An investigation to determine the critical habitat requirements of the breeding Blue Swallow ***Hirundo atrocaerulea*** Sundevall

by

James Wakelin

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"One of the penalties of an ecological education is that one lives alone in a world of wounds. Much of the damage inflicted on land is quite invisible to laymen. An ecologist must either harden his shell and make believe that the consequences of science are none of his business, or he must be the doctor who sees the mark of death in a community that believes itself well and does not want to be told otherwise"

Aldo Leopold, 1853

In loving memory of my father

Duncan James Wakelin

ABSTRACT

This study investigated the critical habitat requirements of breeding Blue Swallows *Hirundo atrocaerulea* Sundevall, in KwaZulu-Natal, South Africa. Blue Swallows, as a 'flagship species' of the KwaZulu-Natal endemic Mistbelt Grassland, were tagged and radio-tracked to obtain positional data to determine their habitat use while breeding. This information was correlated to the type and nature of the habitat used and to the nature of the land cover to determine the likely impact of habitat transformation and fragmentation on breeding Blue Swallows. Insect type and abundance was assessed in five surrounding habitat types using Malaise insect traps and the findings correlated to Blue Swallow habitat usage. Data on environmental variables were collected using HOBO® sensors and the findings related to insect type and abundance within each habitat type. A comparative investigation was undertaken using temperature and humidity data obtained below-ground at a Blue Swallow nest site and compared to temperature and humidity findings from above-ground. Preliminary investigations were also made into the breeding system used by the Blue Swallow using unique wing markings to estimate the number of individuals involved at a single active nest.

Overall, wetland and grassland were first choice habitats a function of the increased individual insect mass in these habitats. Tea plantations were the next most important habitat type and timber plantations were avoided. Furthermore, it was shown that the Blue Swallow is a species that favours ecotones as preferential forage zones, particularly the ecotone between wetland and grassland. Malaise insect traps were effective in gathering suitable insect samples for analysis, revealing that significant differences occur in insect order, number and mass between habitat types. The most significant finding is that average insect mass per order, which was correlated closely to habitat type, matches the order of positive habitat type selection by the Blue Swallow. These findings were statistically significant and it is suggested that this correlation is the

main reason behind the habitat selection by Blue Swallows. This study found a clear indication that insect numbers and mass, in grassland and wetland, increase with an increase in temperature and decrease with a decrease in average temperature. Clear trends were obvious during long periods of either cold or dry weather which negatively influenced insect abundance and potentially, in turn, Blue Swallow well-being. The underground cavity used as the nesting site by Blue Swallows, experiences a greatly moderated climate in terms of the range of environmental factors compared with those experienced above-ground. This climate moderation is thought to be a clear advantage for the well-being of the Blue Swallow eggs and nestlings.

Through the use of radio-tracking, visual markers and video footage it was clear that Blue Swallows breed with a number of adult birds at one nest. The recorded average sex ratio was 1♂ : 3♀, however, the need remains to elucidate the co-operative breeding system used by the Blue Swallow.

In conclusion, the findings of this work present recommendations and suggestions on habitat management, offer insight into future research opportunities, and suggest strong conservation action for the species.

PREFACE

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any University or other academic institution. Where use has been made of the work of others, it is duly acknowledged in the text.

All the experimental work described in this dissertation was carried out in the School of Biological and Conservation Sciences under the supervision of Prof. Steven Piper and Prof. Trevor Hill of the University of KwaZulu-Natal.

Author

James Wakelin
Date: 18-12-2006

Supervisors

S. E. Piper

Professor Steven Piper
Date: 12-12-2006

Professor Trevor Hill
Date: 15-12-2006

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

The Blue Swallow *Hirundo atrocaerulea* has been described as an open montane grassland specialist (Evans *et al.*, 2003; Spottiswoode, 2005; Turner, 2004; Urban and Keith, 1992), and is aptly named the Montane Blue Swallow by Turner (2004). The Blue Swallow is sparsely distributed throughout its grassland range in South Africa (Evans *et al.*, 2003; Spottiswoode, 2005; Turner, 2004; Urban and Keith, 1992), and the remaining populations are in a state of decline (Evans *et al.*, 2003; Spottiswoode, 2005; Turner, 2004; Urban and Keith, 1992). The decline of the Blue Swallow is surmised to be a result of extensive grassland habitat transformation and fragmentation (Evans *et al.*, 2003; O'Connor, 2002; Spottiswoode, 2005; Turner, 2004; Urban and Keith, 1992). There is consensus that natural habitat transformation and fragmentation negatively affect species richness and community biomass (Bender, Contreras and Fahrig, 1998; Brooks *et al.*, 2002; Gonzalez and Chaneton, 2002; Ney-Nifle and Mangel, 2000; Turner, 1996), and it is generally accepted that the pressures from transformation and fragmentation are biased towards the rare and endangered species (Gonzalez and Chaneton, 2002; Wilcove *et al.*, 1998). Increased pressure on the planet is as a result of the world's human population consuming goods and services at an unsustainable pace with serious consequences for the well-being of people, other species and the planet. (World Watch Institute, 2004). Over-use is commonplace and many natural resources are being used beyond their sustainable limit (Nel, 2004).

1.1.1 Global Species Loss and Landscape Destruction

Humans make use of the land they inhabit to a degree unmatched by any other species (Nel, 2004). Human impact is most marked in the temperate and tropical zones, where land represents approximately 29% of the Earth's surface of which farmland occupies 11% (World Watch Institute, 2004). Alarmingly, many of the Earth's resources are still being removed at rates and in volumes far greater than their capacity for renewal (Nel, 2004; UNEP, 2002; World Watch Institute, 2004). For example, Sumatra has lost virtually all its lowland forest in the space of 25 years and on the African continent, over 70% of agricultural dry lands have experienced moderate to serious degradation (World Watch Institute, 2004). Worldwide, there exists 33% less tropical rainforest today than what occurred historically, with Brazil and Indonesia accounting for 45% of the total loss. In the next 30 years, 11000 species may face extinction. In total, more than 5000 plants, 1000 mammals and 5000 other animals (including 1183 birds) are endangered as they are declining in number as a direct result of habitat destruction, and over-exploitation (UNEP, 2002).

Africa has some of the most species-rich areas in the world. However, economic, political and social pressures threaten African wildlife and ecosystems, where already 126 faunal species are extinct with a further 2018 threatened and where over 120 plant species are extinct with a further 1771 threatened (World Watch Institute, 2004). Community involvement is imperative if this large-scale species loss is to be halted. In addition to community support, ecological studies and research on important species are required to guide appropriate conservation action to improve efficiency and effectiveness through such action (Nel, 2004).

1.1.2 Southern African Context

In South Africa, a similar pattern of biodiversity loss is evident (Cowan and Kumalo, 2003). South Africa occupies approximately 2% of the world's land surface area but is home to nearly 10% of the world's vascular plants and 7% of the reptiles, birds and mammals and consequently it has been ranked the third most biologically diverse country on Earth, after Brazil and Indonesia (DEAT, 2001; DEAT, 2002). Within a spectacular range of land forms, South Africa has 403 terrestrial protected areas with a total area of 6 638 658 ha which amounts to 5.44% land area under formal protection (Cowan and Kumalo, 2003; DEAT, 2001; DEAT, 2002).

Degradation of vegetation and soils is also a widespread problem in southern Africa, where rapid population growth and inappropriate government policies encouraged cultivation of unsuitable areas and the use of poor agricultural methods to produce food for rural subsistence (Nel, 2004). One of the most important causes of biodiversity loss is the degradation and transformation of natural ecosystems (Wilcove *et al.*, 1998), with over 8% of South Africa being invaded by alien vegetation (EWT, 2002), and millions of hectares affected by bush encroachment (Acocks, 1988). Five per cent of soils are affected by water erosion, and the average soil loss is 2.5 tonnes per hectare per year, with a maximum of 60 tonnes per hectare per year. This is more than eight times the rate of soil formation, and clearly is unsustainable (Barnard and Newby, 1999).

Degradation of the natural environment is the result of not only poor agricultural practices; urbanisation, by the late 1980s, was estimated to have transformed approximately 2.5% of South Africa's land cover: the ecological impacts of urbanisation are much greater than its low spatial extent (Macdonald, 1989). Approximately 25% of the land surface area of South Africa has been transformed by various intensive uses; of which, 12 to 13% was transformed as a result of the need for cultivation (Macdonald, 1989). In some localised areas of the country, some serious incidences of over-transformation have been reported. In the Western Cape, according to Hoffman (1997), agriculture has transformed almost 96% of southwest - and west-coast Renosterveld. As a result of the localised and often very intensive levels of transformation, 34% of the 440 terrestrial ecosystems in South Africa are threatened and of these at least 5% are critically endangered, 13% are listed as endangered and 16% as vulnerable (Driver, *et al.,* 2005).

1.1.3 KwaZulu-Natal

KwaZulu-Natal, as one of the nine provinces of the Republic of South Africa, was constituted in 1994 from the union of the former KwaZulu homelands and Natal and is founded upon a diverse human culture with immense natural value (Aylward, 2003), covering an area of 94 860 km² and is a province of great natural ecosystem diversity (Goodman, James and Carlisle, 2002). These ecosystems range from coastal plains with coastal forests to mesic grasslands, sandy bushveld and sandforests in the east, to savanna in semi-arid river basins and temperate forests and grasslands edged by alpine grasslands in the west. KwaZulu-Natal is an important agricultural and economic centre and produces much of the country's water (Goodman *et al.,* 2002).

In the year 2000, 58% of KZN remained untransformed, 12% was considered to be degraded while 30% was irreversibly transformed. Between 1994 and 2000, the amount of degraded land increased by 45% and the amount of transformed land increased by 14%, while the amount of untransformed land declined by 12% (P. Goodman, *pers comm.,* 2005). Forbes (2003) noted that just under 12 % of the province, or 1 118 313 ha, has both soil and vegetation in a severely degraded state. This is the case particularly in the Mistbelt Grasslands which fall within a zone of high agricultural suitability and an area of intensive agricultural activity (Granger and Bredenkamp, 1996). Of concern is the fact that more than 90% of this veld type has been permanently transformed by a diverse array of land-uses. Of the original extent of the Natal Mistbelt Grassland, approximately only 1% remains in a near pristine state (Scott-Shaw, 1999). To exacerbate this growing ecological crisis is the fact that this vegetation type is critically under-represented within formally protected areas at only 0.3% (Scott-Shaw, 1999). An opportunity exists to use charismatic species, such as the Blue Swallow, to represent ecosystem health and functioning, in order to monitor the impact of land cover change, and to intervene with appropriate conservation action.

