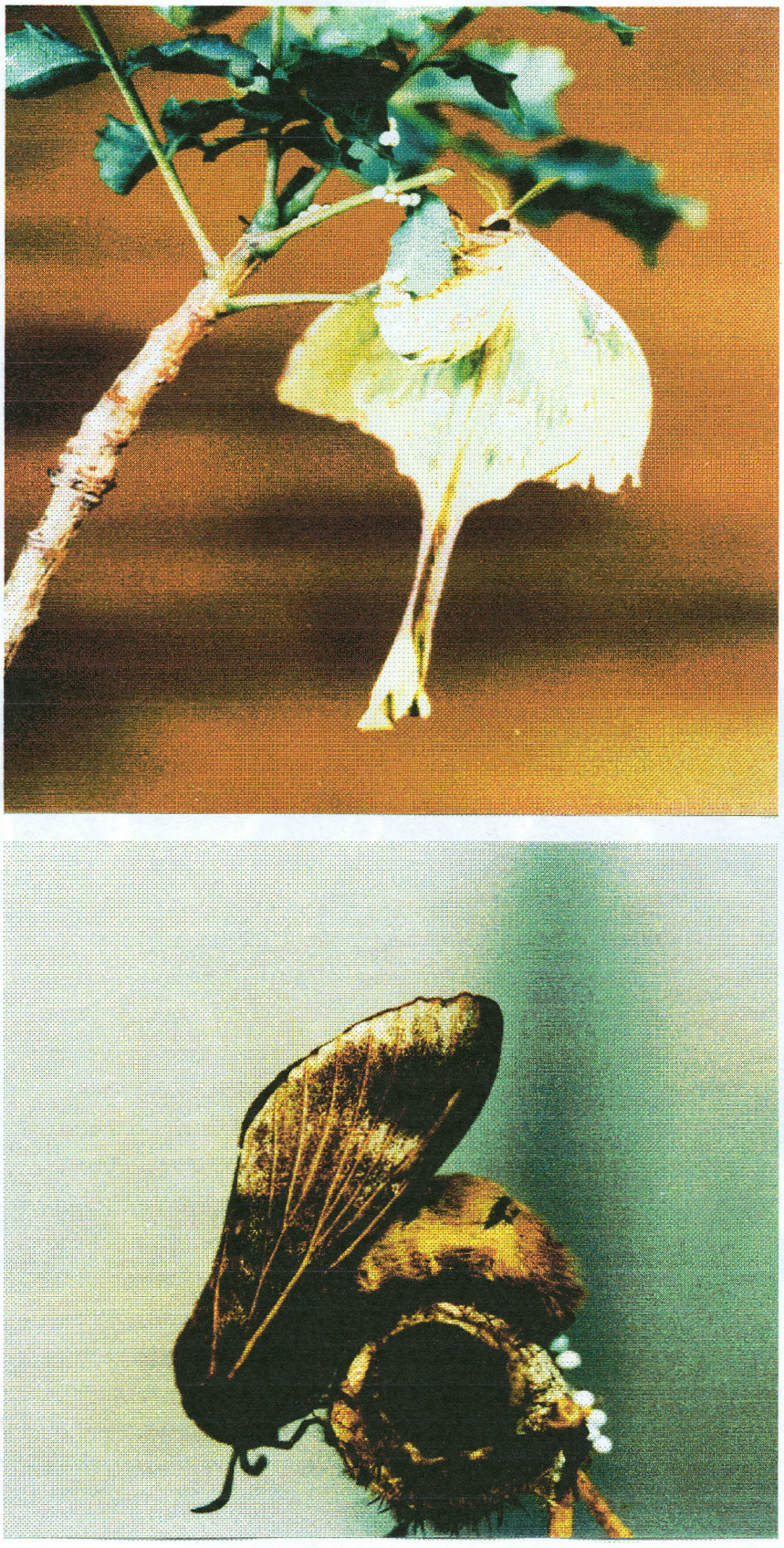
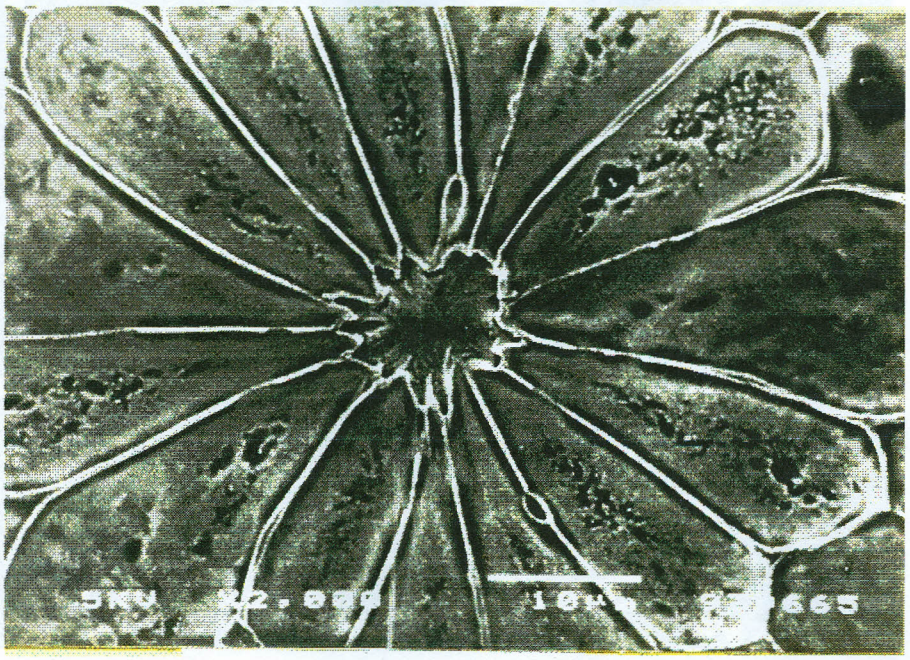


Plate 4.4: Egg laying in wild silkmoths: *Argema mimosae* laying on the lower leaf surface of *Sclerocarya birrea* (top); *Gonometa* sp. laying on the cocoon shell (below).

(a)



(b)

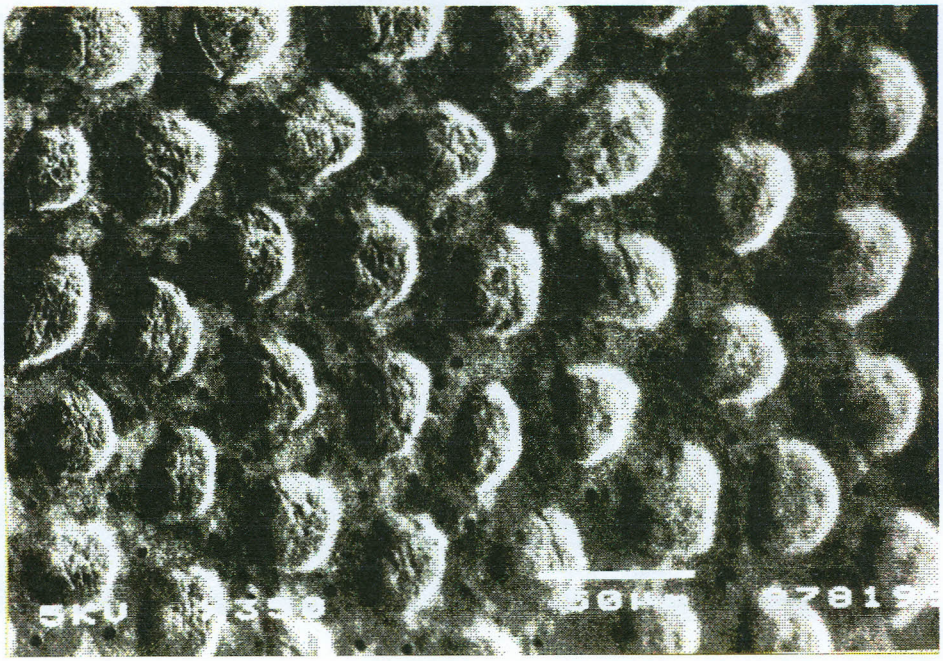
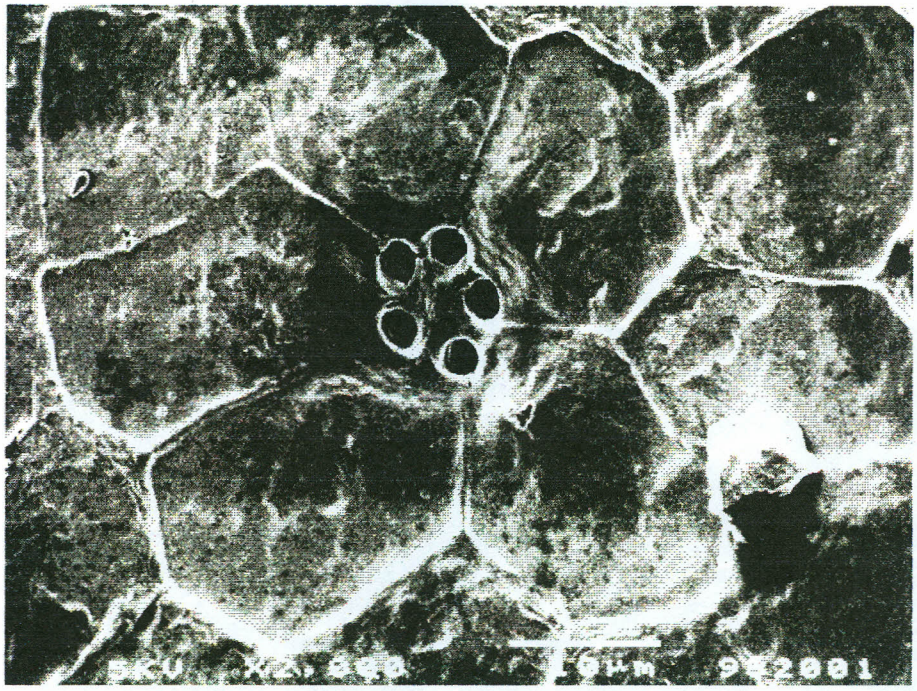


Plate 4.5: Surface structure of the micropyle region (a) and the general chorionic pattern (b) under a scanning electron (SEM) for the eggs of the wild silkmoth, *Argema mimosae*

(a)



(b)

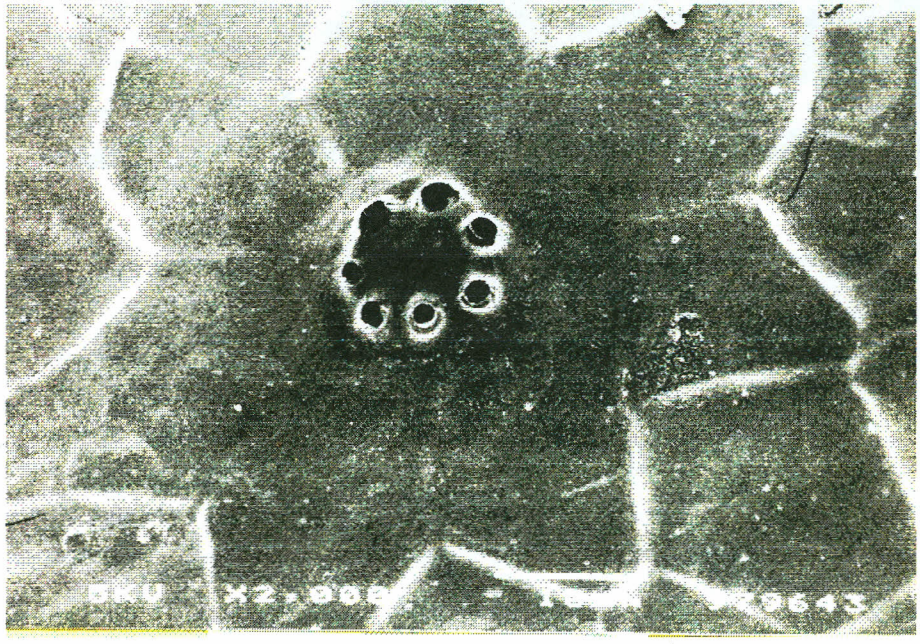


Plate 4.6: Surface structure of the micropyle region of eggs of the wild silkmoth, *Gonometa* sp. as seen under the SEM. (a) five openings (b) seven openings

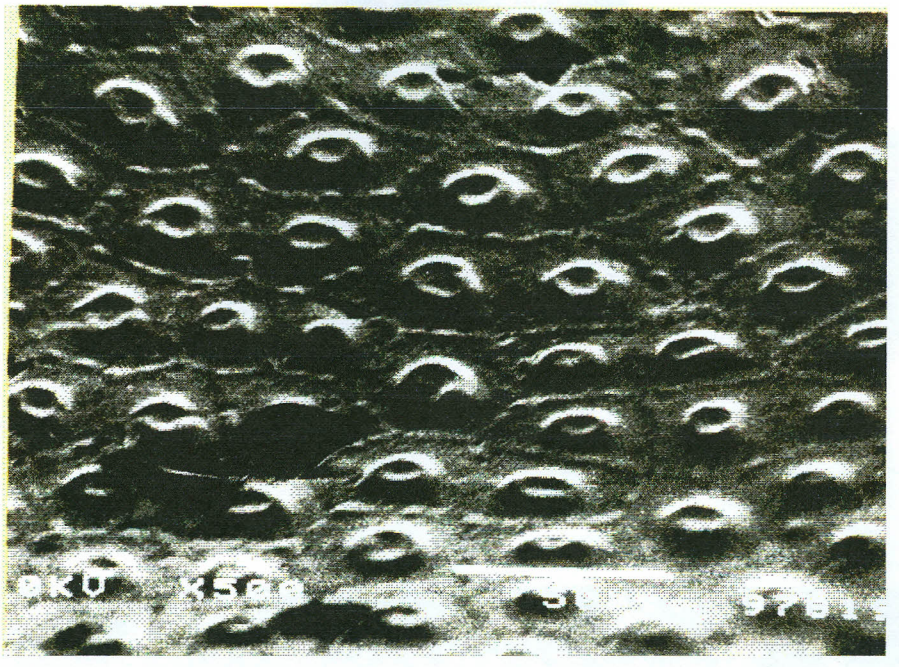


Plate 4.7: Surface structure of the general chorionic pattern under SEM for the eggs of *Gonometa* sp.