1.2 Birds as Indicator Species for Ecosystem Monitoring

There is good evidence to show that bird taxa are appropriate indicators for monitoring changes at an ecosystem scale (Burger, 1993; Jansson, 1998; Jansen and Robertson, 2001; Koskimies, 1989; MacArthur, MacArthur and Preer, 1962; Martikainen, Kaila and Haila, 1998; Paillisson, Reeber and Marion, 2002; Stauffer and Best, 1980; Uliczka and Angelstam, 2000). Although there remains some debate regarding appropriateness of using vertebrate species as indicators (Landres, Verner and Thomas, 1988), species selection for indicators will probably remain heavily in debate (Eiswerth and Haney, 2001) as well as the trade-offs between the need to make predictions and the accuracy of those predictions (Thomson *et al.*, 2005).

There are clear reasons why bird taxa are considered to be good indicator species of ecosystem change. The best is that many individual bird species are associated with particular habitats across a broad gradient of man-made disturbance, from pristine wilderness to metropolitan areas (Browder, Johnson and Ball, 2002). Here long-term monitoring can be achieved by using breeding bird survey data collected over a long period (Robbins, Bystrak and Geissler, 1986). Birds are also generally short-lived animals so changes in species composition and abundance will be manifested relatively quickly after a disturbance (Szaro, 1986, Croonquist and Brooks, 1991). Birds are also generally systematically and extensively well surveyed because of their conspicuousness and they allow for relatively easy observation and monitoring (Harrison *et al.*, 1997). Birds are also of interest to a large segment of the wider public and therefore the public may relate better to concerns about changes in bird communities than to those of other taxa, such as plants or invertebrates (Browder *et al.*, 2002). Furthermore, associations of taxa of birds with habitats can be used to predict the relative level of man-made disturbance (Szaro, 1986, Croonquist and Brooks, 1991; Bradford *et al.*, 1998, Canterbury *et al.*, 2000). When studies have focused on using birds as indicator species, and in particular in grasslands, the findings attributed declines in grassland birds to the extensive and continuing transformation of the grassland habitat (Bollinger and Gavin, 1992). The conversion of grassland to agricultural cropland and to increasingly more intensive agricultural practices was shown to be directly related to habitat loss (Herkert, 1994; Bollinger and Gavin, 1992).

In KwaZulu-Natal, an increasing trend in the threat status of certain species such as the Blue Swallow and Wattled Crane *Bugeranus carunculatus* is being related directly to a decline in the grassland biome and associated wetland habitats, as well as the services delivered by these systems (P. Goodman, *pers comm.*, 2005). It is presumed that both the Blue Swallow and Wattled Crane are good indicator species of ecosystem functioning and the fact that these species are easily noticeable and charismatic has facilitated the monitoring of their population trends. Trends within these species could indicate possible impacts within the Mistbelt Grassland biome (P. Goodman, *pers comm.*, 2005). It is my personal opinion that the impact upon many other grassland-dependent bird species that are more shy and retiring may go unnoticed, but the Blue Swallow as a grassland dependent specialist bird species is charismatic and could fulfil the requirements as an appropriate indicator of habitat transformation and ecosystem functioning.

1.2.1 Blue Swallow *Hirundo atrocaerulea* as a Charismatic Grassland Species

According to Johnson (2000), there is a clear and consistent increase in the threat status of grassland birds. Reliable data show that over the past 20 year period Blue Swallow nest sites and habitat have declined (Evans *et al.*, 2003), and the numbers of nests continue to decline (Barnes, 2000; Evans *et al.*, 2003). Current nest numbers are also well below their KwaZulu-Natal conservation target level which is set at 156 breeding pairs (P. Goodman, *pers comm.*, 2005). As a result, during 2000, the Blue Swallow was classed as being Critically Endangered (Barnes, 2000), and recognition was given to its significant conservation value in South Africa.

Because it has been widely suggested that a correlation exists between the loss of virgin Mistbelt Grassland and the number of active Blue Swallow nest sites (Allan *et al.*, 1987; Allan, 1986; Allan and Earlé, 1997; Clancey, 1985; Evans *et al.*, 2003; Spottiswoode, 2005; Turner, 2004; Urban and Keith, 1992), the Blue Swallow renders itself as an obvious species for ecosystem monitoring.

1.3 Aim and Objectives of the Study

Although the decline in nesting Blue Swallows in KwaZulu-Natal is thought to be a direct result of a loss of primary grassland through land transformation (Allan *et al.*, 1987; Allan, 1986; Allan and Earlé, 1997; Clancey, 1985; D.N. Johnson, *pers. comm.*, 2001; Spottiswoode, 2005; Turner, 2004; Urban and Keith, 1992; Wakelin, 2001; Wakelin, 2004; Wakelin and Hill, *in press*), the reasons are still not entirely clear why Blue Swallows disappear when land is transformed from its natural state.

It is in response to this conjecture and to the recommended outcomes from the population and habitat viability assessment (PHVA) of the Blue Swallow Working Group (Evans *et al.*, 2003), that the aim of this study was to investigate the influence of land cover on the habitat use of breeding Blue Swallows during foraging. This study could then potentially give insight into the reasons why Blue Swallows are in a state of decline. In order to gain insight into the extent and nature of the habitat usage, Blue Swallows will be radio-tracked and their distribution correlated with mapped land cover. These findings could potentially give an indication of whether or not the Blue Swallow preferentially selects certain habitats for foraging. The study is also intended to investigate the abundance and diversity of insects in the different habitats surrounding the Blue Swallow nests. If habitat selection is found to be exhibited by Blue Swallows, it is hoped that the findings from the insect investigations could potentially explain that selection. Humidity and temperature data from inside a nest site will also be collected and correlated to humidity and temperature data collected from above-ground. The influence of an underground nesting cavity related to environmental variables could then possibly be better understood in terms of their environmental nesting requirements.

The specific research objectives are as follows:

1. *To determine habitat use of breeding Blue Swallows during foraging by using radio-tracking in order to investigate habitat selection.* (It is important to investigate the usage of Blue Swallow habitat in order to determine the habitat preferences of the species so that any further habitat loss can be prevented).

2. *To investigate insect abundance and diversity within five habitat classes and to correlate these findings to Blue Swallow habitat usage and to changes in temperature and humidity.* (It is hypothesised that insect prey is a major factor in determining habitat use; if this is the case improved and focused habitat management could benefit the Blue Swallow by means of improved insect production. The notion that inclement weather negatively affects Blue Swallow forage will also be investigated).

3. *To investigate the protective role played by the nesting cavity and its regulation of temperature and humidity.* (To better understand the protective role played by the nesting cavity. Insight may also be offered into the breeding system employed by the Blue Swallow by better understanding the role and function of the nest cavity).

4. *To undertake preliminary investigations into the breeding system used by the Blue Swallow and to estimate the number of individuals involved.* (Understanding the breeding system of the Blue Swallow is crucial in order to gain insight into and an understanding of effective population and recruitment potential).

1.4 Dissertation Structure

In Chapter 2, a literature review and theoretical background are provided to the following subjects pertinent to the research: land cover change and habitat fragmentation; Blue Swallow ecology, including co-operative breeding and the reasons that promote co-operation in breeding; and a description of the species and its distribution. The feeding, breeding and nesting requirements of the Blue Swallow, the threats to the species, the impact of various environmental factors, including insect abundance and diversity, as well as an overview of radio-tracking as a technique covering direction finding and triangulation and the receiving sub-system and the transmitting device are also addressed. In Chapter 3, the study area and the landscape in which this investigation took place are described; whilst in Chapter 4 the various methods, and their advantages and limitations are introduced, described and justified. In Chapter 5, results and a brief interpretation are provided. These results are discussed in Chapter 6 and linked to the theoretical background, provided in Chapter 2. Furthermore, Chapter 6 includes limitations which were identified during the research and could benefit future studies. In Chapter 7, conclusions to the research are provided, recommendations are made as to further research needs and management, and the objectives of the study are reviewed.

CHAPTER TWO
LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1 Introduction

In this chapter, an overview is provided of the natural history of the Blue Swallow, its population ecology and conservation biology with emphasis on threats and limiting factors. Habitat and land cover change, including landscape transformation and fragmentation are also reviewed in order to provide an overview of the potential factors causing the decline of the Blue Swallow.

2.2 Blue Swallow Ecology

2.2.1 Introduction

Swallows and Martins form a unique family of birds, known as Hirundinidae, with 83 species known worldwide (Turner, 2004), 22 species represented in southern Africa (Hockey, Dean and Ryan, 2005), and 16 species in KwaZulu-Natal (Rhodes and Piper, 2001). The members of this family are all distinct from other passerines as a result of their specialised lifestyle developed from feeding on aerial insects. Hirundinidae are well adapted anatomically for their specialised way of life and have streamlined bodies with a short neck, long pointed wings, short poorly developed legs with reduced muscles and a short broad bill (Hockey, Dean and Ryan, 2005, Turner, 2004; Urban and Keith, 1992).

The first specimen collected of the Blue Swallow *Hirundo atrocaerulea* Sundevall, was in the Umvoti river region of KwaZulu-Natal by the Swedish naturalist and explorer, J. A. Wahlberg (1810-1856), during the course of his field work in the 1840s. The species was named and described by Prof. C. J. Sundevall (Anon, 1984), and is sometimes considered to form a superspecies with the central African Black and Rufous Swallow *Hirundo nigrorufa* (Turner, 2004).

The Blue Swallow is an intra-African migrant which is a summer breeding resident in the Southern African sub-region (Spottiswoode, 2005; Turner, 2004; Urban and Keith, 1992), and is currently listed as Threatened: Critically Endangered in the South African IUCN Red Data Book (Evans and Barnes, 2000) and globally Vulnerable (BirdLife International, 2000). According to Arnott (2005), approximately 43 breeding sites are active within KwaZulu-Natal.

Past research and field observations suggest that both the range and abundance of the Blue Swallow have seriously declined over the past 20 years, largely as a direct result of continued habitat transformation and fragmentation of the swallows' preferred montane grassland habitat in their summer breeding range (Allan, 1988; Allan *et al.*, 1987; Cooper and Fraser, 1988; Ginn, McIlleron and Milstein, 1989; Turner, 2004; Urban and Keith, 1992; Wakelin, 2001; Wakelin, 2004; Wakelin and Hill, *in press*,).

2.2.2 Species Description

The Blue Swallow is a relatively easily identifiable species (Allan and Earlé, 1997; Clancey, 1985; Spottiswoode, 2005), as the adult birds have a highly lustrous dark metallic steel-blue appearance with long tail streamers (Plate 1), particularly noticeable in the male (Clancey, 1985). Originally the Blue Swallow was placed into a separate genus (*Natalornis*), owing to the lack of white spots in the tail feathers, and because the species lacks red in its plumage (Turner, 2004). The fact that these features are variable suggested that this unique and separate classification was unnecessary (Brooke, 1984; Turner, 2004). The Blue Swallow also possesses on the rump and flanks white feathers that are visible at close range when the birds are preening, and especially during courtship (Clancey, 1985). In poor light, the Blue Swallow appears almost black, and therefore could possibly be mistaken for the Black Sawwing Swallow *Psalidoprogne holomelas*, especially as the Sawwing is a common bird species throughout the breeding range of the Blue Swallow (Allan *et al.*, 1987; Allan and

Earlé, 1997; Clancey, 1985). The call of the Blue Swallow is a distinctive metallic wheezy chittering, uttered in flight (Ginn *et al.*, 1989; Spottiswoode, 2005; Turner, 2004; Urban and Keith, 1992).

Blue Swallows moult once annually after breeding, while on the over-wintering grounds (Spottiswoode, 2005; Turner, 2004). The moult sequence in the Blue Swallow follows the typical passerine pattern where the primary flight feathers are renewed descendantly from the innermost primary (P1) to the outermost (P9), and the secondaries moulting in order from one to six (Plate 2.) (Earlé, 1987).

Plate 1. Adult male Blue Swallow in flight, showing the characteristic long tail streamers.

Plate 2. Primary moult sequence exhibited on a Blue Swallow captured in Uganda. Note the single old outer primary wing feather and the feather marking used for bird identification and the tail streamers not yet grown.

2.2.3 Blue Swallow Distribution

The Blue Swallow is endemic to Sub-Saharan Africa and is an intra-African migrant, which heads the list of endangered South African birds (Evans and Barnes, 2000). Its total distribution (Fig. 2.1) extends from the KwaZulu-Natal midlands northwards through Mpumalanga, Swaziland, and the eastern highlands of Zimbabwe, north-eastern Zambia, Malawi, southern Tanzania, south-eastern Democratic Republic of Congo, Uganda and south-western Kenya (Allan and Earlé, 1997; Clancey, 1985; Ginn *et al.*, 1989; Keith, Urban and Fry, 1992; Spottiswoode, 2005; Turner, 2004; Urban and Keith, 1992). The breeding distribution of the species includes Malawi, the eastern Zimbabwe highlands, north-eastern Zambia, the Mapumalanga and Swaziland escarpments and the KwaZulu-Natal midlands. KwaZulu-Natal represents the southernmost breeding area for the species and has the largest breeding population in South Africa (Allan and Earlé, 1997; Arnott, 2005). The species over-winters in the basin of Lake Victoria of western Kenya and Uganda and north-eastern Democratic Republic of Congo, but does not breed in those regions. (Allan *et al.*, 1987; Allan and Earlé, 1997; Clancey, 1985; Spottiswoode, 2005; Turner, 2004; Urban and Keith, 1992).

Figure 2.1 Breeding and non-breeding range for Blue Swallow in Sub-Saharan Africa (after Urban and Keith, 1992).

2.2.4 Feeding Requirements

The habitat requirements of the Blue Swallow are open montane grasslands uncluttered by vegetation, where it can feed easily on the wing (Allan *et al.*, 1987; Allan and Earlé, 1997; Clancey, 1985; Keith *et al.*, 1992; Spottiswoode, 2005; Turner, 2004; Urban and Keith, 1992; Wakelin, 2004; Wakelin and Hill, *in press*). The diet consists of small aerial insects, which include beetles, ant alates and flies (Clancey, 1985; Hawkes, 2003). The flight of the Blue Swallow can be described as quick and erratic when hunting on the wing (Ginn *et al.*, 1989).

2.2.5 Breeding and Nesting

Blue Swallows have very specific nesting requirements and use underground sinkholes or Antbear *Orycteropus afer*, burrows (Allan *et al.*, 1987; Allan and Earlé, 1997). The species can be enticed to nest in artificial nest cavities (Johnson, Morford and Croft, 1996; Maclean, 1993). The mud nest is in the form of a half cup and is mixed together with fine grass and roots (Plate 3); White feathers are used to line the nest (Spottiswoode, 2005; Urban and Keith, 1992). The nesting sites are repaired annually and re-used many times by the same breeding pair, as long as the condition of the nesting cavity is maintained (Evans *et al.,* 2003; Turner, 2004). Two to three eggs are laid. Incubation lasts approximately 15 days, and the chicks fledge after a period of approximately 22 days (Clancey, 1985; Keith *et al.*, 1992; Spottiswoode, 2005; Turner, 2004; Urban and Keith, 1992). Blue Swallows are territorial when breeding, and a successful pair of swallows can be expected to produce two broods in a single breeding season which, is usually between November and March (Clancey, 1985; Spottiswoode, 2005; Turner, 2004; Urban and Keith, 1992). Triple broods have been reported from South Africa (Turner, 2004).

2.2.6 Habitat Requirements

Blue Swallows occur singly or in small social units over montane grassland (Spottiswoode, 2005; Urban and Keith, 1992; Turner, 2004). The habitat requirements described by Spottiswoode (2005) and Turner (2004) consist of open primary montane grasslands, free of trees and shrubs with an absence of steep slopes (Plate 4). Requirements for basal cover were described by Allan *et al.* (1987) as being moderate to high with a low grass sward height of less than 250 mm. Unfortunately, basal cover was not quantified in measurable terms by the aforementioned study. However, O'Connor (2002) could find no influence of grassland condition on the breeding success of Blue Swallow, and no evidence to suggest that grassland condition is an important factor determining their breeding success.

Plate 3. Blue Swallow chicks on the nest, in a sinkhole, at the Roselands farm in KwaZulu-Natal.

2.2.7 Threats

A lack of knowledge of the species and the very small active and potential breeding population remaining in KwaZulu-Natal constrains current research, as does the lack of benchmark information (Johnson, 2000).

It is assumed that owing to the high level of specialisation and the unique nesting requirements of the Blue Swallow, suitable forage and nesting sites are being limited by rapidly encroaching agricultural activities (Allan *et al.*, 1987; Spottiswoode, 2005; Turner, 2004; Wakelin, 2004; Wakelin and Hill, *in press*). It is clear that the habitat of the Blue Swallow is well suited for intensive agriculture, especially afforestation, due to high rainfall and deep well drained soils (Acocks, 1988; Granger and Bredenkamp, 1996), which has led to the transformation of primary grasslands. Only four pairs currently breed within a formally protected area in South Africa: three are in KwaZulu-Natal at Impendle Nature Reserve (Arnott, 2005), and only a single active nest is at Kaapsehoop (M. McNamara, *pers comm.,* 2006). The majority of the population occurs largely on privately owned agricultural land outside formal protected areas. The Blue Swallow can therefore not be considered to be adequately protected in KwaZulu-Natal (Evans *et al.,* 2003), owing to a lack of control of land cover change on privately owned land, which is motivated by economics (Wakelin and Hill, *in press*). Of additional concern is that the conservation authorities in South Africa have no control over the Blue Swallow populations at their over-wintering grounds outside the country (D.N. Johnson, *pers comm.*, 2001), these concerns are shared by Nasirwa and Njoroge (1997).

Additional concern has been raised that the small population size of the South African breeding Blue Swallow may lead to problems associated with inbreeding depression (Turner, 2004). However, conservation effort for the species has reportedly been focused on identifying and protecting the non-breeding areas, monitoring breeding progress (Evans *et al.,* 2003), and controlling the effect of alien invasive plants (Turner, 2004).

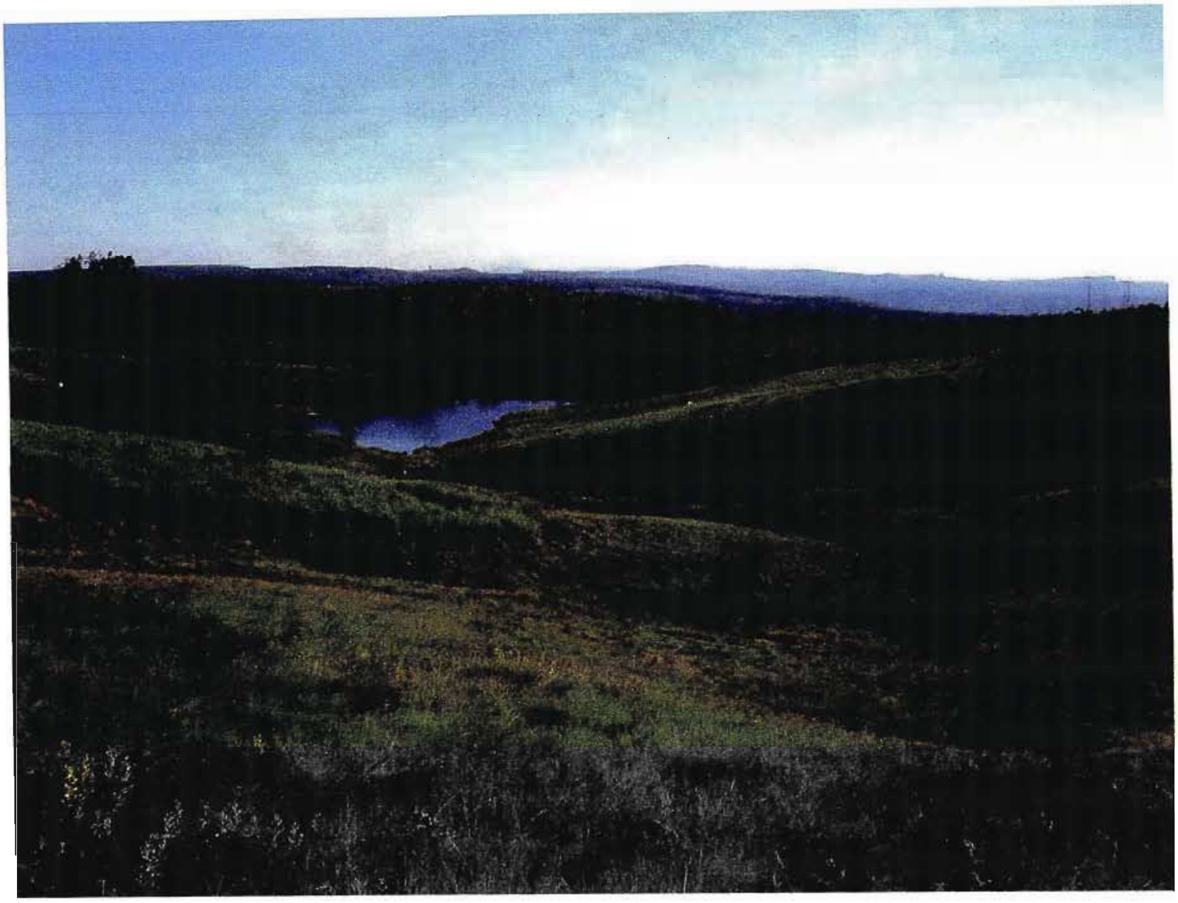

Plate 4. Typical mosaic of land-use at the Roselands farm in KwaZulu-Natal depicting sugar-cane and plantations surrounding grassland and wetland habitats.