(a)

(b)

Plate 4.8: Larvae of *Argema mimosae*: Top, first instar and below fifth

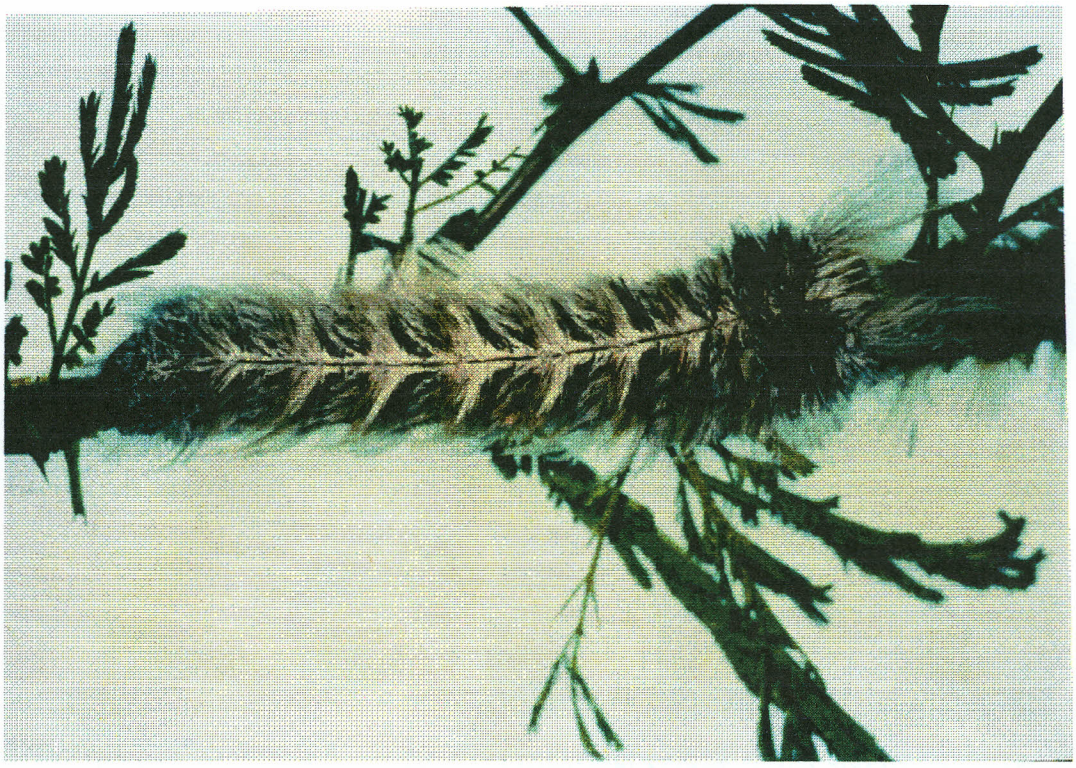


Plate 4.9: Fifth instar larva of *Gonometa* sp. resting on *Acacia elatior*

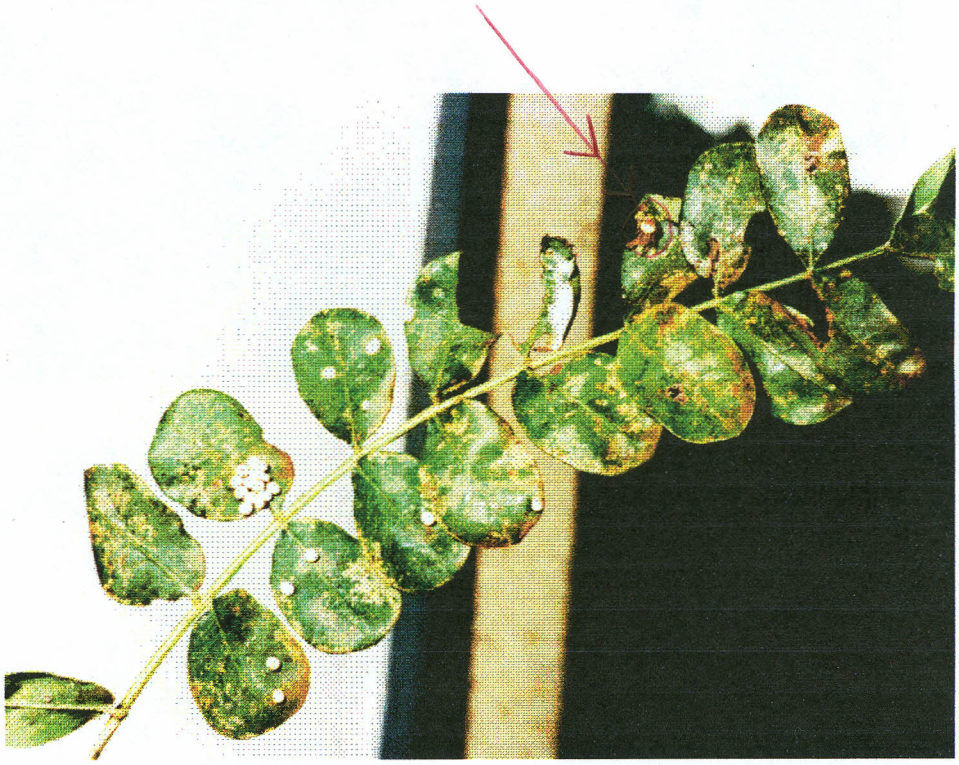


Plate 4.10: Possible predator, a brown and yellow spider spotted near the eggs of *Argema mimosae* on leaves of *Sclerocarya birrea* at Sultan Hamud

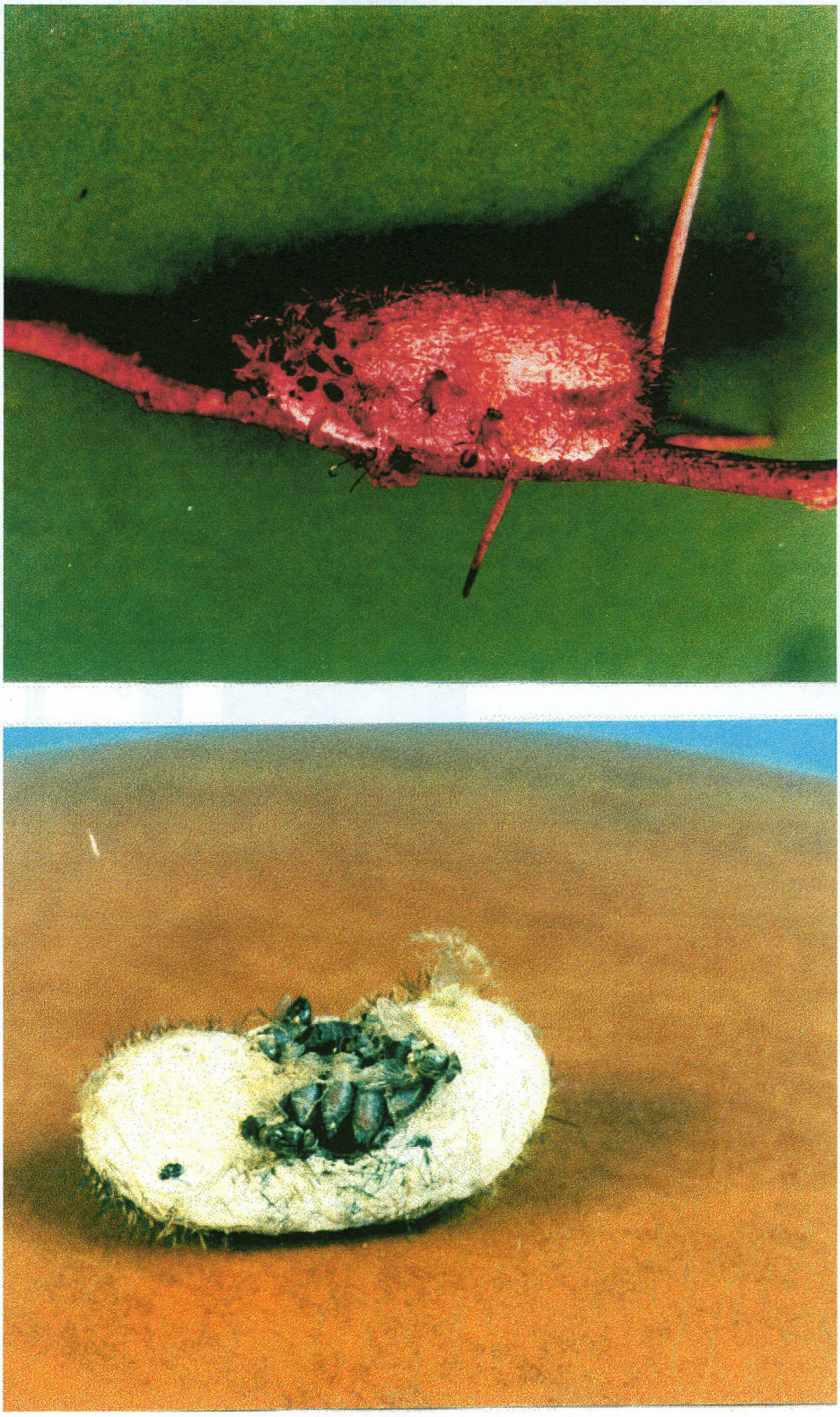


Plate 4.11: *Gonometa* sp. cocoons showing damage by different parasitoids: Hymenopteran *Goryphus* sp. (top) and Tachnid flies (below)

Figure 4.1: Percent parasitism of wild silkmoth eggs by two egg parasitoids, *Mesocomys pulchriceps* and *Pediobus anastati* in the field.

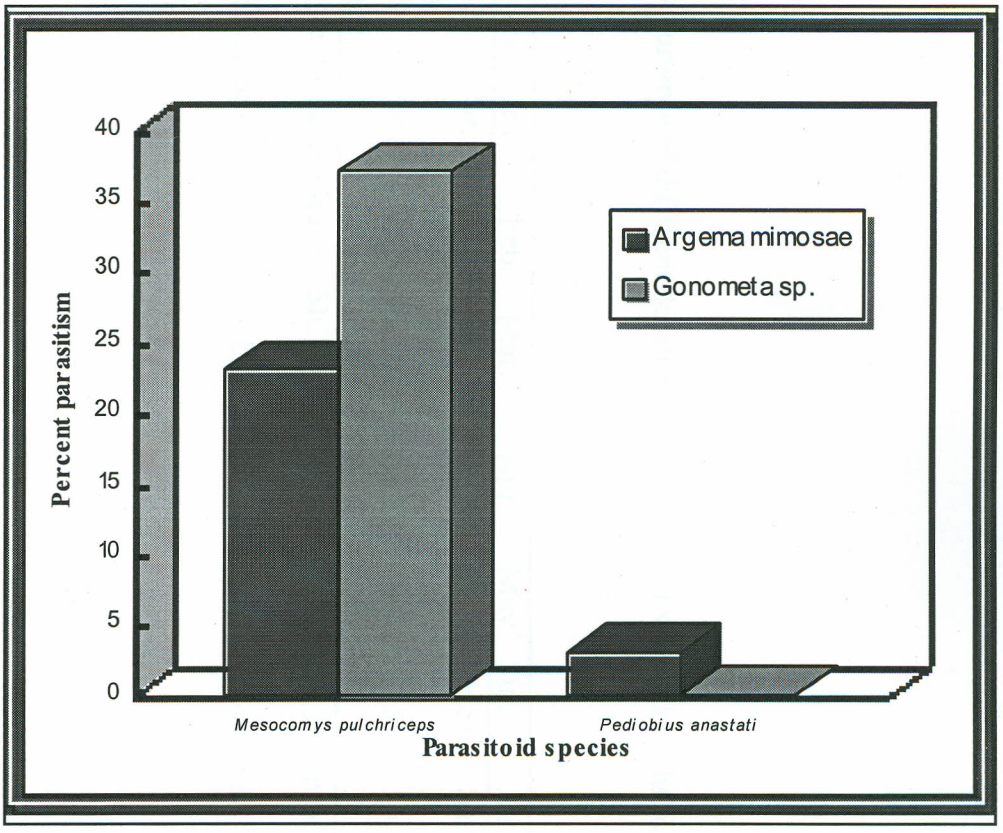


Table 4.1: Occurrence of different developmental stages of wild silkmoths in the field and the synchronization with hostplant state

Year	Hostp/Insect	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec
1996	Plant state	Gr, Sh	Ll,Nl	Gr,Nl	Gr,Nl	Gr	Gr,Sh	Sh,Ll	Ll, Nl	Ll,Nl	Gr,Nl	Gr,Nl	Gr,Nl
1996	Insect stage	P	P	A,E,L,P	A,E,L	L,P	P	P	P	P,A	A,E,L,P	A,E,L	L,P
1997	Plant state	Gr,Sh	Ll,Nl	Ll,Nl	Gr,Nl	Gr	Gr,Sh	Sh,Ll	Ll,Nl	Ll,Nl	Gr,Nl	Gr,Nl	Gr, Nl
1997	Insect stage	P	P	A,E,L,P	AEL	L,P	P	P	P	P,A	A,E,L,P	A,E,L	L,P

Hostplant state: Gr, green leaves; Sh, shading leaves; Ll, leafless; Nl, sprouting new leaves.

Insect stage: A, adult moths; E, eggs; L, larvae; P, pupal stage in cocoons.

Table 4.2: Duration of the different developmental stages of *Gonometa* sp. and *Argema mimosae* in days (Mean ± SD).

Species	Adults	Eggs	Silkworms	Pupae
Gonometa sp	6.4 ± 3.2a	11.3 ± 0.1a	53.5 ± 6.2a	95.9 ± 16.5a
A. mimosae	7.5 ± 2.1a	10.9 ± 0.3a	32.9 ± 3.8b	78.3 ± 29.5b

Means followed by the same letters are not significantly different (SNK $p < 0.05$).

Table 4.3: Oviposition sites and mean (±SD) egg cluster sizes in *Gonometa* sp. and *Argema mimosae* in the field.

	Argema mimosae		*Gonometa sp.*	
Oviposition substrate	Number of clusters	Mean no. eggs per cluster	Number of clusters	Mean no. of eggs per cluster
Upper leaf surface	25	1.7 ± 1.4	19	19.1 ± 12.1
Lower leaf surface	35	2.1 ± 1.6	25	17.3 ± 14.3
Stem	70	1.4 ± 0.6	17	34.1 ± 15.5
Flower	10	1.5 ± 0.7	-	-
Net sleeve	111	2.3 ± 1.6	16	18.4 ± 5.5
Others	3	3.0 ± 2.0	-	-

Table 4.4: Comparison of the mean lengths of *Argema mimosae* and *Gonometa* sp. eggs

	A. mimosae	*Gonometa* sp
Major axis (mm)	2.519±0.013A	2.321±0.007B
Minor axis (mm)	2.152±0.008A	2.074±0.008B

Each value represents mean ±SE. Means followed by the same letter are not significantly different (SNK $P < 0.01$)

Table 4.5: Percent parasitism of *Gonometa* sp. and *Argema mimosae* eggs in the field.

	Parasitoid species			
Silkmoth species	*Mesocomys pulchriceps*	*Pediobius anastati*	*Telenomus* sp.	Un identified Encyrtidae
Gonometa sp.	37 %	0.4 %	-	-
A. mimosae	23 %	3 %	1 %	0.4 %

Table 4.6: Larval mortalities of *Gonometa* sp. larval instars in a cage at Nguni during the short rains season of 1996.

Larval instar	Age at start of instar	Number entering	Mortality recorded	Percent mortality
I	0	152	24	15.8
II	5	128	17	13.3
III	10	111	40	36.0
IV	16	71	8	11.3
V	25	63	16	25.4
VI	34	47	21	44.7
PUPAL STAGE	50	26	-	-

The overall mortality recorded for the larvae from first instar to spinning was 82.9 %.

Table 4.7: Larval mortalities of *Gonometa* sp. larval instars in a cage at Nguni during the short rains season of 1997.

Larval instar	Age at start of instar	Number entering instar	Mortality recorded	Number at end of instar	Percent mortality
I	0	474	428	46	9.7
II	5	428	266	162	37.9
III	12	266	247	194	7.14
IV	22	247	194	53	21.5
V	31	194	100	94	48.5
PUPAL STAGE	45	100	-	-	-

The overall larval mortality recorded for the larvae from 1st instar to spinning was 78.9 %.

Table 4.8: Larval mortalities of *Argema mimosae* larval instars in a cage at Sultan Hamud during the short rains season of 1997.

Larval instar	Age at start of instar	Number entering instar	Mortality recorded	Percent mortality
I	0	500	72	14.4
II	4	428	158	36.9
III	9	270	30	11.1
IV	14	240	45	18.8
V	19	195	97	50.3
PUPAL STAGE	28	97	-	-

The overall mortality recorded for these larvae from 1st instar to spinning was 80.6 %.

Table 4.9: Larval mortalities of *Gonometa* sp. reared enclosed in net-sleeves in a cage at Nguni during the long rains season of 1997.

Larval instar	Age at start of instar	Number entering instar	Mortality recorded	Percent mortality
I	0	197	13	6.6
II	7	184	2	1.1
III	11	182	0	0
IV	17	182	4	2.2
V	24	178	19	10.7
VI	33	159	9	5.7
PUPAL STAGE	48	150	-	-

The overall mortality recorded for these larvae from first instar to spinning was 23.9 %.

Table 4.10: Species composition of the wild silkmoth predators recorded in the field.

Predator	Associated silkmoth species
Maccroraphis spurcata (Asopinae, Pentatomidae, Hemiptera)	*A. mimosae*
Cilnia sp. (Mantinae, Mantidae, Orthoptera)	*A. mimosae, Gonometa* sp.
Crematogaster sp. (Myrmicinae, Formicidae, Hymenoptera)	*A. mimosae*
Unidentified sp. (Formicinae, Formicidae, Hymenoptera)	*Gonometa* sp.
Unidentified Spiders and Lizards	*A. mimosae, Gonometa* sp.

CHAPTER FIVE

POST HARVEST CHARACTERISTICS OF COCOONS OF *GONOMETA* SP. AND *ARGEMA MIMOSAE*

5:1 INTRODUCTION

Silk fibre can be obtained from cocoons through reeling. Reeling is the simultaneous unwinding of filaments from cocoons and winding the raw silk on to a bobbin. Silkmoth species which spin cocoons of closed type give continous fibre where as species that spin open cocoons give spun silk. The maximum yield of raw silk from cocoons is an important aspect of sericulture. The extend to which this aspect is attained depends upon several variable factors but primarily on the quality of cocoons (Majhi and Chatterjee, 1994). The objective of this study was to investigate *Gonometa* sp. and *A. mimosae* cocoon characteristics evaluating their potential for silk production.

5:2 MATERIALS AND METHODS

5:2:1 Cocoon weight and size

Freshly field collected cocoons were weighed in the laboratory on an electronic balance. Each cocoon was marked with a permanent ink. Cocoon length and width were

measured in centimetres and sex of each cocoon was recorded and kept in the incubator till moth emergence.

5:2:2 Cocoon shell weight and shell ratio percentage

Once the moth emerged from the cocoon, the shell was emptied and cleaned of all the pupal remains and weighed. The shell ratio percentage was then calculated as follows: weight of the cocoon shell divided by the weight of the fresh cocoon multiplied by a hundred (Majhi and Chatterjee, 1994).

5:2:3 Reeling of cocoons

Only *Gonometa* sp. cocoons were used for reeling as *A. mimosae* cocoons were unreelable because of the valve. Fresh cocoons were individually weighed then dried in an oven at 60^0 C for two hours. This process kills pupae and stops moth emergence as moths spoil cocoons by making exit holes when emerging. Cocoons were then boiled in water with a tinge of 2% liquid soap for 30 minutes. The boiling is a vital operation as it softens the hard cocoon shell making it possible to unwind the silk filament. Cocoons were individually reeled up to the possible extend of the inner most layer of the shell. The filament length was determined using a simple manual apparatus known as an epprouvette (Plate 5.1). The epprouvette has an indicator for showing the filament length (Fig. 5.1).

Weights of the waste silk (floss) and of silk filament were measured. The number of breaks occurring in the fibre during the reeling of each cocoon were recorded. Raw silk percentage was determined as per formula which is used in Indian wild silk sector for the assessment of individual cocoons (Majhi and Chalterjee, 1994). This is by dividing weight of reeled silk filament with that of reeled silk plus weight of floss multiplied by one hundred. The non breakable filament length was calculated by dividing the obtained filament length with one plus number of breaks recorded during the reeling of each cocoon.

5:3 RESULTS

5:3:1 Cocoon weight and size

Table 5.1 presents a comparison of mean cocoon weight and size measurements for females and males within a species. Weight of fresh cocoons of both species showed significant differences between females and males whereas some of the size variables did not show significant differences between the sexes. In *Gonometa* sp., the mean weight for female cocoons was 8.83 ± 2.77 g which was significantly greater ($p = 0.0001$) than 3.44 ± 0.91 g recorded for males. Both cocoon length and width also showed statistically significant differences at the $P = 0.0001$ level.

In *A. mimosae* female cocoons had significantly higher ($p = 0.040$) mean weight of 6.04 ± 0.96 g compared to the 4.95 ± 1.30 g observed in males (Table 5.1). Like in the *Gonometa* sp., mean cocoon length for the females was significantly longer ($p = 0.0001$) than in males. However, the cocoon width in both sexes of *A. mimosae* did not show significant differences.

5:3:2 Cocoon shell weight and shell ratio

The mean values for shell weight and ratio percentage varied with *A. mimosae* recording an overall significantly lower ($p = 0.0001$) mean shell weight of 0.89 ± 0.22 g and *Gonometa* sp 1.30 ± 0.30 g. The overall shell ratio percentage for cocoons of the two species was significantly different ($p = 0.006$). That of *A. mimosae* being 17 ± 5.36 g and that of *Gonometa* sp. 26.32 ± 9.17 g. In both species, males had a significantly higher shell ratio percentage than the females. Results of a comparison between males and females of *Gonometa* sp. during the long rains of 1996 are shown in Table 5.3. Though the females had a significantly higher fresh cocoon weight and heavier cocoon shell, the shell ratio % for the females was 21.9 ± 2.2 % which was significantly less ($p = 0.0001$) than the 35.1 ± 16.9 % recorded for males.

5:3:3 Reeling of cocoons

Table 5.3 shows the data obtained from *Gonometa* sp. single cocoon reeling. The silk fibre obtained was lustrous and brown in colour (Plate 5.2). The silk length obtained from each cocoon was significantly ($p = 0.003$) longer in females with a mean of 706.34 ± 222.4 m compared to that of males which had a mean of 521.49 ± 204.2 m. Non-breakable silk length ranged from 137.8 ± 73.9 m in males to 175.5 ± 65.5 m in females but these were not significantly different ($p = 0.118$). Also there was no significant difference in the number of breaks recorded for females and males which were 3.10 ± 0.2 and 3.3 ± 1.5 for females and males respectively.

The weight of silk and floss was significantly more in female than in male cocoons, $p = 0.0001$ and $p = 0.0015$ respectively (Table 5.3). However, the raw silk percentage in both sexes was not significantly ($p = 0.584$) different with 27.4 ± 9.6 % in females and 30.2 ± 6.9 % in males. Pupal weight varied significantly ($p = 0.0001$) between the sexes in *Gonometa* sp. with females weighing 5.65 ± 2.6 g and males 2.23 ± 1.47 g.

5:4 DISCUSSION

The cocoon weights observed for *Gonometa* sp. and *A. mimosae* during this study are quite encouraging as they are in the same range of other wild silkmoth species being utilised elsewhere in the world. Majhi and Chatterjee (1994), while studying cocoon characteristics of the wild silkmoth, *A. proylei* recorded weight of 4.5 - 6.1 g. Dash *et al.* (1994) obtained a range of 7.8 - 12.4 g for cocoons of the wild silkmoth *A. paphia*. The cocoon weight recorded for *Gonometa* sp and A. *mimosae* was in the range of 2.9 - 9.9 g. In the domesticated silkmoth, *Bombxy mori*, Janarthanan *et al.* (1994) recorded a cocoon weight of 1.88 ± 0.09 g and 0.33 ± 0.02 g for females and males respectively.

The shell weight recorded for *A. proylei* and *A. paphia* ranges between 1.2 - 2.84 g (Majhi *et al.*, 1994; Dash *et al.*, 1994). In this study the shell weight recorded for *Gonometa* sp. was 1.2 ± 0.7 g for males and 1.8 ± 0.4 g for females. In *B. mori*, shell weight of 0.31 ± 0.01 g for females and 1.54 ± 0.08 g for males has been recorded (Janarthanan *et al.*, 1994). Since wild silkmoth species grow out doors and suffer from adverse conditions of the environment, the higher cocoon shell weight is probably an adaptability to protect the pupae. This is more likely to be the case as the pupae is the stage through which the wild silkmoths survive the dry seasons. Therefore the cocoon shell must be an adaptive strategy by these insects to protect the pupae from prolonged adversity.

The silk filament from *Gonometa* sp. was found to be continous and reelable. The larvae of *Gonometa* sp. spin closed cocoons whereas, *A. mimosae* leave brush-like valves in the cocoons thus limiting the silk fibre continuity. In the *Gonometa* sp., the percentage raw silk was found to be higher in the males. This relatively lesser silk conversion ability in the females may be due to the greater resource allocation by the female larvae for egg production. Such sexual dimmorphic nature due to differential resource allocation in the two sexes has also been proposed by Ochieng-Odero (1990). This could imply that this quality is independent of environmental factors and hence is genetically determined.

From the weight of silk obtained from the males and female cocoons, it implies that to make a kilogram of silk, 2,326 - 4,762 *Gonometa* sp.cocoons are required. This ranges within the number of cocoons required to make a kilogram of *Antherea proylei* raw silk as recorded by Majhi and Chatterjee (1994). The unreelability of *A. mimosae* cocoons should not disqualify them from being utilised for wild silk production. Cocoons of other wild silkmoth species whose cocoons are not reelable like the eri silkmoth, *S. cynthia,* are spun into thread like cotton and this weaving is a cottage industry in Assam, India (Jolly *et al.*, 1979). Also cocoons of the atlas moth, *Attacus atlas,* are made into floss-silk and spun silk yarn from which fagara silk is made (Peigler, 1993).

The high pupal weight observed indicates that quite a big proportion of the silkmoths' resources are in this stage. In South East Asia, pupae of various species of silkmoths, partly a by product of the silk industry, are eaten and provide an important

source of nutrients for many people. Some biochemical findings on the domesticated silkmoth pupae have revealed that they contain water, protein, fat, glycogen, chitin, minerals and other compounds in the proportions of 7.81, 48.49, 39.57, 4.65, 3.37, 2.19, and 1.70 % respectively (Roychoudhury and Joshi, 1995). With the introduction of wild silkmoth farming in East Africa, it may be necessary to investigate the possible uses for the pupae. In India, it has been estimated that 50,000 - 60,000 tonnes (Datta, pers. comm.) of de-oiled *B. mori* pupae are produced annually and much of this is fed to chicken. Pupae of african wild silkmoth may form an excellent source of proteins for animals and their oil extracted for making soap.

Table 5.1: Comparison of mean cocoon weight and size for females and males of *Gonometa* sp. and *Argema mimosae*.