2.3 Co-operative Breeding

2.3.1 The Blue Swallow and Co-operative Breeding

The existing literature describes the Blue Swallow as being a monogamous species (Spottiswoode, 2005; Urban and Keith, 1992), where rarely more than one nest occurs at a site, where intruders are also aggressively chased away and the nest territory is defended (Evans, *et al.,* 2003; Turner, 2004).

However, Tree (1989) reported an observation where an adult male Blue Swallow and two females were seen assisting with the feeding of a brood of young chicks nesting in a mine shaft in Zimbabwe. This observation was anecdotal and was not based upon any systematic observation, but remains the only record of possible breeding assistance in Blue Swallows. Reacting to this statement, Du Plessis *et al.* (1995) listed the Blue Swallow as a bird species that was not considered to be a co-operative breeder, because helping is not a regular event, or is likely accidental or misdirected care. Based upon the observation made by Tree (1989), Monadjem (1996) classed the Blue Swallow as being a facultative co-operative breeder, and noted that were no records existing of brood parasitism in Blue Swallows.

Contrary to current understanding, during the preliminary investigations conducted for this research, it was noted that more than one pair of Blue Swallows were involved in the breeding system at several nests observed. It was believed that value exists in understanding the breeding system of the Blue Swallow because of conservation management implications.

2.3.2 Co-operative Breeding

Co-operative breeding is a general term that describes a wide array of breeding and social systems (Ligon, 1999). Co-operative breeding in birds can be best identified when three or more individuals contribute towards raising a single brood at a single nest site. Simply put, non-parental helpers at the nest assist with the feeding and raising of young birds. This can be referred to as alloparental behaviour (Brown, 1987; Davies, 1992; Stacey and Koenig 1990). Although Dickinson and Hatchwell (2004) state that co-operative breeding is rare and occurs in only approximately 3% of bird species worldwide, Brown (1987) has described 13 separate categories of co-operative breeding.

Among birds, in particular, there is a great diversity with respect to co-operative breeding (Stacey and Koenig, 1990). Since the 1990s there has been extensive development in the research into co-operative breeding and certain patterns and trends exhibited by co-operative breeding birds have been identified (Emlen, 1997). In contrast, Cockburn (1998) believes that the majority of issues pertaining to co-operative breeding remain unanswered.

Heinsohn, Cockburn and Mulder (1990), Mumme (1992) and Cockburn (1996), all agree that the majority of studies on co-operative breeding aimed to identify the ecological factors that have promoted or determined the development of co-operative breeding, but that the majority of the studies seeking associations between co-operative breeding and ecological factors have been largely unsuccessful. Du Plessis, Siegfried and Armstrong (1995), however, concluded that co-operative breeding in birds in South Africa is associated with seasonal environments, and predicted that species from north-temperate zones were unlikely to be co-operative breeders as opposed to those bird species in the tropics and the sub-tropics. Important, however, is the fact that prediction cannot be based upon environmental conditions but rather on whether or not the species in question has co-operative breeding relatives (Ligon and Burt, 2004). Researchers attempting to identify the ecological factors that could predict co-operative breeding have largely been unsuccessful (Heinsohn *et al.,* 1990).

Studies of co-operative breeding demonstrate that bird species that participate in this phenomenon share many important characteristics. They are: year round residency, high survivorship and production of small clutch sizes (Arnold and Owens, 1998; Brown, 1987; Hartley and Davies, 1994; Koenig *et al.,* 1992). The ecology of the Blue Swallow does not appear to mirror these life history traits.

2.3.3 The Factors That Promote Co-operative Breeding

It has been hypothesised that in co-operative breeding, there needs to be a direct benefit to the helpers to offset the cost they expend through breeding assistance (Dickinson and Hatchwell, 2004). According to Stacey and Koenig (1990) helpers involved in co-operative breeding derive indirect fitness benefits by increasing the productivity of their parent's nest by ensuring that their related genes have a greater chance of being passed on, but this does not compensate fully for the net fitness cost to helpers. Ligon (1981) and Brown and Brown (1984) state that extended parental investment promotes offspring fitness through prolonged brood care associated with the quality and familiarity of the natal site. In other social mating systems, all members of a social unit are either breeders or potential breeders with the ultimate goal for each group member being parentage (Davies, 1990). According to the findings of Ligon and Burt (2004), the actual non-breeding helpers are usually the offspring of one or both members of the breeding pair.

It is widely recognised that social living is often a response to predation pressures (Alexander, 1974). This notion is supported by Stacey and Ligon (1987), who record that co-operative breeding leads to lowered mortality in the young rather than the other way around. Many adaptive features, such as predator deterrence and sentinel behaviour, lower mortality rather than low mortality promoting group living.

The question remains whether or not the Blue Swallow breeds co-operatively. An opportunity exists during this research to observe whether or not more than one pair of Blue Swallows is involved with breeding.

2.4 Land-Cover Change

Human induced landscape change is thought to have important consequences for many species which cannot persist in the modified landscapes. The aspects of habitat change which determine the distribution and persistence of key species, such as the Blue Swallow, need to be determined and are discussed in the following sections.

2.4.1 Landscape Transformation

The process of habitat transformation may reduce the total area of a habitat and the viability of populations of different species within that habitat. These populations are affected and reduced through the disruption of the ecological processes which are responsible for the maintenance of these populations and the provision of a wide range of ecological services and products (Driver *et al.,* 2005).

Transformation may fragment the habitat into a number of different sized and isolated patches, as well as reduce the proportion of the habitat left intact. Decreasing the remaining habitat in the landscape may lead to fewer individuals, who are more isolated, existing within the remaining landscape. The remaining population groups are then at a greater risk of local extinction due to their isolation (Opdam, 1991; Harrison and Bruna, 1999). Species survival and the maintenance and delivery of ecological processes and services are also directly dependent on the size of the remaining intact patches and the degree of isolation of these patches. An increase in patch number and the concomitant decrease in patch size results in increased patch isolation with a reduction in patch functionality within the ecosystem, thus affecting the remaining patches and species richness negatively (Kareiva and Wennergren, 1995).

2.4.2 Habitat Loss and Fragmentation

More than 80% of the world's endangered birds are threatened by habitat loss as a direct result of fragmentation and transformation (Temple, 1986). However, habitat loss continues unabated with continued negative implications for birds (Askins, 2000; Boulinier *et al.*, 2001; Richards, 1990; Hansen *et al.*, 2002). It has been suggested that remaining patch size, the amount of edge and the isolation thereof are the greatest causes of species loss (Bruna, Vasconcelos and Heredia, 2005; Kareiva and Wennergren, 1995; Yahner, 1996). Furthermore, the more isolated a patch within the landscape, the lower the chance of species re-colonisation (Opdam, 1991; Harrison and Bruna, 1999). Increases in edge length with transformed landscape can have a negative impact upon species within a patch if these species are reliant on the interior of the patch habitat and are sensitive to changes in vegetation structure or micro-climatic factors (Camargo and Kapos, 1995). Furthermore, reduction in suitable habitat often leads to reduction in populations by simply reducing available space for territories, nest sites and general resources (Rolstad, 1991). MacNally, Bennett and Horrocks (2000) recorded that species richness was positively related to patch size and their findings indicated that there were twice as many species present in an 80 ha area as opposed to a 10 ha area. Species loss will increase with fragmentation (Burkey, 1995), and species loss could conceivably occur with a change in land cover, particularly if that change involves a change in vegetation structure. Thus, habitat loss can occur without habitat fragmentation.

However, Stephens *et al.* (2003) found that the nesting success of birds is affected by habitat fragmentation at larger scales, but of importance are the findings of Andrén (1994) who found that when more than 30% of the original natural habitat remained, fragmentation did not appear to cause a loss in the bird species richness. However, if the amount of natural habitat remaining was reduced to less than 30% of the original extent, habitat fragmentation became the primary cause for species decline. Considering the high levels of transformation within the Mistbelt Grassland biome in KwaZulu-Natal and the state of decline in nesting Blue Swallows (Wakelin, 2001), it would appear that the Blue Swallow is a good surrogate as an indicator species for monitoring the consequences of the continuing process of fragmentation of Mistbelt Grassland in KwaZulu-Natal.

2.5 Impact of Temperature and Humidity

All organisms have certain ecological requirements which allow them to maintain ecological and biological viability (Primault, 1979), which must be keyed into appropriate seasonal cycles to avoid lethal temperature and other environmental extremes (Powell and Logan, 2005). Cossins and Bowler (1987) note that temperature is one of the most important environmental factors influencing the biology of animals as it determines the niche the animal can occupy. Furthermore, the absolute range and the rate of change of temperature are significant in affecting the life history traits of birds and mammal species. Birds, as endotherms, possess physiological specialisation for precise thermoregulation (Cossins and Bowler (1987), requiring high rates of food acquisition which allows for the development of specialist feeding patterns. Also, as endotherms, birds cannot fast for extended periods without ill-effects.

Hardy (1979) states that temperature was found to be a major limiting factor in a wide spectrum of biological processes, e.g. the rate of a single chemical reaction, the ecological distribution of an animal species etc. According to Hardy (1979) energy exchange between an animal and its environment is exceedingly complex. At its simplest, it includes the exploitation of chemical energy in the diet and heat exchange with the environment which is determined by the physical processes of conduction, convection, radiation and evaporation. Hardy (1979) added that the enzymes involved in the metabolic processes in mammals and birds are most stable within the temperature range of 30° to 40°C.

Relative humidity also affects the level of insect activity and abundance (Blackwell, 1997; Murray, 1975; Nevill, 1971; Walker, 1977) and where temperature is suitable, precipitation directly influences the distribution of insect species and numbers through limiting the availability of breeding sites in the form of wet organically enriched soil (Braverman, Galun and Ziv, 1974; Lubega and Khamala, 1976; Mellor, Boorman and Baylis, 2000; Walker, 1977; Verhoef, 1977; Walker and Davies 1971). The seasonal effects of moisture on life history traits of insects remain an important but little studied phenomenon (Mills, 1986; Tauber *et al.*, 1998). However, it is well known that low humidity is generally stressful for most insect species (Edney, 1979), and high mortality can be expected at below the threshold of 60% relative humidity (Weissling and Giblin-Davis, 1993).