	Gonometa sp.		*Argema mimosae*	
Variable	Females	Males	Female	Males
Weight (g)	8.83 ± 2.77a	3.44 ± 0.91b	6.04 ± 0.96a	4.95 ± 1.30b
Length (cm)	5.38 ± 0.63a	4.16 ± 0.37b	5.90 ± 0.45a	3.92 ± 1.23b
Width (cm)	2.26 ± 0.30a	1.67 ± 0.20b	2.43 ± 0.29a	2.24 ± 0.96a

Means ± SD followed by the same letters in the same row within a species are not significantly different (t-test $p < 0.05$). See text for the different probability levels for each variable.

Table 5.2: Comparison of cocoon weight, shell weight and shell ratio % in females and males of *Gonometa* sp during the long rains season of 1996.

Sex	Weight	Shell weight	Shell ratio %
Females	8.5 ± 1.6a	1.8 ± 0.4a	21.9 ± 2.2a
Males	2.8 ± 1.0b	1.2 ± 0.7b	35.1 ± 16.9b

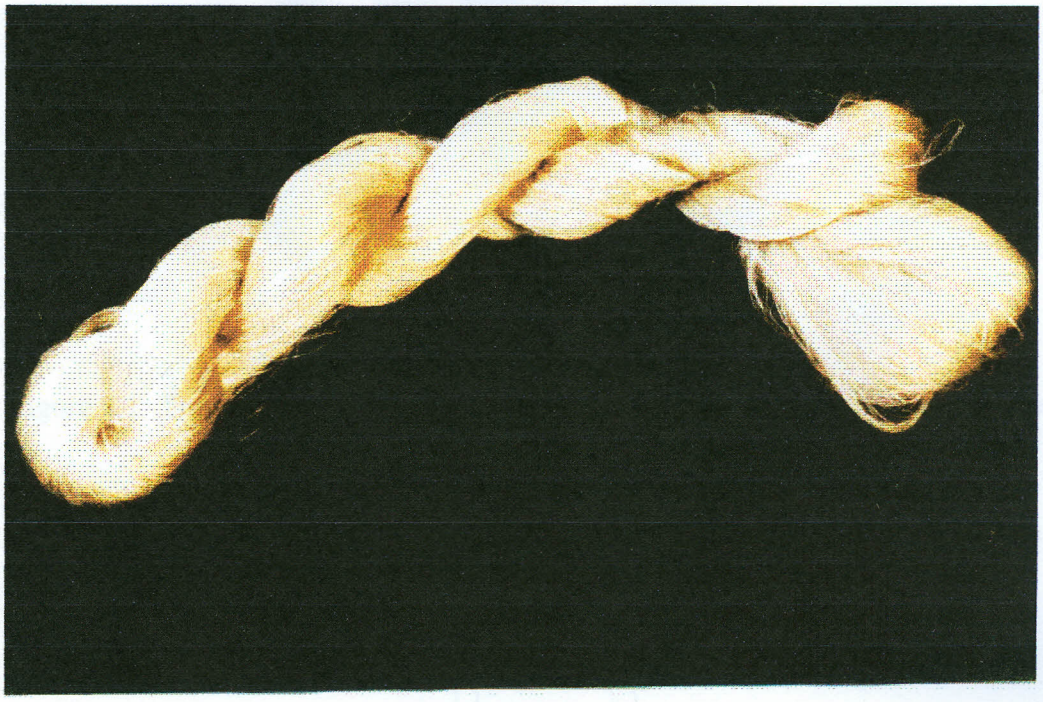
Means followed by the same letters are not significantly different (t-test $p < 0.05$). See text for the different probability levels.

Table 5.3: Comparison of the reeling performance of female and male *Gonometa* sp. cocoons

Cocoon gender	Silk length	Silk weight (g)	Raw silk %	Non-breakable length (m)	Number of breaks	Floss weight (g)	No. of cocoons for 1Kg silk	Pupal weight (g)
Female	706.34 ± 222.4a	0.43 ± 0.17a	27.4 ± 9.6a	175.5 ± 65.5a	3.1 ± 0.2a	1.4 ± 0.9a	2,325.6	5.65 ± 2.7a
Male	521 ± 204.2b	0.21 ± 0.01b	30.2 ± 6.9a	137.8 ± 73.9a	3.3 ± 1.5a	0.7 ± 0.2b	4,761.90	2.23 ± 1.5b

:Figures are means followed by SD where applicable. Means followed by same letters are not significantly different (t-test $p < 0.05$). See text for the different probability levels.

Plate 5.1: Reeling of *Gonometa* sp. cocoons using an epprouvette



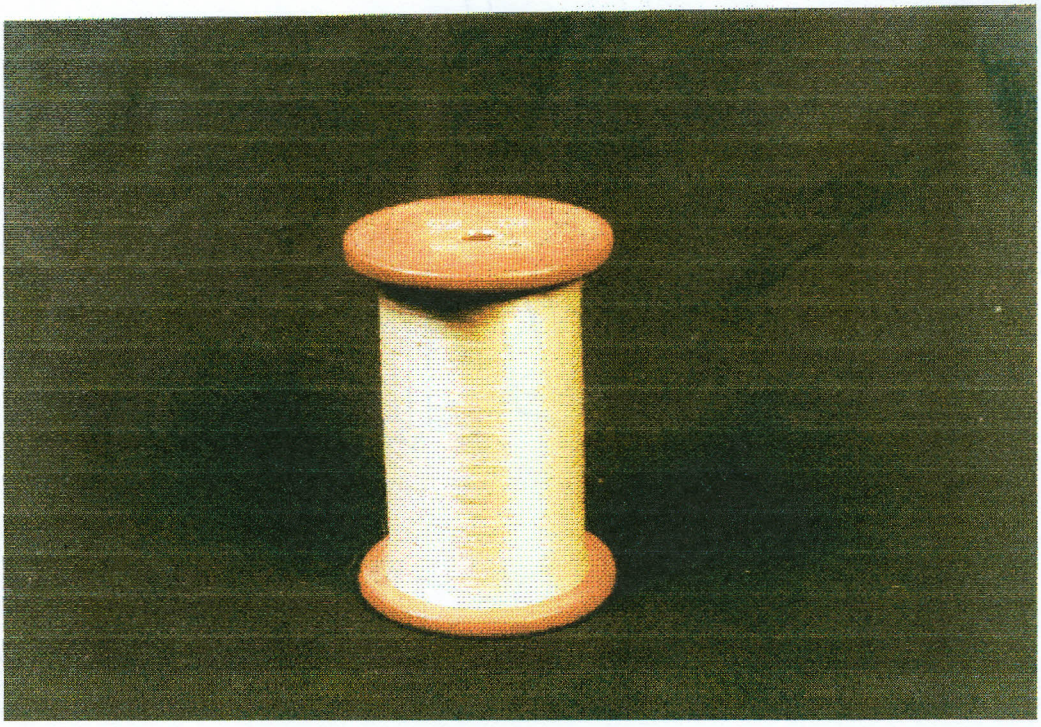
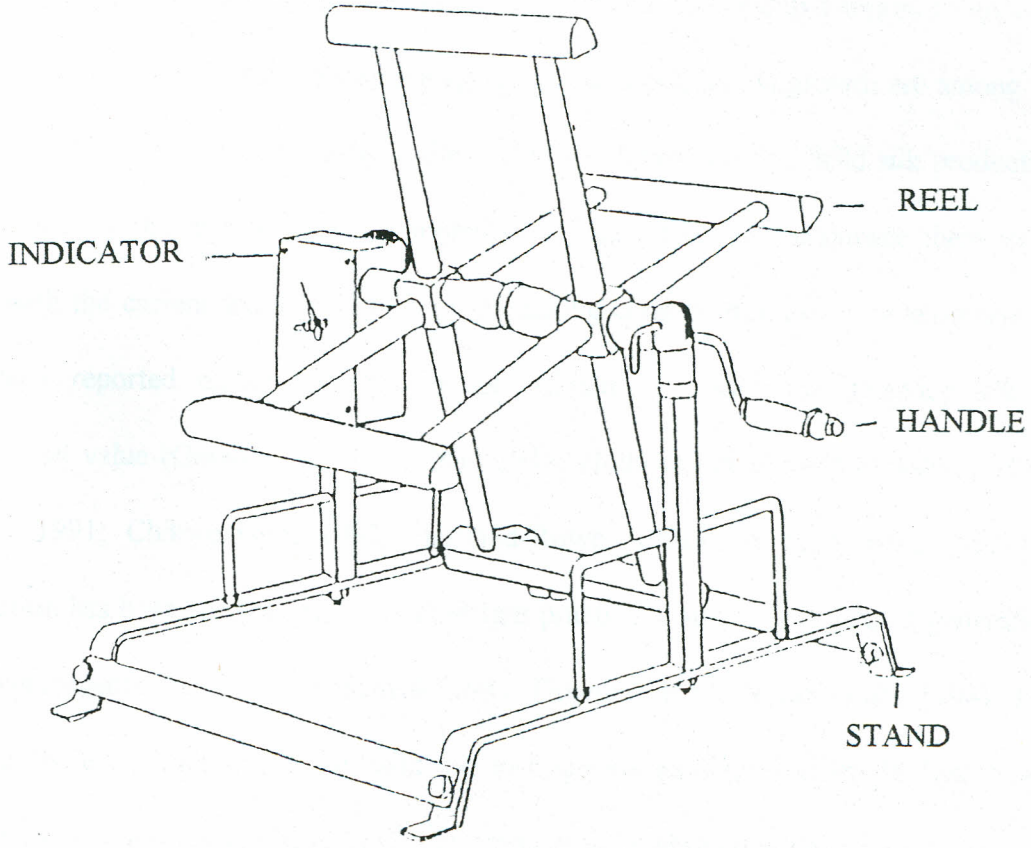


Plate 5.2: Silk of *Gonometa* sp.: Skein of raw silk (above) and a bobbin (below)

Figure 5.1: The different components of an epprouvette used for single cocoon reeling.



CHAPTER SIX

GENERAL DISCUSSION AND FUTURE RESEARCH

6:1 GENERAL DISCUSSION

In the past, economic incentives in East Africa have forced dependence on primary production, largely in agriculture, for sustaining demands for food and wealth to improve the people's living standards. Extensive agriculture and population growth are among the main causes of the rapid dwindling of the region's rich biodiversity. Wild silk production could diversify the rural people's economic base, and therefore, encourage them to be allied with the current world efforts in promulgating conservation-based development. It had been reported earlier that species of African wild silkmoths produce silk of commercial value (Gowdey, 1953; Scultze, 1914; Holloway *et al.*, 1987; Ashiru, 1988; Ashiru, 1991; Chikwenhere, 1992; Hartland-Rowe, 1992). Much equally, wild silk production has been recognized as an important practice in sustainable income generation and environmental amelioration (Schenk, 1981; Gowdey, 1953; Nayak *et al.*, 1994). The fact that there is a high diversity of wild silkmoth species distributed widely in East Africa indicates a very good potential for wild silk production in these countries.

Assessement on the rural farmers awereness of the economic value of wild silkmoth cocoons showed that most farmers were not aware of the cocoons economic

value. This does not mean that they can not participate in the wild silk production. This is just an indication of what has been reported earlier by Oberprieler (1995) that silk production has not been much practised in Africa in the past. However, the high willingness of the community to be involved in silk production is encouraging. This only calls for numerous demonstrations and training to farmers. This has been taken up and many women groups have been visited and have also visited ICIPE for training. The emphasis on women is because much of the rural community consist of women and the United Nations (UN, 1975) estimates that in sub-saharan Africa, women contribute two thirds of the hours spent in traditional agriculture. Women will more likely be the main beneficiaries of this alternative source of income.

Although hostplants of the wild silkmoths were widely distributed, it became evident from the ground survey that the numbers in farmers' land are few with only 16 % of the questionaire corespondents having more than ten trees. Several factors could be associated with the low numbers of hostplants. The trees are preferred for other purposes like charcoal burning and construction poles. To improve on the conservation of these wild silkmoth hostplants, it calls for economic incentives that integrate biological conservation with the economic development for the people. The introduction of wild silk production may offer an important economic incentive to farmers in East Africa. If they can get some income from the wild silkmoths feeding on these trees, then there will be a voluntary change of attitude and conservation of these hostplants can be enhanced. Such kind of voluntary changes in behaviour towards insect conservation for income generation

have been reported in Malawi (Munthali and Mughogho, 1992) where local people have been given the right to harvest saturniid caterpillars for food and sale and establish beehives in exchange for curbing other uses which are incompatible with the objectives of the Kasungu National Park.

Sinha and Chaudhuri (1992) reported that a close relationship exists between rain and the emergence phenology of tasar silkmoth, *A. mylitta*. The natural environmental signals dictate its developmental fate and regulate the whole mechanism by which a somewhat synchrony is achieved. Further, the appearance of suitable food for the establishment of young larvae on hostplant which also reflushes with abundant leaves during the rainy season also provides optimum life conditions for the silkmoths. The time of emergence of an individual adult insect is determined by the underlying physiological rhythms which are governed by the environmental factors. Phenology of the wild silkmoths, *Gonometa* sp. and *Argema mimosae* involving two generations a year probably evolved as an adaptation to the sharp seasonality of rainfall in East Africa which consists of two wet and two dry seasons.

The ability of the *Gonometa* sp. and *A. mimosae* to oviposit on different substrates indicates that these females may not be very specific to the hostplant with regard to oviposition. This suggestion concurs with the findings of Hartland-Rowe (1992) who reported that, *G. rufobrunnea* in northern Botswana does not usually lay eggs on the foodplant, mophane, but on thin stems of grass or other herbage beneath bushes, though

sometimes a batch is laid upon a mophane leaf. This characteristic behaviour in the African wild silkmoths can be used to enhance the laboratory egg production for the supply to different farmers.

In this study, there were a number of parasitoids and predators recorded attacking silkmoths at different developmental stages. There was however a significant reduction in larval mortality when reared in the net sleeves. This was an indication that the net acted as a mechanical barrier to some of the would be parasites. This is encouraging as Hartland-Rowe (1992) in Botswana reported that the impact of parasitoids and predation are often severe. The would be wild silk farmers would have to be trained on the protection of the silkworms in the field. Other possibilities also exist of evading the parasitoid effect. Weseloh (1993) indicated that parasitoids tend to have a narrower habitat tolerance than their hosts and that hosts may be able to escape parasitization by colonizing a new plant species or microhabitat. Tuskes *et al.* (1996) indicated that the host-parasitoid relationship is an evolutionary game of hide and seek. The environmental manipulation can be used to desynchronise the silkmoth and parasite life cycles. The emergence of wasps that belong to the hyperparasitoid groups could also be a possible solution to the parasites problem in wild silkmoth farming.

Primary defense mechanisms were prominently exhibited by both larvae of *Gonometa* sp. and *A. mimosae*. In his review of the caterpillar defense mechanisms, Lederhouse (1990) found that among North American saturniids, the most common

primary defense mechanism was inconspicuousness aided by cryptic colouration and reduced movement. In another group of Lepidoptera, the sphingids, Schmidit (1990) also observed larvae cryptic colouration combined with a general tendency to remain relatively sedentary as means of escape from predation. In *A. mimosae* the larvae colour progressively changed from one instar to the other to match that of the hostplant leaves. Tuskes *et al.* (1996) observed that cryptic larvae, such as *Hyalophora* and *Callosamia* had brightly coloured scoli (tubercles) though the adaptive significance of these structures has not been systematically studied. Like observed in *A. mimosae*, the scoli usually become smaller relative to body size as the larvae grow from one instar to the next. The *Gonometa* sp. larvae also probably escape predation by means of cryptic colouration, presence of spines in combination with a general tendency to remain relatively sedentary during the day.

The pupal stage of the silkmoths is enclosed in the silk cocoon. This stage was observed to take the longest duration of all the developmental stages of the two silkmoth species whose phenology was studied. The pupal cocoon case could have been developed to avoid climatic extremes or predation or both. Pupal diapause in the African wild silkmoths of the family Lasiocampidae was reported by Pinhey (1975) who noted that a few of these moths spend years in the cocoon state awaiting favourable season to emerge. In Japan, Masaki (1980) observed that lasiocampid moths enter summer diapause as pupae and winter diapause as eggs. It has been reported that pupal diapause in wild silkmoths of

the genus *Antheraea* can be manipulated through a change in the environmental conditions (Janarthanan *et al.*, 1994; Chowdharry *et al.*, 1996). Manipulation of the pupal diapause can be used to enhance seed production.

Distinct sexual dimorphism was evident in the *Gonometa* sp. moths. This kind of sexual dimorphism in the adults has also been reported in the wild silkmoth, *Anaphe venata* in Nigeria (Ashiru, 1991). Sexual dimorphism of adults could be advantageous for commercial silk production as trainning of extension personnel and farmers for sorting out the insects into sexes would be easy.

Fecudity measured as number of eggs laid (Ghosh *et al.*, 1996) in both *Gonometa* sp. and *A. mimosae* was high and showed a positive correlation to the female moth body weight.These findings supported Shamachary and Krishnaswani (1980) report that positive weight correlations exist between the silkmoth, *Bombyx mori* and the eggs laid. In terms of wild silkmoth production, this implies that quality seed moths have to be provided for the enhancement of egg production. In terms of survival, the high fecudity could be viewed as a survival strategy. Tuskes *et al.* (1996) noted that saturniids employ a strategy of overcoming losses to predators, parasitoids and effects of adverse environmental factors through the production of large number of eggs.

The architecture of egg shells of the two species studied was suited to allow the exchange of gases. These findings supported what has been observed by Hinton (1969,

1970). Morphological analyses of egg shells of various species of silkmoths have been conducted on *Bombyx mori* (Regier *et al.*, 1980), *B. mori* and *B. mandarina* (Kawaguchi *et al.*, 1996) and on the genus *Antheraea* (Jolly, 1981). Morphological differences have been used as a species identification tool. The consistency observed in both the *Gonometa* sp. and *A. mimosae* egg structure could be a useful tool for future distinction of the different species in these genera.

Lower cocoon weights for the males observed in both silkmoth species in this study were in agreement with the findings reported for the domesticated silkmoth *B. mori* by Janarthanan *et al.* (1994). It was however interesting to note that the raw silk percentage was higher in males than in females. This observation could indicate that the females convert less of their resources to silk, allocating more of the resources to egg production. Ochieng-Odero (1990) also proposed differential resource allocation in explaining such sexual dimmorphism in the black lyre leafroller. The calculated number of cocoons required to make one kilogram of *Gonometa* sp. silk, 2,326 - 4,762 cocoons compares very well with 4,000 - 5,000 cocoons required for 1 kg of *A. proylei* raw silk (Majhi and Chatterjee, 1994). This indicates that the african wild silkmoths can compete quite well in terms of silk production with the other species of wild silkmoths.

6:2 SUMMARY

1. A study was carried out to investigate the diversity of wild silkmoth species in Kenya, Uganda and Tanzania. Community awereness on the occurrence and importance of wild silkmoths was also assessed. Phenology of the selected species *Gonometa* sp. and *Argema mimosae* was studied at Nguni, Mwingi and Sultan Hamud in Makueni. The raw silk yielding capacity of the reelable *Gonometa* sp. cocoons was evaluated.

2. Fifty eight wild silkmoth species were recorded in three Lepidoptera families: Saturniidae, Lasiocampidae and Thaumetopoeidae. The species diversity varied in these three families. In Saturniidae, 19 species were recorded in 6 genera, 33 species in 17 genera in Lasiocampidae and 6 species in one genus in Thaumetopoeidae. These indicate a good potential for wild silk farming in East Africa.

3. Two case studies on the distribution of *Bridelia micrantha*, the hostplant of the wild silkmoth *Anaphe panda* and *Sclerocarya birrea*, the hostplant of the silkmoth *Argema mimosae* revealed that the hostplants are widely distributed in Kenya, Uganda and Tanzania. A ground survey in western Kenya confirmed the availability of *B. micrantha* with 84 % of the farmers having it in varying numbers in their land.

4. A questionaire which was distributed to 50 local farmers near the Kakamega forest to assess the community awareness on the occurrence of wild silkmoths and their

economic value revealed that all the farmers were aware of the existence of the wild silkmoth cocoons but were not aware of their economic importance. Ninty eight percent of the farmers responded positively to wanting to be involved in wild silkmoth farming for extra income generation. This indicates a good chance to introduction of wild silk farming to these willing farmers.

5. Phenological studies on the selected species, *Gonometa* sp. and *A. mimosae* at Nguni, Mwingi and *A. mimosae* at Sultan Hamud, Makueni showed that these silkmoths have two generations each year coinciding with the two yearly rain seasons recorded in these regions. The silkmoths passed through the dry seasons in the pupal stage which is enclosed in the silk cocoon. The moth emergence and consequent egg laying and the sprouting of new leaves from the hostplants had a unique synchronization.

6. The overall duration of the developmental stages was longer in the *Gonometa* sp. which recorded a mean of 6.4 ± 3.2 days for adults, 11.3 ± 0.1 days for eggs, 53.5 ± 6.2 days for larvae and 95.9 ± 16.5 days for pupal development. In *A. mimosae* the durations were, 7.5 ± 2.1 days for adults, 10.9 ± 0.3 days for eggs, 32.9 ± 3.8 days for larvae and 78.3 ± 29.5 days for pupae. Pupal stage had the longest duration and this could suggest the existence of pupal diapause in these species.

7. Pupae observed in the controlled environmental conditions in an incubator had a significantly shorter life span (87.2 ± 3.6 days) compared to those observed under room condition (124 ± 11.2 days). This is an indication that the pupal diapause in these species can be manipulated for continuity of the life cycles depending on the availability of foodplants.

8. A high larval mortality of the silkmoths of both species was recorded in the field. The overall mortality from the first instar to the onset of cocoon spinning for *Gonometa* sp. reared on caged hostplant, *Acacia elatior* was 82.9 % during the short rains of 1996 and 78.9 % during the short rains of 1997. In *Argema mimosae*, reared on caged hostplant, *Sclerocarya birrea*, 80.6 % larval mortality was only recorded during the short rains of 1997. Rearing the *Gonometa* sp. silkworms in net sleeves enclosing the hostplant branches reduced the larval mortality to 23.9 %.

9. The mean number of eggs laid by *Gonometa* sp. was 301 ± 114.0 eggs and 359.9 ± 71.8 eggs for *A. mimosae*. Those of *A. mimosae* were laid in small clusters consisting of a mean of 2 eggs whereas those of *Gonometa* sp. consisted of larger clusters of a mean of 25 eggs.

10. Both species oviposited their eggs on different substrates including upper and lower surfaces of leaves, stems and surfaces of net sleeves. In addition, *A. mimosae* females also oviposited on the flowers of hostplants. This characteristic behaviour of not

being very specific on oviposition site can be tapped to enhance egg production in captivity for supply to farmers and for enhancing wild silkmoth populations in the wild.

11. There was a significant positive correlation ($r= 0.62$, $p< 0.01$) between the female moth weight and the number of eggs laid.

12. The length of the major and minor axis of *A. mimosae* eggs were significantly greater than those of the *Gonometa* sp. The egg shell of each species consisted of characteristic raised knobs between which numerous aeropyles were found. The consistency of these chorionic patterns makes them a good tool for future taxonomic work.

13. Hymenopteran parasitoids, *Mesocomys pulchriceps* and *Pediobius anastati* were found to parasitize eggs of both *A. mimosae* at Sultan Hamud and *Gonometa* sp. at Nguni. *Telenomus* sp. and unidentified wasps of the family Encyrtidae were recorded only from *A. mimosae* eggs collected from the field in Sultan Hamud.

14. Field collected *A. mimosae* cocoons did not yield any parasites. Both dipteran and hymenopteran parasitoids emerged from field collected cocoons of *Gonometa* sp. These parasitoids damaged cocoons leaving exit holes as the adults emerged. These holes spoilt the continuity of silk filament from these cocoons.

15. Predators attacking these two species of wild silkmoths were recorded. The insect predators belonged to various genera of the families Pentatomidae (Hemiptera), Formicidae (Hymenoptera) and Mantidae (Orthoptera). There was also a possibility of spiders and lizards being involved in the predation of these silkmoths.

16. Cocoon weights for both species was higher in females as compared to males but males had a significantly higher shell ratio percentage compared to the females in both species.

17. Cocoons of *A. mimosae* were not reelable but those of the *Gonometa* sp. were reelable giving long continous filaments of lustrous brown silk.

18. There was a significant difference in the length of silk fibre obtained from the *Gonometa* sp. females (706.34 ± 222.4 m) and males (521.49 ± 204.2 m).

19. Long continous silk fibres were obtained from both male and female *Gonometa* sp. cocoons with only a mean of 3 filament breaks being recorded for each cocoon reeled.

20. Raw silk percentage in the *Gonometa* sp. varied between males and females, being more in the male cocoons. It was calculated that 2326 - 4762 cocoons are required to make one kilogram of *Gonometa* sp. raw silk.

6:3 AREAS OF FUTURE RESEARCH

It was not possible during this study to look into all aspects of the biology, taxonomy, ecology and behaviour of the wild silkmoth species due to time limitation. Ecosystem analysis which includes population changes in relation to biotic and abiotic factors require a long time to study. Through the long time of study one can be able to substantiate the changes with time. It is therefore recommended that the following aspects be tackled in detail to provide better research back up for the establishment of wild silkmoth farming in East Africa.

1. Population changes and seasonal fluctuations with respect to different environmental factors such as temperatures and relative humidities.

2. Taxonomic revision of these groups based on morphology as well as biochemical characters where necessary.

3. Detailed interactions between the wild silkmoth species and their hostplants.

4. Comprehensive studies on the wild silkmoth predators, parasitoids and possible hyperparasitoids in the field.

5. Monitoring the impact of wild silkmoth farming on the biodiversity of the wild silkmoth species is important. This investigation requires long term observations to be able to evaluate its effect in improving the economic status of the community and their environment.

REFERENCES

Agarwal, S. C., Jolly, M. S., Sinha, A. K. and Banerjee, N. D. (1974). The utilisation of by-products in tasar industry. Proc. 1st Int. Sem. Non-Mulberry Silks. Ranchi, India. 225-230.

Akerele, L. L. (1970). A review of the technique of silkworm rearing and silk production. Federal Institute of Industrial Research, Nigeria. Technical Memorandum No. 24.

Ashiru, M. O. (1988). Determination of the number of instars of the silkworm *Anaphe venata* Butler (Lepidoptera: Notodontidae). *Insect Sci. Applic.* **9** (3): 405- 410.

Ashiru, M. O. (1991). Adult morphology of the silkworm *Anaphe venata* Butler (Lepidoptera: Notodontidae). pp. 17-21 in H. Akai and M. Kiuchi (eds.), Wild Silkmoths' 89.'90. International society for wild silkmoths, Ibaraki, Japan.

Aurivillius, P. O. C. (1927). Rhopalocera. In Seitz's Macrolepidoptera of the world, **13**: 613pp.

Badhera S. (1992). Relationship between pupal dimensions and fecudity in tasar silkworm, *Antheraea mylitta* Drury (Lepidoptera: Saturniidae). *J. Zool.*, **12** (1): 37-39.

Behrens, W. (1984). Environmental aspects of Insect dormancy. In *Environmental physiology and biochemistry of insects* (edited by K. H. Hoffman). Springer Verlag, Berlin Heidelberg.

Carpenter, G. D. H. (1920). A naturalist on Lake Victoria. London : Fisher Unwin, Ltd.

Chikwenhere, G. P. (1992). Distribution and abundance of the African silkmoth (*Gonometa rufobrunnea*) in Matebeleland provinces of Zimbabwe. *Zimbabwe J. Agric. Res.*, **29** (2),133-137.

Child, G. (1988). Economic incentives and improved wildlife conservation in Zimbabwe. Paper presented at Workshop on Economics, IUCN General Assembly, 4-5 February 1988, Costa Rica.

Chowdhary, S. K., Choudhary, A. B., Khajuria, R. K. and Jain, S. M. (1996). Studies on enhancing egg production in the tasar silkmoth, *Antheraea mylitta* D., by glucosides of steroids and polyphenolics. *Sericologia*. **36** (3): 497-506.