2.6 Insect Investigations and Feeding Ecology of Blue Swallow

The Blue Swallow remains an under-researched species in many facets of its ecology and biology (Evans *et al.,* 2003, D. N. Johnson, *pers comm.,* 2001). According to Hawkes (2000), a study of diet was undertaken in 1999, which investigated the contents of Blue Swallow faecal pellets in comparison to insect samples collected on Blue Swallow breeding sites. Hawkes (2003) states that there were shortcomings in his study as the reference samples were collected predominantly during the morning, and were not therefore strictly comparable to the faecal pellet samples collected from nesting Blue Swallows which forage throughout the day. Insects that are active in the afternoon such as ant alates would be under-represented. For this reason, Hawkes (2003) further investigated the specifics of Blue Swallow diet using modified Malaise traps, and included investigations into the possible influences of habitat and weather on food availability.

Hawkes (2003) found that both numerical abundance and total mass of insects were influenced by weather conditions. Insect numbers decreased substantially in overall abundance and mass with an increase in cloud cover, as well as an increase in the duration of rainfall and mist, if such conditions persisted for longer than three days. However, insect numbers and biomass increased with short duration of rain and mist. Neither minimum nor maximum temperatures appeared to have a significant effect on abundance or mass of insects captured. Hawkes (2003) suggests that these findings supported the hypothesis that extended periods of mist and rain may result in an increase in nestling mortality by reducing food availability, and that factors such as reduced visibility might play an important part in Blue Swallow foraging efficiency.

According to the study by Hawkes (2003), climatic factors appear to be significant in influencing the availability of insects, and it was for this reason that a similar investigation was incorporated into this study. It is thought that one of the key issues would be to gain insight into the feeding ecology of the Blue

Swallow within its Mistbelt Grassland habitat, in order to inform appropriate conservation action through improved habitat management that supports improved insect production.

2.7 Radio-tracking

2.7.1 Introduction

Opportunities are increasing for obtaining a better understanding of wildlife problems with improved technology (Kenward, 2001). Nevertheless, increases in technology can complicate simple wildlife questions and the sight could be lost of the main question under investigation in this research, which was to understand spatial location of foraging Blue Swallows within a mosaic of different habitat types. In order for this research to be successful in all aspects, a thorough knowledge and understanding of the ability and shortcomings of the technology was needed.

According to the Ministry of Environmental, Lands and Parks Resources Inventory Branch for the Terrestrial Ecosystems Task Force Resources Inventory Committee (1998), wildlife radio telemetry may be defined as the transmission of information from a transmitter on a free ranging wild animal to a receiver. Known as radio tagging or radio-tracking, or more simply as 'tagging' or 'tracking', biologists use animal radio tags for two main purposes: first, to locate study animals in the field, and second, to transmit behavioural and physiological information on the tagged animal (Kenward, 2001). Radio-tracking facilitates studies where cover or darkness prohibits direct observation and makes animals accessible to systematic sampling (East and Hofer, 1986; Greig-Smith, 1985; Kenward, 2001; Hanski and Haila, 1988).

Mech (1983), stated that radio-tracking as a technique is so revolutionary that there is no other wildlife research technique that comes close to matching the wide range of associated benefits. Prior to radio-tracking, the study of animal movement depended upon live trapping and tagging in the hope of recapturing them elsewhere. A refinement of the mark and recapture technique was the introduction and use of visual markers, which enabled observers to identify uniquely marked individuals from afar (Mech, 1983; Mech and Barber, 2002).

2.7.2 Radio-tracking as a Technique

Radio-tracking is an electronic technique to obtain spatial and temporal information regarding an animal through the use of radio signals originating from a transmitting device carried by the animal. The signals are transmitted through the atmosphere by radio waves and therefore radio-tracking is basically the transmission of radio waves to a receiver (Mech and Barber, 2002). The components of a radio-tracking system are a transmitting device and a receiving sub-system. The radio transmitters have a power source and a propagating antenna. The receiving sub-system includes a receiving antenna, a signal receiver with a reception indicator and a power source.

The first wildlife radio tags transmitted a continuous signal; however, by pulsing the transmitting signal from the radio tag, battery cell life was greatly extended. Furthermore, a pulsed signal is easier for the human ear to detect against the continuous background noise than a continuous whine is (Kenward, 2001). According to Mech and Barber (2002), there are three distinct types of radio-tracking used: 1) conventional Very High Frequency (VHF) radio-tracking, 2) Satellite tracking – Ultra High Frequency (UHF) and 3) Global Positioning System (GPS). Currently UHF tags weigh approximately 20 gm, can transmit for a maximum of 400 hours, and are bulky and only suitable to be carried, without negative effect, by birds which have a mass in excess of 500 gm. These UHF tags provide signals once a week (Kenward, 2001). The location data from this type of tag is less accurate than from most VHF tracking; these tags are thus most suited to studies of migration on wide-ranging foragers such as Albatrosses (Jouventin and Weimerskirch, 1990; Prince *et al.*, 1992). VHF radio tagging is more suitable for Blue Swallows owing to the small size of the device.

The early radio-tracking studies generally focused upon descriptive issues such as home range determination, habitat preference and dispersal and survival (Kenward, 2001). However, there are many case studies where complex relationships are investigated between an animal and changes in its environment (Mech and Barber, 2002), for example, the relation of albatross foraging to global weather pattern changes. The list of species used in radio-tracking studies is extremely wide and varied and includes species such snakes, crayfish, lizards, bats, turtles, elephants, tigers and salamanders, with a wide range of bird species tagged successfully (Mech and Barber, 2002; Ministry of Environmental, Lands and Parks Resources Inventory Branch for the Terrestrial Ecosystems Task Force Resources Inventory Committee, 1998).

According to Kenward (2001), successful use of radio tagging as a technique requires sound biological questions to be asked (see Section 1.3), and careful planning to address those questions as well as training to use the planned techniques. Many projects fail to acknowledge the time required to develop the field techniques required to achieve success (Kenward, 2001; Mech and Barber, 2002; Ministry of Environmental, Lands and Parks Resources Inventory Branch for the Terrestrial Ecosystems Task Force Resources Inventory Committee, 1998).

2.7.3 Direction-Finding and Triangulation in Radio Telemetry

Direction finding stations suitable for simple radio tags have largely been based upon rotating two or more Yagi antennas at different locations simultaneously to determine an estimation of location through triangulation (Kenward, 2001). Triangulation involves obtaining two simultaneous signal bearings from different locations which then cross at the site of the animal. Triangulation locates an animal with minimal disturbance since the researcher can be a distance from the animal while obtaining a bearing. However, the further away the researcher is, the greater the error (Heezen and Tester, 1967; Kenward, 2001; Mech, 1983; White and Garrott, 1990). Errors can arise in many different ways, for example, in well wooded or mountainous regions signals can be deflected or be interfered with. The influence of antenna error increases with distance from the radio tag (Fig. 2.2). If an antenna gives a bearing error of 5°, the lateral error of the tag's location will be 9% of the distance to it. This equates to approximately 100 m across the line of bearing in 1 km (Kenward, 2001).

In addition to antenna error, placement of fixed base stations is crucial to achieve bearings as close to 90° as possible (A and C), (Fig. 2.3). The size of the error polygon increases in size with a reduction in angle between base stations (A and B), as opposed to the error polygon formed between base stations close to 90° (A and C), (Kenward, 2001).

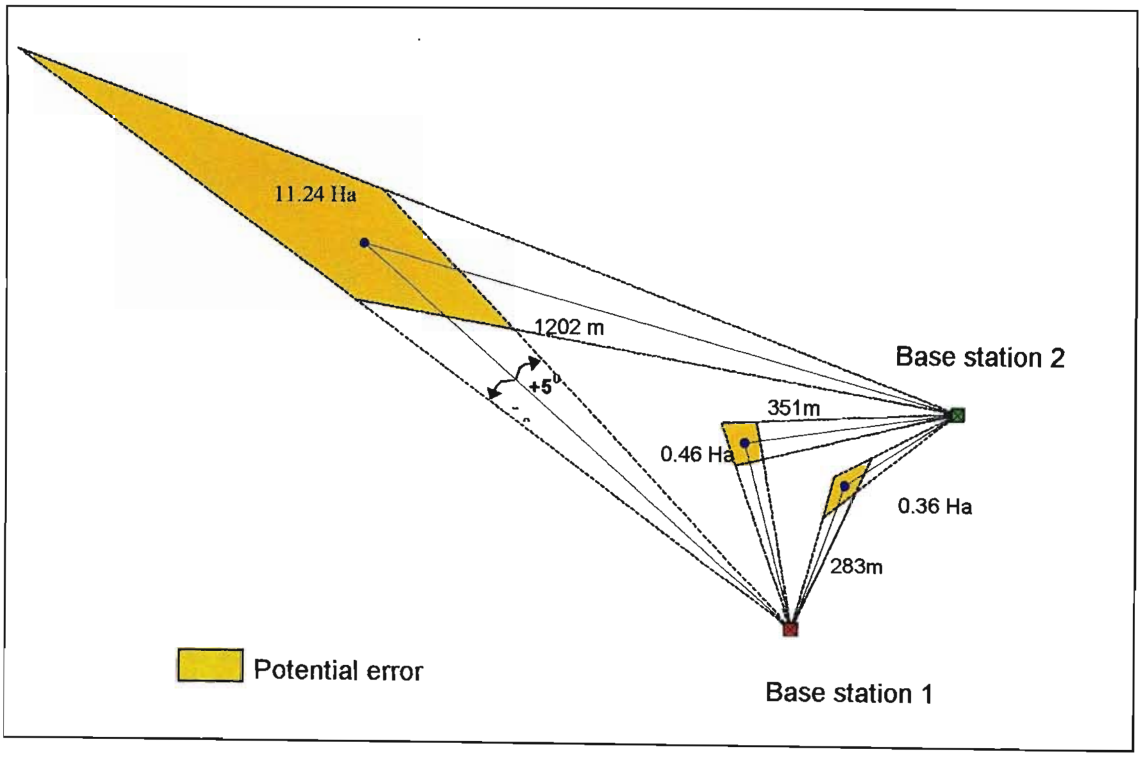

Figure 2.2. Precision in locality data decreases with an increase in distance from the base stations. This example shows how the size of error polygon increases with distance: tag distance of 283 m resulted in 0.36 ha error polygon, 351 m equalled 0.46 ha and 1202 m produced 11.24 ha.