Clausen, C. P. (1940). Entomophagus insects. Hafner, New York

Coe, M. and Beentje, H. (1991). A field guide to the acacias of Kenya. Oxford Univ. Press.

Coffelt, M. A. and Schultz, P. B. (1992). Parasitism of orangestriped oakworm (Lepidoptera: Saturniidae) eggs in the urban landscape. *Biological Control* **2**: 306-311.

Coffelt, M. A. and Schultz, P. B. (1993a) Population biology of orangestriped oakworm (Lepidoptera: Saturniidae) in southeastern Virginia. *J. Entomol. Sci.* **28**: 218-229.

Coffelt, M. A. and Schultz, P. B. (1993b). Larval parasitism of orangestriped oakworm (Lepidoptera: Saturniidae) in the urban shade tree environment. *Biological Control* **3**: 127-134.

Cohn, J.P. (1995). Connecting by computer to collections. *Bioscience*, **45** (48) , 518-521.

Criel, B., Vanden-Berghe & Sequeira, G. (1995). The biodiversity database. Centre for biodiversity research reports: Biodiversity database, Number 6. National museums of Kenya.

Crotch, W. J. B. (1956). A silkmoth rearer's handbook. The Amateur Entomologists' Society.

Dash, A. K., Patro, P. C., Nayak, B. K. and Dash, M. C. (1994). Cocoon crop performance of the indian wild tasar silkworm *Antheraea paphia* (Lepidoptera : Saturniidae) reared on different food plants. *Int. J. Wild Silkmoth and Silk* **1**, 72-74.

De Meyer, M., Vanden-Berghe, E. & Whittington, A. E. (1995). Specimen database: Syrphidae (Diptera) of East Africa. Centre for biodiversity research reports: Biodiversity database, Number 1. National Museums of Kenya.

Denlinger, D. L. (1986). Dormancy in tropical insects. *Ann. Rev. Ent.*, **31**, 239-264.

Elhance, D. N. (1977). Practical problems in statistics. Kitab Mahal, Allahabad, pp 159-160.

Elson, J. A. (1937). A comparative study of Hemiptera. *Ent. Soc. Amer. Ann.*, **30**: 579-593.

Fiske, W. F. (1920). Investigations into the bionomics of *Glossina palpalis. Bull. Ent. Res.* **10**: 347.

Frost, P. G. H. (1991). Perspectives of wildlife utilisation in communal lands in the Zambezi Valley, implications for land use planning. FAO report, ZIM/86/018. Rome: FAO.

Geertsema, H. (1975). Studies on the biology, ecology and control of the pine tree emperor moth *Nudaurelia cytherea cytherea* (Fabr.) (Lepidoptera: Saturniidae). *Annale van die Universiteit van Stellenbosch*, 50: (A) (1): 1-171.

Global Biodiversity Status of the Earth's Living Resources, (1992). Edited by Brian Groombridge. Chapman and Hall.

Gosh, M. K., Babu, C. M., Ponnuvel, K. M., and Srivastava, R. C. (1996). Correlation between female moth weight and fecudity in the oak tasar silkworm, *Antheraea proylei J. Sericologia*, **36** (3): 561-564.

Gowdey, C.C. (1953). On the utilisation of an indigenous African silkworm *(Anaphe infracta*, WLS.) in Uganda. *Bull. Ent.Res.*, **3**:. 269-274.

Hartland-Rowe, R. (1992). The biology of the wild silkmoth *Gonometa rufobrunnea* Aurivillius (Lasiocampidae) in northern Botswana, with some comments on its potential as a source of wild silk. *Botswana Notes and Records*, **14**: 40-46.

Hinton, H. E. (1969) Respiratory system of insect egg shell. *Ann. Rev. Ent.* 14: 343-368.

Hinton, H. E. (1970) Insect egg shell. *Sci. Am.* 223: 84-91.

Holloway, J. D., Bradley, J. D. & Carter, D. J. (1987). *C.I.E. Guide to insects of importance to man, Lepidoptera* (edited by C. R. Betts). C.A.B. International Institute of Entomology.

Holloway, J.D. & Stork, N. E. (1991). The dimensions of biodiversity: The use of invertebrates as indicators of human impact. In *The biodiversity of microorganisms and invertebrates: Its role in sustainable agriculture (* edited by D. L. Hawksworth). CAB International.

Janarthanan, S., Sathiamoorthi, K. M. and Krishnan, M. (1994). Photoperiod effect on larval-pupal characters, fat body nucleic acids and protein of silkworm, *Bombyx mori* L. *Insect Sci. Applic.* 15 (2): 129-137.

Jolly, M., S., Chaturvedi, S. N. and Prasad, S. (1968). A survey of tasar crops in India. *Indian J. Seric.* **1**: 50-58.

Jolly, M. S., Sinha, S. S. and Razdan, L. L. (1971). Influence of temperature and photoperiod on termination of pupal diapause in the tasar silkworm, *Antheraea mylitta*. *J. Insect Physiol.*, **17**: 753-760.

Jolly, M. S, Sen S. K, Sonwalkar T. N. and Prasad G. K. (1979). Non-mulberry silks. F.A..O. *Agric. Seri. Bull.* Rome **29:** 1-164.

Jolly, M. S. (1981). Distribution and differentiation in *Antheraea* species (Saturniidae: Lepidoptera). In the proceedings of the Symposium of study and utilization of non-mulberry silkworms (August 3-9,1980,Kyoto,Japan). Edts S.Sakate & H. Yamada. International Society of Non-mulberry silks, 1-14.

Kasule, F. K. (1991). Association of fecudity with adult size in cotton stainer bug, *Dysdercus fasciatus*. *Heredity*, **66**: 281-286.

Kato, Y. and Sakate, S. (1981). Photoperiodic and temperature conditions affecting summer diapause of *Antheraea yamamai* pupae. In the proceedings of the Symposium of study and utilization of non-mulberry silkworms (August 3-9,1980,Kyoto,Japan). Edts S.Sakate & H. Yamada. International Society of Non-mulberry silks, 1-14.

Kawaguchi, Y. Banno Y. Koga K. Kawarabata T. and Doira H. (1996) Comparison of Chorion structure of eggs from *Bombyx mori*, *Bombyx mandarina* (Lepidoptera: Bombycidae) and their Filial Generation. *Appl. Entomol. Zool.* **31:** (3): 407-415.

Khamala, C. (1984). Ecological studies in Kakamega forest as a sample unit in the global

strategies of conservation in vulnerable tropical ecosystems with special reference to the status of insects. Report for UNEP, 31 pp.

Kotikal, Y. K. , Reddy, D. N. R., Prabhu, A. S., Bhat, G. G., and Pushpalatha, S. (1989).Relationship between pupal size and egg production in eri silkworm, *Samia cynthia ricini* (Lepidoptera: Saturniidae). *Indian J. Seric.*, **28**: 80-82.

Kumar, K. S. A. (1995). Changing non-traditional silk export markets of India. *Indian silk*, **34** (3), 41-45.

Larsen, T.B. (1991). The butterflies of Kenya and their natural history. Oxford University press, New York, USA.

Lederhouse, R. C. (1990). Avoiding the hunt: primary defenses of Lepidoptera caterpillars.pp175-190 in D. L. Evans and J. O. Schmidt (eds), Insect Defenses. State Univ. N. Y. Press, Albany.

Majhi, S. K. and Chatterjee, S. M. (1994). Some characteristic aspects of wild silk cocoon. *Int. J. Wild Silkmoth & Silk*, **1** (93): 93-98.

Marsh, F. L. (1937). Ecological observations upon the enemies of *Cercropia*, with particular reference to its hymenopterous parasites. *Ecology*, **18**: 106-112.

Masaki, S. (1980). Summer diapause. *Ann. Rev. Ent.*, **25**: 1-25.

Miller, A. T., Cooper, W. J. and Highfill, J. W. (1982). Relationship between pupal size and egg size production in reared female *Antheraea polyphemus*. *Ann. Entomol. Soc. Am.*, **75**: 107-108.

Mkanda, F. X. (1992). The potential of Kasungu National Park in Malawi to increase income and food security in neighbouring communities. Paper presented at IV World Congress on National Parks and protected areas. 10-12 February 1992, Caracas, Venezuela.

Munthali, S.M. and Mughogho, E. C. D. (1992). Economic incentives for conservation: bee-keeping and Saturniidae caterpillar utilization by rural communities. *Biod. Conserv.* **1**:143-154.

Nakajima, F. (1981). The present situation of rearing of wild silkworms in Nagano prefecture. In the proceedings of the Symposium of study and utilization of non-mulberry silkworms (August 3-9,1980, Kyoto,Japan). Edts S.Sakate & H. Yamada. International Society of Non-mulberry silks, 15-16.

Nayak, B. K. and Dash, M. C. (1991). Environmental regulation of voltinism in *Antheraea mylitta* Drury (Lepidoptera : Saturniidae), the indian tasar silk insect. *Sericologia,* **31** (3): 479-486.

Nayak, B. K., Dash, A. K.,Mishra, C. S. K., Nayak, U. K., Dash, M. C. and Prabhakar, D. R. (1994). Innovation of technology for commercial rearing of Indian wild tasar silk insect, godamodal ecorace of *Antheraea paphia* Linn. (Lepidoptera: Saturniidae). *Int. J. Wild Silkmoth & silk,* **1**: 75-79.

Nguyon-cong-Huan, A. (1974). Wild sericigenous insects and non-mulberry food plants in South Vietnam. Proc. 1st Int. Sem. Non-Mulberry silks, Ranchi, India. 7-23.

Oberprieler, R. G. (1987). Emperor moths (Saturniidae) as botanists - the value of food-plant data in classification and conservation. *Proceedings of the first Lepidoptera Conservation Symposium, Lepidopterists' Society of Southern Africa*, 18-21.

Oberprieler, R. G. (1995). The Emperor Moths of Namibia. Sigma press, Pretoria.

Ochieng-Odera, J. P. R., (1990). Critical, pupal and Adult weight in the size related metarmorphosis of the black lyre leafroller, *Cnephasia jactatana. Ent. Exp. applic.*, **54**: 21-27.

Oliveira, J. F. S., De Carvalho, R. F. X., De Sousa, B. and Simao, M. M. (1976). The nutritional value of four insects consumed in Angola. *Ecol. Food Nutr.* **5**: 91-97.

Peck, O. (1963). A catalogue of the Nearctic Chalcidoidea (Insecta: Hymenoptera). *Canad. Ent.*, Supplement **30**: 1-1092.

Peigler, R. S. (1989). A revision of the Indo-Australian Genus *Attacus*. The Lepidoptera Research Foundation, Beverly Hills, California.

Peigler, R, S. (1993). Wild silks of the world. *Amer. Entomol.*, **39** (3): 151-160.

Peigler, R. S. (1994). Catalog of parasitoids of Saturniidae of the world. *J. Res. Lepid.* **33**: 1-121.

Perry, B. D., Lessard, P., Norval, R. A. I., Kundert, K., Kruska, R. (1990). Climate, vegetation and the distribution of *Rhipicephalus appendiculatus* in Africa. *Parasitology Today*, **6** (4): 100-104.

Pinhey, E. C. G. (1956). The emperor moths of Eastern Africa. *J. E. Afr. Nat. Hist. Soc*, 1-62.

Pinhey, E. C. G. (1975). Moths of Southern Africa. Capetown: Tafelberg.

Prinsloo, G. L. (1987). A revision of the genus Ooencytus Ashmead (Hymenoptera: Encyrtidae) in sub-Saharan Africa. Republic of South Africa, Department of Agriculture & Water Supply, Entomological Memoir, **67**:1-46.

Reddy, J. K., Singh, M. K., Murthy, T. S. K. and Ram, M. G. (1995). A new method to control wasps in tasar culture. *Indian Silk*, **34** (3): 34-38.

Regier J. C., Mazur G. D. and Kafatos F. C. (1980). The silkmoth chorion: morphological and biochemical characterization of four surface regions, *Develop. Biol.*, **76**: 286-304.

Rogers, D. J. and Randolf, S. E. (1984). Local variations in the population dynamics of *Glossina palpalis palpalis* (Robieau- Desvoidy) (Diptera: Glossinidae). 1. Natural population regulation. *Bull. Ent. Res.*, **74**: 403-423.

Roychoudhury, N. and Joshi, K. C. (1995). Silkworm pupae as human food. *Indian Silk*, **34** (3): 10

SAS Institute, (1988). SAS/STAT users guide, Release 6.03 edition, Cary North Carolina, USA.

Schenk, A. (1981). The wild silk production is necessary for the future of silk textiles. In the proceedings of the Symposium of study and utilization of non-mulberry silkworms (August 3-9, 1980, Kyoto, Japan) (Editors S. Sakate & H. Yamada). International Society of non-mulberry silk.

Schmidt, J. O. (1990). A kaleidoscope of cryptic colours: polymorphic caterpillars and camouflaged adults on a multi-coloured host plant. pp. 61-67 in M. Wicksten (ed.) Adaptive Colouration in Invertebrates. Texas A&M Univ. Press, Austin.

Scultze, A. (1914). Die afrikanischen seidenspinner und ihre wirtschaftliche bedeutung. *Zeitschrift furangewandte entomologie*. **1**: 223-231.

Shamachary, S. M. V. and Krishnaswami, S. (1980). Some useful correlation studies of silkworm and its products such as cocoon, pupa, shell and egg weight. *Indian J. Seric.*, **19**: 4-8.

Sinha, A. K. and Chaudhuri, A. (1992). Factors influencing the phenology of different broods of tropical tasar silkmoth, *Antheraea mylitta* Drury (Lepidoptera:

Saturniidae) in relation to its emergence and post-emergence behaviour. *Environ. Ecol.*, **10** (4): 952-958.

Singh, Y. R. and Prasad, B. (1987). Correlation among body weight, pupal weight and fecudity in eri silkworm, Philosamia ricini Hutt. (Lepidoptera: Saturniidae). *Sericologia*, **27**: 49-60.

Stamp, N. E. and Bowers, M. D. (1990). Phenologyof nutritional differences between new and mature leaves and its effect on caterpillar growth. *Ecol. Ent.*, **15**: 447-454.

Thangavelu, K., Chakraborty, A. K., Bhagowati, A. K. and Isa, M. D. (1988). Handbook of Muga culture. Central Silk Board, Bangalore, India.

Tuskes, P. M., Tuttle, J. P. and Collins, M. M. (1996). The wild sik moths of North America.Cornell Univ. press, Ithaca.

United Nations (1975). Handbook on women in Africa. United Nations, New York.

Van Den Berg, M. A. (1971). Studies on the egg parasites of the mopani emperor moth *Nudaurelia belina* (West.) (Lepidoptera: Saturniidae). *Phytophylactia*, **3**: 33-36.

Van Den Berg, M. A. (1974). Natural enemies and diseases of the forest insect *Nudaurelia cytherea clarki* Geertsema (Lepidoptera: Saturniidae) *Phytophylactia*, **6**: 39-44.

Van Huis, A. (1996). The traditional use of arthropods in sub-saharan Africa. *Proc. Exper. & Appl. Ent.*, N.E.V. Amsterdam, **7**: 3-20.

van Someren, G. R. C. (1988). Pioneers of Afrotropical ornithology V. G. L. van Someren (1886-1976). Tauraco, **1**: 90-98.

Vane-Wright, R. I. (1991). Why not eat insects. *Bull. Entomol. Res.* **81**: 1-4.

Weseloh, R. M. (1993). Potential effects of parasitoids on the evolution of caterpillar foraging behaviour. pp. 203-223 in N. E. Stamp and T. M. Casey (eds.), Caterpillars, Ecological and Evolutionary Constraints on Foraging. Chapman and Hall, New York.

Wilson, J. W. (1933). The biology of parasites and predators of *Laphygma exigua* Huebner reared during the season of 1932. *Fla. Ent.* **17**: 1-15.

APPENDICES

Appendix 1: Diversity of cocoon forming species in three wild silkmoth families: Lasiocampidae, Saturniidae and Thaumetopoeidae, occurring in East African countries, Kenya (K), Uganda (U) and Tanzania (T).

Appendix 1a: Silk cocoon forming species in the Lepidoptera Family Lasiocampidae

SPECIES	COCOON STRUCTURE	DATE COLLECTED	COLLECTOR	LOCALITIES	HOST PLANTS RECORDS	OTHER DISTRIBUTION RECORDS
Bombycopsis indecora Walker	compact, small cream colour	1929 18.ix.1958	H. Hargreaves Z. Nyiira	Uganda Kawanda (U), Kitale (K), Thika (K), Usambara (T)	None	Namaya, Ethiopia
Bombycopsis bifascia Walker	compact, small, brown in colour	x/xi 1958	B. T. Parson E. Pinhey	Machakos (K) Thika road, Nairobi (K)	None	
Ceratopacha salambo Vuillot	compact,small, brown colour	iv.1969 iv. 1964 iii. 1950 iv. 1954	M. Clifton R. H. Carcasson N. Mitton Mrs. Adamson	Isiolo (K), Kitale (K) Mtito Andei (K) Sokoke forest (K), Shimba Hills (K) Dodoma (T), Iringa (T)	None	Zambia Ethiopia
Chrysopsyche mirifica Butler	small, soft, yellow in colour	1958	J. Bowden	Kawanda (U), Lugazi (U)	None	
Diapalpus congregarius Strand	soft, small, brown colour	25.ii.1932	H. Hargreaves	Uganda	None	

Gonometa regia Aurivillus	compact, big to medium, brown with spines	8.Vii. 1936 1909	Hopkins D. Bruce	Hoima (U) Mpumu (U)	None	Type locality, Uganda
Gonometa nysa Druce-		ii.1968 Xi/Xii. 1967 Vi/Vii. 1966 X.1960	A. I. Archer A. I. Archer J. G. Williams R. H. Carcasson	Sango Bay (U) Bungoma forest Unyoro (U) Budongo forest (U) Katera Sango Bay (U)	None	Type locality- Cameroon, Nigeria, Congo, Ivory Coast
Gonometa rufobrunnea Aurivillius	Compact, big to medium size, brown in colour with spines	X.1938 14. iV.1949 23. iii. 1947 Vii.1953 Viii.1939 .ii. 1951 6.X. 1944 X/ Xi. 1951 iX. 1951 iX. 1978 V.1965 XI.1954 14. iii. 1922 31.X. 1921 22.Viii.1938	A. Townsend A. Townsend R. H.N. Simmonds T.H. E. Jackson Father Conrad C. A. Hopper T. H. Jackson Fowler & Coulson B. T. Parsons Mrs Marshall J. G. Williams J.Adamson W. Feather Dr. Baxter H. Hargreaves T. H. C. Taylor	Nakuru(K) Nakuru (K) Nairobi (K) Embu (K) Ukwele (T) Nairobi (K) Mt. Elgon (K) Ngong (K) Makueni (K) Magadi road (K) Nairobi (K) Isiolo (K) Kibwezi (K) Mpapua (T), Itumba (T) Mubende (U) Kiagwe, Magira (U)	None	Type locality- Germ. East Africa, Ndola (Zambia)

Gonometa podocarpi Aurivillius	compact, large to medium size, brown colour with spines	25.V. 1965 1950 IV.1963 Viii. 1949 Xii. 1952 1946 1.iX. 1950 25.iii. 1952 14.11.1931 30.vii.1980 iii.1949 ii.1973 17.xi.1979 x.1972	K. W. Brown J. C. M. Gardner B. T. Pearson T. E. Jackson Col. Chaplin A. Townsend J. C. M. Gardner J. Muhangani J. S. William Van Someren Robertson	Muiko forest, Kabate (U) Kabete (K) Kitale (K) S. Kinangop (K) Nyeri (K) Kitale (K) Limuru (K) W. Abardares (K) Nairobi(K) Nairobi (K) Nairobi (K) N. Nandi forest(K) Nairobi(K)	*Pinus patula* ex *Cupressus* Podo ex *Cupressus* Podo	Type locality, Mt Elgon (U)
Gonometa titan Holland		xi.1961	R. H. Carcasson	Kalinzu forest, Ankole (U)	-	Type locality Nigeria
Gonometa postica Walker		xi.1957 x.1922	E.S. Ross & E. Leech W. Feather	Taite hills (K) Kibwezi (K)	-	Type locality South Africa, Zulu land, Natal
Gonometa christyi Sharpe		iii. 1932	W. Feather	Suna, S. Kavirondo (K)	-	Type locality Nigeria
Grammodora nigrolineata Aurivillius	soft,medium size, yellow	x/xi. 1950	B.T. Parson	Machakos (K) Nachingwea (T)	- -	Katanga (Congo) Zambia
Haplopacha bifascia Walker	soft looking, small size	1950 x.1950 1950	N. Mitton E. Pinhey B. T. Parson	Arusha (T) Thika (K) Machakos (K)	-	

Leichriolepsis jacksoni B-Baker	small size, soft looking brown	7.x.1929 1954	H. Hargreaves M. Magala	Kayi forest (U) Kawanda (U)	- -	
Leichriolepsis nigrivenis Strand	soft looking, grey in colour	25.I.1944	T. H. C. Taylor	Uganda	-	
Leichriolepsis citrina Schauss	smooth texture, yellow colour	13.vii.1958	J. Bowden	Uganda	-	
Leichriolepsis griseola Aurivillius	soft, yellow in colour	viii/Xi 1965 xi.1976 1954 vi. 1957	T. H. E. Jackson M. Clifton J. A. Burgess	E. Usambara (T),Kagera, Masaka (U), Kakamega forest (K), Entebbe (U), Abera forest, Gulu (U)	-	
Leichriolepsis leucostigma Humpner	soft, medium size, yellow in colour	1951	T. H. E. Jackson	Kigezi (U)	-	
Leipoxais marginepuncta Holloway	smooth, medium size black in colour	20.I. 1932 4.ii. 1953	H. Hargreaves M. Magala	Uganda Uganda	- -	
Leipoxais emargineta Aurivillius	soft, small size, brown in colour	vi/x. 1951 i/iii. 1965 ii. 1966	B. T. Parsons Mrs Chalmers I. Robertson	Makueni(K) Morogolo (T) Ilonga (T)		
Mallocampa audea Druce	compact, small , yellow in colour	2.ix.1932	-	Kampala (U)	-	

Mimopacha cinerascens Holloway	soft, medium size off white in colour	1960 xi. 1953 iv. 1954 vii. 1951	J. Bowden C. R. Howard B. T. Parsons E. Pinhey	Kawanda (U) Kitale (K) Amani (T) Usambara (T) Makueni (K) Entebbe (U) Thika (U)	-	
Pachymeta stigma Strand	compact, large brown in colour and with spines	3.x. 1957	Watkins	Kawanda (U)	-	
Pachypasa subfascia Walker	loosely spun, large brown	9.vi. 1996 16.I.1931 ii. 1953	D. Rotich H. Hargreaves E. Pinhey	Kitale (K) Kampala (U) Mt. Elgon , Mbale (U), Kalinzu forest (U), Makerere (U), Kawanda (U), Amani (T)	-	
Pachypasa morosa Walker	soft, medium, brown colour	iv. 1963 vii. 1961 iii/iv 1954	B. T. Parson Fowler & Coulson	Nairobi (K), Machakos (K), Kabete (K), Makueni (K), Ngong (K)		
Pseudometa minima Holloway	smooth, whitish in colour	xi. 1950	-	Nairobi (K)	ex grass	Zambia
Streblota diplocyma Hamps	smooth, green in colour	27.xi. 1935	H. Hargreave	Kawanda (U)	-	
Streblota butiti	smooth, golden colour	17.I.1957 12.xii.1916	T.R. Odhiambo Gowdey	Kawanda (U) Uganda	ex mutuba	

Taragama grabeli Dewhurst	very loosely spun, small yellow in colour	15.iii. 1990	W. Cheluget & J. Muriuki	Katera forest (U) Amani, Usambara (T) Thika (K)	ex Macadamia	
Taragama aculeatum Walker	loosely spun, small white in colour	ii.1964 iii.1959 xi/xii 1967	B. T. Parsons N. Mitton A. Areles	Nairobi (K) Moshi (T) Bugoma forest, unyoro (U),	-	
Taragama diplocyma Humpson	loosely spun	vi. 1936 1971	A. Townsend B. Watulege	Nakuru (K) Kitobo forest Taveta (K)	-	
Trabala charon Druce	greenish yellow	2.vii.1953	M. Magala	Kayi forest (U)		

Appendix 1b: Silk cocoon forming species in the Lepidoptera Family Saturniidae

SPECIES	COCOON STRUCTURE	DATE COLLECTED	COLLECTOR	LOCALITIES	HOSTPLANT RECORDS	OTHER REMARKS
Antistathmoptera daltonae Tams		ii.1953 xii.1934 27.x.1962	C. Howard E. Dalton D.M. Cookson	Amani, E. Usambara Mts(T) Amani (T) Siluve (T)	-	Type locality Tanganyika
Argema mimosae Boisduval	compact, medium to large size,silver in colour	1952	B. T. Parsons	Makueni (K)	-	Type locality South Africa, Natal, Malawi, Mozambique
Argema besanti Rebel	Compact, medium size,silverlish in colour	11. xi. 1911 23.xi.1911 - iii.1951	L. Ayimer W. Feather C.W. Hobley -	N. Waso Nyiro R. (K) Kedai (B.E. Afri) Manyani (K) Mandera (K)	-	
Epiphora mythmnia Westwood	compact, small brownish in colour	1952 iii.1922 1929	Van Someren W. Feather Lieut. M. S. Moore	Madi opei (U) Kibwezi (K) Arusha (T)	-	Malawi, S. Africa, Mozambique
Epiphora albida Druce	-	1902 1954	Cap. Ratray Van Someren	Entebbe (U) Kayonza, Kigezi (U)	-	Type locality Cameroun Mts. Angola, Congo
Epiphora watulegei Rougeot	-	1953	T.H.E. Jackson	Mt. Elgon (K)	-	

Epiphora rectifascia Rothschild	-	x/xi. 1966 iii.1966	Wetulege R. Carcasson	Kakamega forest (K) Kalinzu forest, Ankole (U)	-	Type locality Congo. Sudan
Epiphora vacuna Westwood	-	v. 1967 x.1953	- -	kakamega forest (K) Katwe (U)	-	Type locality Ghana.
Epiphora pelosoma Rothschild	-	iii/iv 1931 1966	Van Someren G. Pringle	Jinja (U) Amani (T)	-	Type locality Tanzania.
Epiphora bauhiniae Guerin-Meneville	-	vii.1966 iv.1954 v 1956 viii. 1971	A. Archer J. B. Harcker R. Carcasson B. Watulege	Kidepo National Park (U) Kapenguria (K) Muhoroni (K) Abera forest, Gulu (U)	-	Type locality West Africa. Gambia, Ghana, Nigeria, Sudan
Epiphora schultzei Aurivillius	-	1934 1929	- Lieut. M. S. Moore	Kenya Arusha (T)	-	Type locality Cameroon. Sudan,
Epiphora lugardi Kirbyi	compact, small size, brown	v. 1922 iv. 1956 iii. 1957 -	W. Feather Adamson B. T. Parsons Dr Baxter	Kibwezi (K), Isiolo (K) Makueni (K) Mpuapua (T)	-	Type locality Uganda. Ethiopia,