2.7.4 The Receiving and Transmitting Sub-System

The function of a receiver is to receive the signal transmitted by the radio tag. The receiver picks up the signal through the receiving antenna and amplifies it to make it audible to the user. Receivers are available in a variety of sizes, shapes and weights from many different suppliers. The receiver is powered by either rechargeable or replaceable batteries. Receivers can be programmed to receive a wide range of frequencies from 30 to 200 kHz (Kenward, 2001; Mech, 1983; Mech and Barber, 2002).

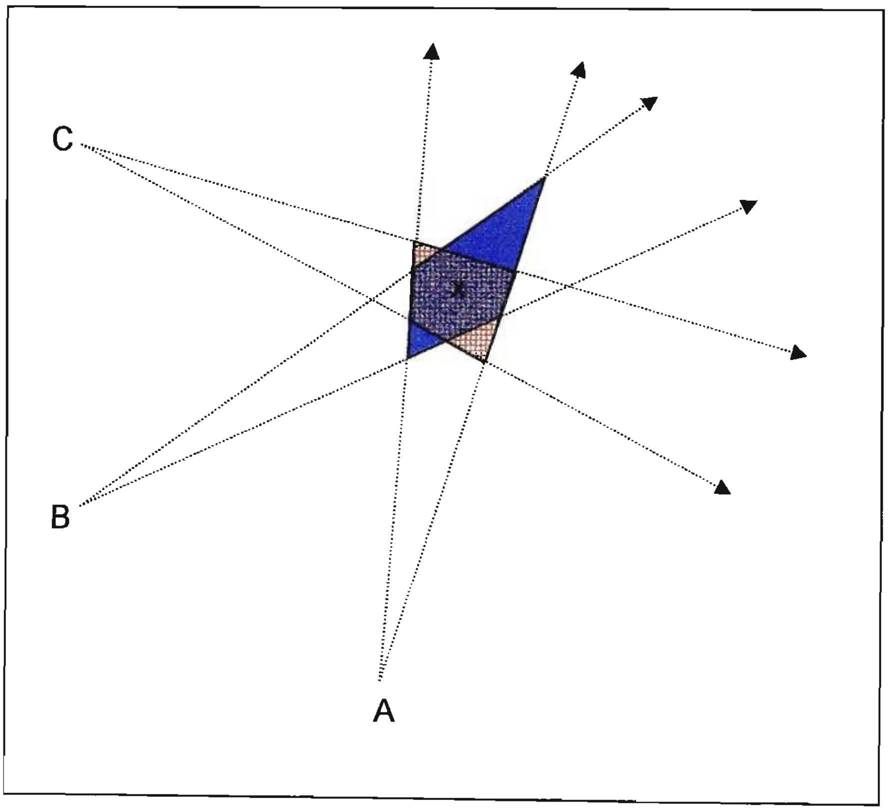

Figure 2.3. The sizes of error polygons increase as the angle between bearings is reduced (after Kenward, 2001).

The radio device cannot receive a radio signal without using a signal enhancing device known as an antenna (Kenward, 2001; Mech and Barber, 2002). According to Mech and Barber (2002), there are many different portable and fixed antenna types which can be used, but the portable directional three-element Yagi antenna, which operates at frequencies above 140 MHz, is the most commonly used. A major advantage of the Yagi antenna is that the signal reception is easy to distinguish between true and reverse bearings and will provide a bearing accuracy greater than 5° in moderately open country (Kenward, 2001). Good quality Yagi antennas are matched to the standard 50 ohms input impedance of radio-tracking receivers, which avoids cumbersome external devices such as a gamma match (Biotrack, undated).

Most European countries have allocated the frequency band of 150 MHz to 151MHz for wildlife radio tags (Kenward, 2001). The majority of tags used in South Africa range between these frequencies. Most radio tagging construction companies produce tags at different frequencies to allow the field researcher to identify different study individuals based upon the different and unique radio tag frequencies. Radio tag size and mass are of utmost importance when applied to small birds that rely heavily on flight for their livelihoods (Kenward, 2001). However, it has been demonstrated that small birds can add fat loadings of more than 50% for migration, and recent work on bats shows that they are able to fly well with packages at 10% of their body weight (Graber and Wunderle, 1966; Stebbings, 1982, 1986). An absolute limit of 5% added weight is suggested as being appropriate for animals with a mass above 10 gm (Cochran, 1980), even though flying species can manage a 5% loading at 70 gm without loss of agility (Aldridge and Brigham, 1988).

According to Alves and Johnstone (1994), the smallest Hirundine to be radio-tagged was the Sand Martin *Riparia riparia*, with an average mass of 12.7 gm, (n=3). Tag mass used was 1.3 gm which equated to a total of 10% of total body mass of the bird, which was twice the widely recommended limit for birds of this size. Radio tags were fitted using tail clips and it was reported that none of the tagged individuals (n=3) showed any negative effects whist carrying the radio tags for a combined total of 22 days. A failed radio-tracking experiment undertaken at Kaapsehoop Nature Reserve in Mpumalanga, South Africa in

1991 used a 1.2 gm tag mounted on the upper back of an adult male Blue Swallow. The radio tag equated to a reported 7.5% of the bird's total body weight and unfortunately the tagged Blue Swallow disappeared within 24 hours, presumed dead as a result of the tagging (Tarboton and Johnson, 1991).

Kenward (2001) recommends a maximum upper limit of 2 to 3% tag to body mass ratio for a target species that relies heavily on flight. The radio tag for a Blue Swallow with a total body mass of approximately 14 to 16 gm using VHF equipment would thus need to be approximately 350 mg, having a maximum expected battery life of approximately one week. Maximum detection ranges with these tags are strongly dependant upon the antenna format and dimensions. The importance of using long whip antennas cannot be stressed too strongly and it is also worth noting that a thick antenna radiates slightly better than a thin one (Kenward, 2001). However, one of the biggest problems with small animals is their ability to carry a long antenna without compromising their welfare (Kenward, 2001). This is particularly relevant when small animals have large foraging ranges.

2.7.5 Ethical Considerations

Despite its popularity, radio-tracking is inappropriate under many circumstances, because it is expensive, time-consuming and has potential ethical implications (Kenward, 2001). Radio-tracking is also unsuitable for certain species owing to the animal's size or life history traits and the skill required by the researcher (Kenward, 2001; Mech, 1983; Mech and Barber, 2002). However, there is consensus that the placement of a radio tag onto an animal represents a commitment by the researcher as the capture and tagging of an animal is undertaken at the expense of the radio-tagged animal. With this consideration in mind, it is crucial that the researcher keeps asking the question if radio tagging is the best research approach (Mech, 1983; Mech and Barber, 2002; Ministry of Environmental, Lands and Parks Resources Inventory Branch for the Terrestrial

Ecosystems Task Force Resources Inventory Committee, 1998), particularly if the target species is classified as endangered.

According to the Ministry of Environmental, Lands and Parks Resources Inventory Branch for the Terrestrial Ecosystems Task Force Resources Inventory Committee (1998), researchers planning a radio-tracking study should obtain guidance from professionals who have experience. This may avoid problems which have already been solved. Capture techniques should be designed to minimise stress and the capture sessions must be timed to avoid disturbing the animals during their most sensitive periods. Caution is also advised in fitting tags with the use of new methods that have not been used before. Preferably, all techniques should first be mastered with the animal in captivity or used on a surrogate species first. As a minimum requirement, tags should be fitted using non-permanent techniques so they can drop off (Kenward, 2001; Ministry of Environmental, Lands and Parks Resources Inventory Branch for the Terrestrial Ecosystems Task Force Resources Inventory Committee, 1998).

2.8 Preliminary Pilot Study

2.8.1 Introduction

The preliminary study investigated the impact of landscape transformation on the distribution and density of the breeding Blue Swallow. The results suggested that nest density is positively related to grassland and arable land and negatively related to an increase in plantation forestry (Wakelin, 2001; Wakelin and Hill, *in press*). A decrease of 55% in active Blue Swallow nest sites coincided with a measured decline in grassland of 46% for the period 1981 to 2000 (Wakelin, 2001). The current rate of loss of Blue Swallow breeding sites is not acceptable and without the conservation of primary grassland habitat, the Blue Swallow is heading towards local extinction in KwaZulu-Natal (Wakelin, 2001). During the preliminary study, appropriate nesting sites were selected for the commencement of the present study. It was these initial field observations that gave insight into co-operative breeding and ultimately informed the implementation of this research project.

2.8.2 Co-operative Breeding

During the 2000/2001 and the 2001/2002 Blue Swallow breeding seasons, nest and bird observations were made at iMpendle Nature reserve (S29° 43' E29° 51'). A hide was constructed inside a large sinkhole where nesting Blue Swallows were photographed and videoed for the national broadcaster SABC. It was noticed that streamer lengths of the adult birds' tails varied during incubation and during the chick feeding stages. Closer scrutiny of the images confirmed suspicions that more than one pair of adult birds were involved in the breeding at a single nest. It was, however, not possible to uniquely identify the adult individuals based upon tail streamer length alone, although a minimum of two different females were recorded and at least one adult male at a single nest. Although the exact number of adult birds involved in the breeding system could not be accurately determined, extended field observation at iMpendle confirmed that this nesting behaviour of more than one pair of adult Blue Swallows in attendance at an active nest was being exhibited at all three active nest sites. It was also noted that the ratio of adult female Blue Swallows to adult male Blue Swallow was always in favour of the female birds.

2.8.3 Radio Tagging

In line with the approach of zero tolerance for error, non-target species such as Brown Throated Martin *Riparia paludicola*, Lesser Striped Swallow *Hirundo abyssinica* and Greater Striped Swallow *Hirundo cucullata* were used as surrogates for the Blue Swallow during the period of refining the radio tagging methods and the wing marking (Plate 5). Both mock-up and fully functional tags were fitted to adult individuals of these species. Initially, the tags were mounted on the centre of lift between the shoulder blades on the back of the bird. On small birds like swallows and martins, this proved to be particularly difficult owing to the extremely small size of feathers in this region. The result was that the tags did not stay attached for the duration of the expected battery life of 14 days. (Average = 1.8 days, maximum = 4 days, n=5). A tail-mounted tag was then deemed more appropriate on non-target species and proved successful. No radio tags failed, nor did they fall off the tagged birds, and all 12 lasted the expected 14 day period. Two sites were used in the testing of this method, iMpendle Nature reserve, and Queen Elizabeth Park (S29° 34' E30° 19').

Plate 5. A non-target species (Lesser Striped Swallow *Hirundo abyssinica*), fitted with a tail-mounted radio tag and wing markings, during the refinement of the study methods (photo by C. Oellermann).

2.9 GIS in Natural Resource Management

Land-use change affects fundamental ecological processes and the persistence and extinction of species (Vitousek, Mooney and Melillo, 1997). Hence, there is an ever-increasing demand by conservationists to protect non-renewable resources from development and to ensure that development takes place in a conservation-sensitive manner (Lang, 1998). This emphasises the importance of more efficient decision support tools as the scientific community takes cognisance of environmental consequences of human activity. One such tool is a Geographic Information System (GIS) which can analyse and display the processes of or some aspects of global change, and the impact of man upon complex natural systems (Larsen, 1999). Akçakaya (1994) stated that a GIS is a valuable tool for ecological studies in determining and monitoring changes in the spatial structure of a landscape inhabited by endangered species.

GIS can integrate and manipulate large amounts of disparate spatial data and communicate results and findings to a large audience allowing greater accuracy, efficiency and flexibility than manual analysis would allow (Aspinall, 1999; Clayton and Radcliffe, 1996; Haslett, 1990; Morrison, 1998; Nelder, Crossley and Cofinas 1995). GIS provides an objective means to display spatial data (Nelder, Crossley and Cofinas, 1995) and it allows exploration of the relation between human and physical processes at a number of spatial scales (Aspinall, 1994; Liebhold, Halverson and Elmes, 1992; Schmiegelow, 1990; Wakelin, van Zyl and McCann, 2004). More importantly, GIS is a dynamic tool in which a model can be developed for predicting the impacts of land-use, climatic or other changes (Agee *et al.*, 1999; Baker, 1989; Dale and Rauscher, 1994).

Spatial data are not static in time and can be updated continuously to provide contemporary information (Aspinall, 1999). Uncertainty of data and models and the limits of predictability are inherent in the study of natural systems, and remains an important issue. This is particularly so because outputs from a GIS analysis can be used as decision-making support tools that may affect survival of a threatened species, or the balance between land for conservation and economic development to sustain rural communities (Barrett, 1992). Local land-use planning rarely incorporates the best available spatial data, partly because access to the data is limited, and partly because it is not clear how the data can be used in the planning process (Cort, 1996). Therefore, conservationists are challenged to bring scientific understanding of natural systems into the planning process to prevent inappropriate development of natural systems. It is here that GIS can play a major role in providing information at a local level (Theobald *et al.*, 2000). The need for better tools to handle ever more critical environmental and resource management problems is obvious, and the rapidly developing field of information technology can provide the necessary machinery (Lam, 1993). Larsen (1999) explains how GIS should become a component of every environmental monitoring system not just for its ability to present data and create aesthetically pleasing maps, but for the ability of GIS to be a tool for data integration and analysis. This statement is supported by Schroeter and Olsen (1996), who add that GIS is becoming more closely integrated with environmental monitoring while at the same time becoming more user-friendly, making GIS more relevant and accessible for non-GIS experts. Lang (1998) added that a GIS is an extremely powerful tool for measuring and analysing spatial patterns and trends over large areas, and is particularly useful for habitat and ecological studies.

Without the use of GIS, the amount of data captured and analysed in this research would not have been possible using more traditional methods, over the same period of time.

CHAPTER THREE
STUDY SITE

3.1 Introduction

The main aim of this study was to investigate habitat use by Blue Swallows during the period of food provision for the nestlings. To satisfy this aim, a Blue Swallow breeding site surrounded by diverse habitats was required in order to isolate specific habitat use within an array of habitat use opportunities. An ideal study site needed to contain multiple active nest sites in order to investigate co-operative breeding investigations and needed to be a mosaic of natural habitats including grassland, wetland and indigenous forests, interspersed within multiple transformed habitats like commercial timber plantations, human settlement and various annual and perennial cash crops.

3.2 Importance of Roselands for the Blue Swallow

The breeding range in South Africa is limited, with an estimated 49 active nest sites, 45 occurring within KwaZulu-Natal, of which four breeding sites have more than three active nest sites (Endangered Wildlife Trust – Blue Swallow Working Group, 2004). Roselands, with four active nests, is one of these properties. Therefore, the importance of this property for Blue Swallow conservation cannot be overstated (Arnott, 2005).

The unavailability of a pristine Blue Swallow breeding site, for comparative studies, removed this consideration from the process of site selection. Therefore, only sites with multiple active nests and diverse adjacent habitats were considered appropriate for this study (see Section 2.3 and Section 2.4). Logistics were also a consideration, because the scope of this study was constrained by limited funds and time. Travel distance, therefore, needed to be kept to a minimum. Only one site in KZN satisfied all these requirements. The close proximity, the diversity of different habitats and four active Blue Swallow nest sites meant that Roselands offered a research opportunity unmatched by the other KZN Blue Swallow breeding sites.

3.3 Roselands' History and Geographical Location

The study site was a privately owned farm, Roselands, and is located in the KwaZulu-Natal midlands of South Africa. The farm has a long-standing history dating back to the mid 1800s and falls into one of the most threatened vegetation types, Mistbelt Grassland (see Section 3.4 below), in KZN which is severely under-represented within formally protected areas.

Roselands is a commercially operational farm, privately owned by the Nicholson family. The 1150 ha farm was purchased by the Nicholson family in 1850 and is one of the original homesteads of the Byrne Settlers. The property was named after the daughter Rose of Mr Deane, the first tenant of the Crown Government (M. Nicholson, *pers. comm.*, 2005). The farm is situated to the south-west of the town of Richmond, on the north bank of the Umkomaas River, approximately 60 km from the city of Pietermaritzburg (Fig. 3.1).

The current land-use on and adjacent to Roselands includes the production of sugar-cane (Plate 6), commercial timber, tea (Plate 7); extensive grazing for beef production; citrus; and eco-tourism and environmental education enterprises. Roselands has had the immediate grassland surrounding the Blue Swallow nest sites proclaimed as a South African Natural Heritage Site and the long-term intention is to list the area as a private nature reserve, which will lead to the proclamation of the untransformed portions of the farm (M. Nicholson, *pers. comm.*, 2005).

3.4 Vegetation

Roselands falls within the KwaZulu-Natal endemic Moist Midlands Mistbelt Grasslands - Acocks veld type 45 (Acocks, 1988), which is the preferred vegetation type for the habitat of the Blue Swallow (Allan *et al.,* 1987).

According to Scott-Shaw (1999), more than 90% of this veld type has been permanently transformed by a diverse array of land-uses and only approximately 1% of the original extent of the Natal Mistbelt Grassland (Fig. 3.2) still remains in a near-pristine state. This vegetation type is critically under-represented with only 0.3% within formally protected areas (Scott-Shaw, 1999).

Mistbelt grasslands are characterised by deep well drained soils and high summer rainfall which make these areas highly favourable to intensive agriculture (Acocks, 1988; Camp, 1997; Granger and Bredenkamp, 1996). Some of the grassland has escaped permanent transformation at Roselands farm, and a large proportion still remains intact. This allows the Blue Swallows to breed during the summer months from October to April (Arnott, 2005). The study area falls into the summer rainfall region and receives 900-1200 mm per annum, and dense mist is frequently experienced in the summer (Acocks, 1988). Temperatures vary between -4° C and 40° C (Granger and Bredenkamp, 1996).

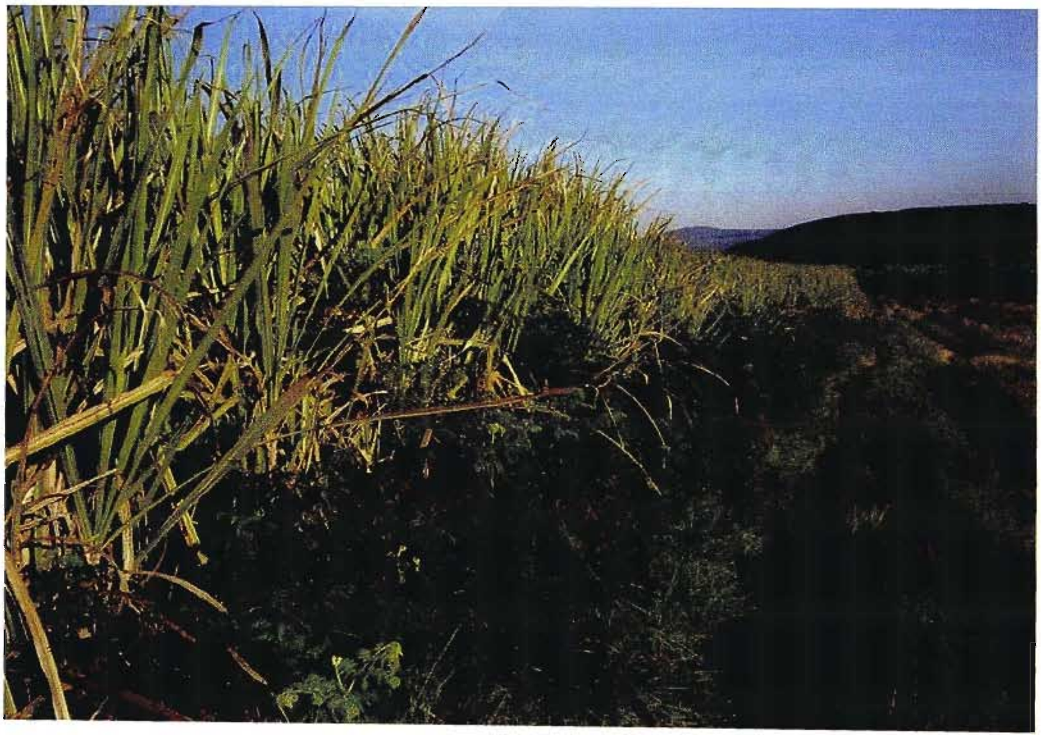

Plate 6. Sugar cane plantation on the farm Roselands.