Epiphora antinorii Oberthur	-	iv. 1970 xi.1964 ix. 1950	B. Watulege M. G. Prettejohn	Njoro (K) Amani (T) Kabete (K)	-	Type locality Ethiopia.
Epiphora imperator Stoneham	-	xi.1932 1934 x.1931	Van Someren J.P.M. Ingham T.H.E. Jackson	Kitale(K) Lushoro (T) Mt. Elgon (K)	-	Type locality Kenya.
Goodia smithi Holloway	very loosely spun small, brown colour	x/xi. 1950 iv. 1967 5.vii.1981 viii-xi 1965	R. H. Carcasson B. Watulege J. Darlington T. H. E. Jackson	Masaka (U) Busia (U) Kajiado (K) Uganda		
Goodia lunata Jordan	loosely spun, small, brown colour	xi.1970 ii. 1969 x/xi 1969	B. Watulege A.L. Archer B. Watulege	Budongo forest (U), Kalinzu forest (U), Kakamega forest (K), Malabigambo forest (U)		
Holocera micropteryx Hering	rough, medium, brown in colour	xi.1964	-	Bukoba (T)	-	Namibia

Appendix 1c: Silk cocoon forming species in the Lepidoptera Family Thaumetopoeidae

SPECIES	COCOON STRUCTURE	DATE COLLECTED	COLLECTOR	LOCALITIES	HOSTPLANT RECORDS	OTHER REMARKS
Anaphe carteri Walsm	-	1945	B. S. Darling	Kawanda (U)	-	
Anaphe moloneyi Druce	-	29.iv. 1939	H. D. Mubbiru	Kawanda hill (U)	-	
Anaphe panda Boisduval	compact, huge nest, brown in colour	vii. 1955 xi.1961 - 4.xi. 1936 iii/iv 1932 v. 1949 ii. 1938 x/xi. 1969 x.1950 I.1980 9.xi. 1976	A. P. G. Michelmore R. H. Carcasson Father Conrad G. H. E. Hopkins Van Someren R. W. Barney Stoneham B. Watulege E. Pinhey M. Clifton J. Waskerich	Kawanda (U) Kalinzu forest (U) Ukerewe I. (T) Uganda Kaimosi (K) Kakamega (K) Kalinzu (U) Kakamega forest (K) Thika (K) Kakamega forest (K) Kisii (K)	ex *Bridelia micrantha*	

Holocera angulata Aurivillius	rough, small, brown in colour	x/ix 1973 vii. 1970 viii. 1974	B.R. H. Carcasson B. Watulege I. Hardy	Abadares (K) Kalinzu forest (U) Rushaga forest (U)		
Ludia orinoptera Karsch	loosely spun, small, brown	26.iii.1958	J. Bowden	Kampala (U)		

Anaphe reticulata Walker	compact, huge nest, brown in colour	26. iii. 1965 iv. 1957 9.iii. 1953 23. I. 1954 - iv. 1954 iv. 1939	N. Mitton T.H.E. Jackson E. Burtt E. Burtt Father Conrad C. Howard A. Townsend	Soroti (U) Tororo (U) Old Shinyanga (T) Old Shinyanga (T) Ukerewe I (T) Kitale (K) Ravine (K)		Zambia
Anaphe venata Butler	-	27.xii. 1933 17.ii.1940 22.xi. 1938	G.H.E. Hopkins H. Hargreaves G.H.E. Hopkins	Mabira forest (U) Kawanda (U) Entebbe (U)		
Anaphe vuillet De Jouan	-	iii. 1927 1.viii.1910 28. ix. 1962 viii.1949	G.D.H. carpenter C.C. Gowdey T. Jones R. W. Barney	Entebbe (U) - Semliki valley (U) Thomson Falls (U)	Temarindus indica	Congo, Sudan

APPENDIX 2: HOSTPLANT LOCALITIES

2A: Localities recorded for *Sclerocarya birrea*

LOCALITY	LATITUTE	LONGITUTE
Bahati	-4.21667	35.75
Chemolingot	0.96666	35.95
Chesegon	1.29167	35.61667
Chyulu hills	-2.5667	37.8333
Dar es salaam	-6.8	39.25
Mara Bridge	-1.15	35.08333
Emali	-2.0833	37.475
Endau	-1.2667	38.56667
Farkwa	-541667	35.6
Ilongo	-8.78333	33.71667
Jilore	-3.2	39.91667
Oropoi	3.76667	34.23333
Kapenguria	1.24167	35.11667
Karibani	-2.025	37.35833
Kiangata	-1.65	34.11667
Kiboko	-1.129329	37.238005
Kibwezi	-2.3583	38.0583
Kidatu	-7.63333	36.9
Kidepo	3.91667	33.8333
Kinango	-4.120631	39.32469
Kitui	-1.371443	38.015485
Kondoa	-6.81667	37.05
Chala	-3.309178	37.75105
L.Manyara	-3.58333	35.8333
Lisekese	-10.7	38.7833
Lodoketemit	2.28333	34.65
Lotuturu	3.73333	32.91677
Machakos	-2	37.66667
Mahali	-6.2	29.83333
Maketi	-9.38333	33.66667
Makonde	-10.71667	39.2
Malya	-2.98333	33.516667
Mara	-1.21667	35.03333
Mara R..	-1.25	34.6
Marigat	0.46666	35.98333

Masai Dist.	-1.75	36.4167
Mathews Range	1.26667	37.28333
Mbeya	-8.83333	33.3333
Meru N.P.	0.121786	38.20541
MidaCreek	-3.35	39.96667
Morogoro	-6.8292	37.675
Moroto	2.53333	34.76667
Moshi	-3.35	37.33333
Mpwapwa	-6.5	36.5
Tarime	-1.35	34.35
Msembe	-7.65	34.91667
Mua Hills	-4.439239	37.20729
Musoma	-4.49167	33.80833
Mwachi	-4	39.53333
Namanga	-2.513048	36.84719
Ngong Hills	-1.41667	36.6333
Ngorongoro crater	-3.16667	35.58333
Nyambene Hills	0.2	37.85
Oloibortoto	-1.825	36.0333
Pangani	-1.278243	36.832925
Puma	-5	34.74167
Ruaha	-7.58333	34.5
Rukwa Rift valley	-7.33333	31.58333
Rungwa	-7.3333	31.66667
Ruponda	-10.25	38.70833
Seronera Lodge	-2.43333	34.81667
Serere	1.5	33.33333
Shimba forest	-4.225	39.4167
Shimoni	-4.65	39.38333
Sigor	1.4833	35.4667
Tanga	-5.03333	39.1
Tarangire	-4.0667	35.9667
Taveta	-9.01667	35.61667
Tiwi	-4.23333	39.575
Tsavo West National Park	-3.42072	37.93941
Tunduru	-11.11667	37.35
Turkana Dist.	2.96564	35.355805
Kaputir	2.08333	35.46667
Vigude	-7.5	37
Wazo	-6.8	39.25
West Nile Dist.	3.	31.5

2b: Localities recorded for *Bridelia micrantha.*

LOCALITY	LATITUDE	LONGITUTE
Arusha-Dodoma road		
Barsemoi-Baringo		
Babati	-4.21667	35.75
Chemolingot	0.96666	35.95
Chesengon	1.29167	35.61667
Chichoroni		
Chobe		
Chyulu hills	-2.5667	37.8333
Dar es salaam	-6.8	39.25
Mara Bridge	-1.15	35.08333
Emali	-2.08333	37.475
Endau	-1.26667	38.56667
Farkwa	-5.41667	35.6
Ganja		
Ilongo	-8.78333	33.71667
Iringa-Dodoma road		
Iringa Mbeya road		
Ishiara-Meru road		
Jilore	-3.2	39.91667
Oropoi	3.76667	34.23333
Kakumongole		
Kapenguria	1.24167	35.11667
Karibani	-2.025	37.35833
Kaya Rabai-Kilifi		
Kiangata	-1.65	34.11667
Kiboko	-1.129329	37.238005
Kibwezi	-2.3583	38.0583
Kidatu	-7.63333	36.9
Kidepo	3.91667	33.83333
Kitiliko		
Kinango	-4.120631	39.32469
Kitui	-1.371443	38.015485
Klinis camp		
Kondoa	-6.81667	37.05
Chala	-3.309178	37.75105
Lake Manyala	-3.58333	35.83333
Lisekese	-10.7	38.78333
Lodoketemit	2.28333	34.65
Lotulturu	3.73333	32.91667
Machakos	-2	37.66667

Mahali	-6.2	29.83333
Makete	-9.38333	33.66667
Makonde	-10.71667	39.2
Malya	-2.98333	33.51667
Mara	-1.21667	35.03333
Mara river	-1.25	34.6
Marakwet		
Marigat	0.46666	35.98333
Masai district	-1.75	36.4167
Mathews range	1.26667	37.28333
Mbeya	-8.83333	33.33333
Meru National Park	0.121786	38.20541
Miambani-Kitui		
Mida Creek	-3.35	39.96667
Mikumi National Park		
Morogoro	-6.8292	37.675
Moroto	2.53333	34.76667
Moshi	-3.35	37.33333
Mpwapwa	-6.5	36.5
Tarime	-1.35	34.35
Msembe	-7.65	34.91667
Mtembur		
Mtimbwani Kangata		
Mua hills	-1.439239	37.20729
Musoma	-1.49167	33.80833
Mwachi	-4	39.53333
Namanga	-2.513048	36.84719
Ngama hills		
Ngong hills	-1.41667	36.63333
Ngorongoro crater	-3.16667	35.58333
Nyambene hills	0.2	27.85
Oloibortoto	-1.825	36.0333
Pangani	-1.278243	36.832925
Puma	-5	34.74167
Rukwa Riftt Valley	-7.33333	31.58333
Ruaha	-7.58333	34.5
Rungwa	-7.33333	31.66667
Rupinda	-10.25	38.708333
Seronera Lodge	-2.43333	34.81667
Serere	1.5	33.33333
Shimba forest	-4.225	39.4167
Shimoni	-4.65	39.38333
Sigor	1.4833	35.4667
Tanga	-5.03333	39.1

Tarangire	-4.0667	35.9667
Taveta	-9.01667	35.61667
Tebere		
Tiwi	-4.23333	39.575
Tsavo west National Park	-3.42072	37.93941
Tunduru	-11.11667	37.35
Turkana district	2.96564	35.355805
Kaputir	2.083333	35.46667
Vigude	-7.5	37
Vikawe-Kisambo		
Vipingo-Takamugu		
Wazo	-6.8	39.25
West Nile District	3	31.5

Appendix 3: Weather data for Sultan Hamud and Nguni for the period January 1996 to December 1997

Appendix 3a: Sultan Hamud

		TEMPERATURE (MEAN)			RAINFALL		RH %
Year	Month	Max.	Min.	Mean	Mean	Total	Mean
1996	Jan	33.39	17.56	25.48	1.00	31.00	77.48
1996	Feb	33.74	18.53	26.14	2.03	59.00	78.76
1996	Mar	33.58	19.45	26.52	1.71	53.00	76.19
1996	Apr	32.48	17.37	24.93	1.88	51.40	76.30
1996	May	31.21	16.55	23.88	1.10	34.80	70.26
1996	Jun	28.87	15.07	21.97	0.21	3.50	72.07
1996	Jul	27.82	14.39	21.12	0.03	1.00	68.39
1996	Aug	28.76	14.00	21.38	0.00	0.00	72.77
1996	Sep	30.95	16.77	23.86	0.00	0.00	67.73
1996	Oct	32.69	17.13	24.91	0.00	0.00	65.39
1996	Nov	31.20	18.85	25.03	6.32	189.80	78.37
1996	Dec	31.34	15.68	23.51	0.06	2.00	72.26
1997	Jan	34.08	15.68	24.88	0.08	2.50	72.61
1997	Feb	35.96	15.86	25.91	0.00	0.00	70.64
1997	Mar	34.90	18.82	26.86	0.38	11.90	67.16
1997	Apr	32.72	19.02	25.87	4.92	147.50	78.80
1997	May	29.84	16.53	23.19	1.98	61.50	81.23
1997	Jun	29.50	15.10	22.30	0.10	2.00	72.80
1997	Jul	29.50	13.30	21.40	0.00	0.00	70.50
1997	Aug	30.50	13.70	22.10	0.00	0.00	65.10
1997	Sep	31.90	15.70	23.80	0.00	0.00	69.90
1997	Oct	31.10	17.80	24.45	0.80	26.20	71.00
1997	Nov	30.00	19.80	24.90	7.30	219.70	84.30
1997	Dec	30.20	18.80	24.50	8.50	264.30	88.80

Appendix 3b: Nguni

		TEMPERATURE (MEAN)			RAINFALL		RH %
Year	Month	Max.	Min.	Mean	Mean	Total	Mean
1996	Jan	28.00	16.50	22.25	0.16	5.10	83.10
1996	Feb	29.50	17.70	23.60	0.00	0.00	77.60
1996	Mar	30.00	18.50	24.25	3.67	113.80	79.70
1996	Apr	28.90	18.00	23.45	0.63	19.40	81.50
1996	May	28.70	16.00	22.35	0.00	0.00	80.30
1996	Jun	25.50	15.80	20.65	0.00	0.00	79.00
1996	Jul	26.40	14.50	20.45	0.00	0.00	77.90
1996	Aug	25.70	14.80	20.25	0.00	0.00	76.40
1996	Sep	27.60	15.60	21.60	0.00	0.00	76.00
1996	Oct	28.90	16.10	22.50	0.00	0.00	74.40
1996	Nov	26.60	17.70	22.15	14.00	419.00	83.40
1996	Dec	27.00	14.90	20.95	0.00	0.00	79.00
1997	Jan	28.00	16.80	22.40	0.76	23.60	81.00
1997	Feb	30.40	16.50	23.45	0.00	0.00	74.50
1997	Mar	30.20	18.40	24.30	0.98	30.40	81.60
1997	Apr	27.90	18.30	23.10	9.06	271.80	85.40
1997	May	26.00	17.00	21.50	2.70	82.20	85.90
1997	Jun	26.20	15.70	20.95	0.00	0.00	86.30
1997	Jul	26.20	14.80	20.50	0.00	0.00	79.40
1997	Aug	27.40	16.40	21.90	0.00	0.00	75.60
1997	Sep	27.10	16.50	21.80	0.31	9.40	78.20
1997	Oct	27.10	17.00	22.05	4.80	144.10	81.90
1997	Nov	26.60	18.00	22.30	21.60	647.00	89.60
1997	Dec	26.60	18.00	22.30	11.50	356.00	87.30