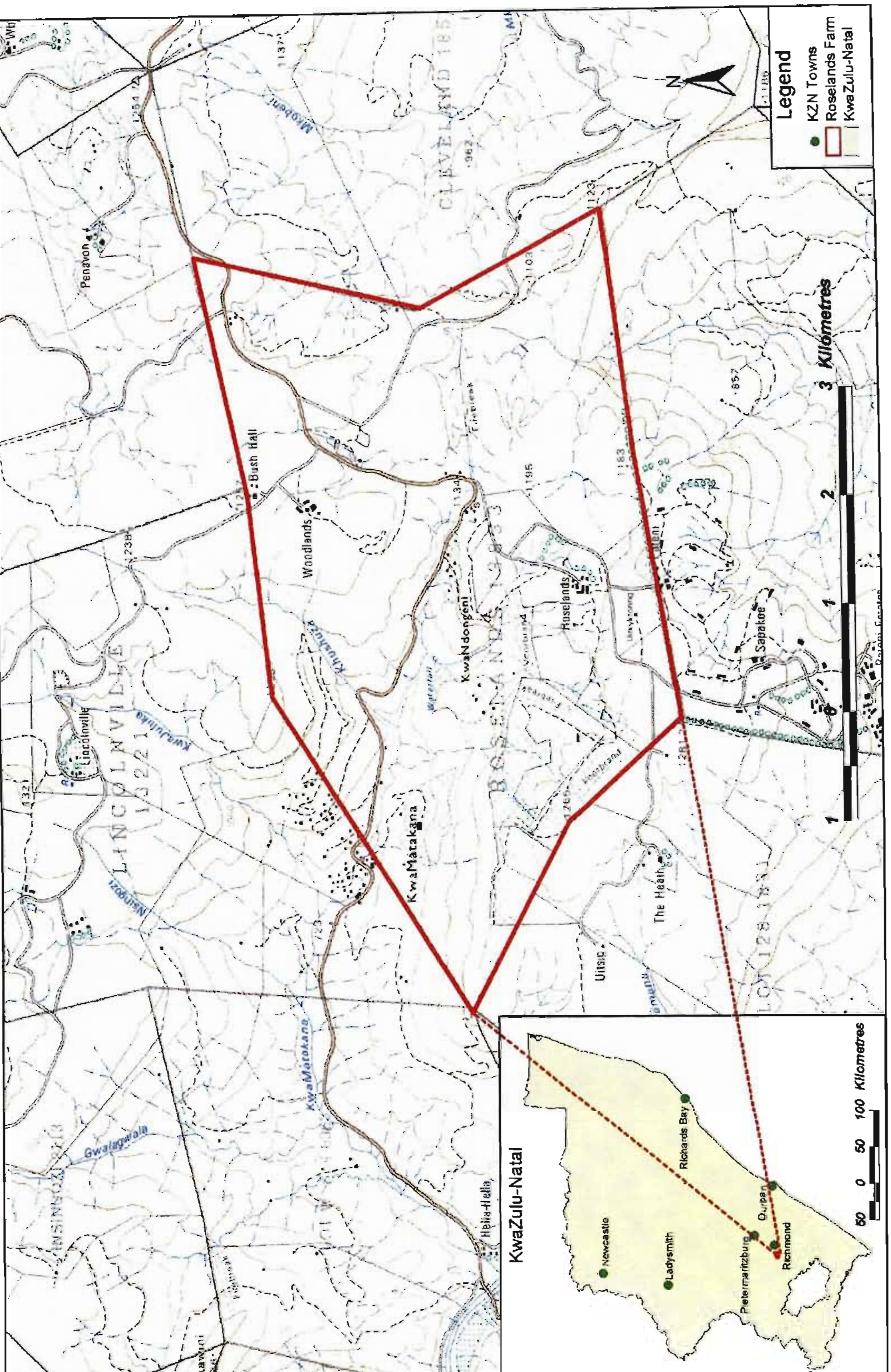

Figure 3.1 Locality map of Roselands farm in KwaZulu-Natal, South Africa.

Plate 7. Tea plantation adjacent to Roselands farm.

3.5 Nest Sites

There are four Blue Swallow nest sites on Roselands. Three were investigated in this study, namely those called Diptank, Florida and Tafeni. All these nests were located in natural grassland, which was surrounded by various transformed habitats. Unfortunately the fourth nest could not be used in this study as the nesting phase coincided with that of another nest already used in this study and only one nest could be studied at a time.

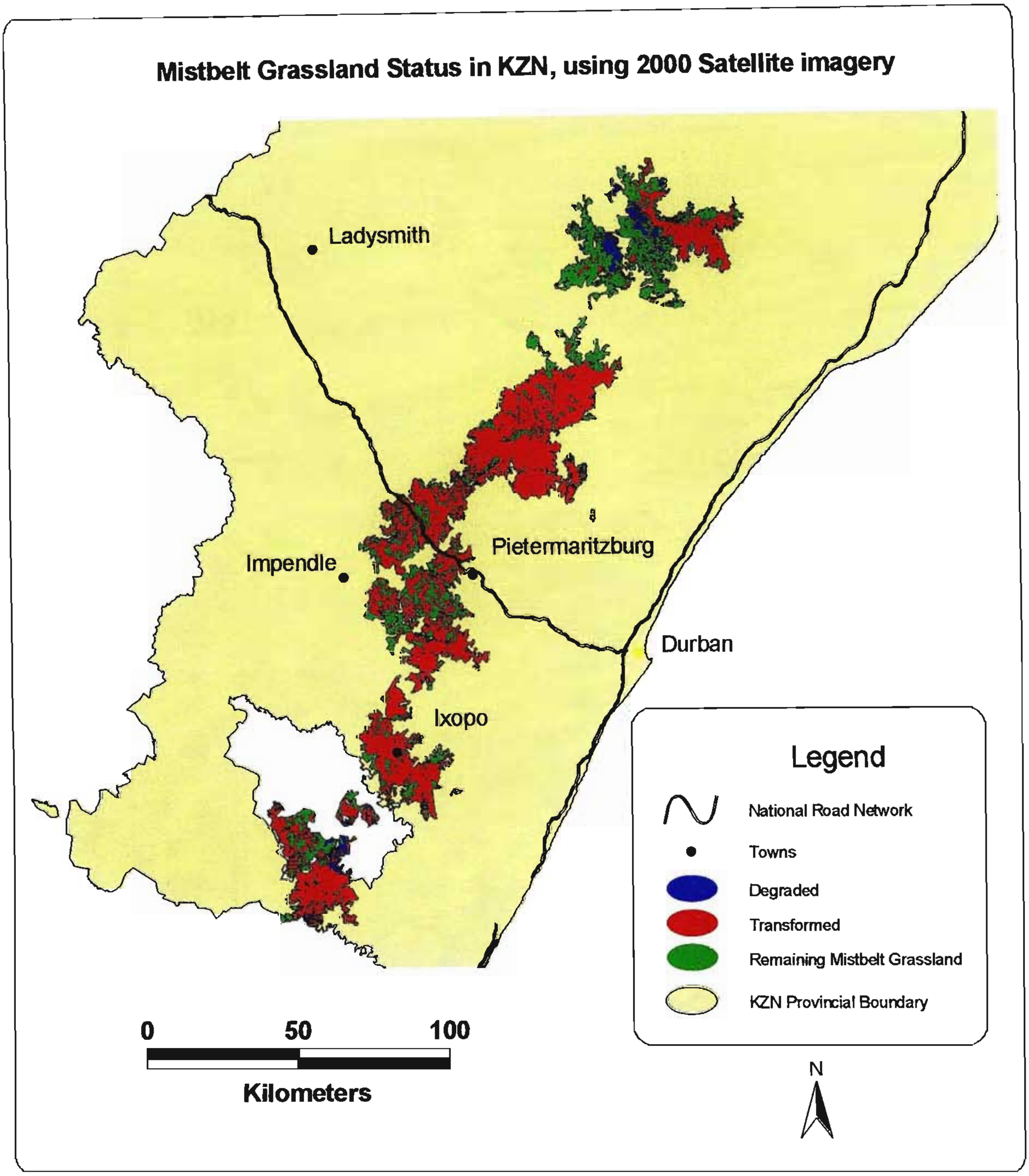

Figure 3.2. Distribution of the remaining Moist Midlands Mistbelt Grasslands (National Plant Ecological Database), in KwaZulu-Natal, depicting the degraded and transformed extents, based on the 2000 National Land cover Standards.

CHAPTER FOUR
METHODS

4.1 Introduction

The overall objective of this research was to determine the critical habitat requirements of breeding Blue Swallows. The research covers space-time use, climatic factors inside and outside a nesting cavity, and co-operative breeding.

4.2 Underlying Assumptions to Research

With all research methods, certain unavoidable assumptions are made which need to be considered. The following assumptions and resultant methods have been used during this research.

1. Little is known regarding the diet of the Blue Swallow (Hawkes (2003), but aerial insects from the order Diptera are thought to be important in the diet of Swallows (Turner, 2004). The Brown-throated Martin *Riparia paludicola* is frequently seen in Blue Swallow breeding habitat and has been recorded feeding upon aquatic insects, termite alates, muscid flies, midges and small beetles (Earlé and Tree, 2005). Insects caught in the Malaise traps were sorted into two main classes: inedible and edible items (Hawkes, 2003). The category of inedible was based upon an estimated edible size for a swallow sized bird and whether or not the insects were winged or not. Wingless insects were all classed as being inedible even if they were larval stages of winged insects. This method of sorting was applied throughout the study.
2. Malaise traps were placed at a central site in the habitat to avoid edge effects; the site was uniformly representative of the particular habitat under investigation. These traps were not moved during the study.

3. The radio telemetry positions obtained from the tagged birds that were located beyond the line of sight of the base stations were not included in the habitat use analysis. It was assumed that if tag locations were obtained outside the visible zone from the base stations, these positions were above the feeding zone of a Blue Swallow and the bird, at that point, was not dependent on a particular habitat to provide specific insect food.

4.3 Ethical Considerations

Considering the endangered status of the Blue Swallow (Barnes, 2000), authority was obtained from the mandated regional conservation agency (KZN Wildlife), and the Endangered Wildlife Trust - Blue Swallow Working Group (EWT-BSWG). This research used the extensive knowledge base at Biotrack in the UK during the pilot study to refine the techniques finally employed for use. In addition, the researcher qualified for and obtained an A-grade bird ringing license, thus ensuring that the captured Blue Swallows were handled professionally to minimise the risk of injury.

Disturbance of a Critically Endangered bird species during breeding is inappropriate, whilst nest disturbance that causes nest site abandonment is intolerable. To prevent unnecessary disturbance and abandonment of the nest site by the Blue Swallow, only nests that had chicks between the ages of 5 and 10 days old were considered to be appropriate candidate sites for this research. The reasoning behind this was that the adult breeding Blue Swallows would be intensely focused on the well-being of their developing chicks and as a result would be less affected by disturbance. The timing of disturbance was in line with the draft chick ringing protocol developed by the EWT-BSWG (Evans, 2004).

4.4 Bird Capture and Ringing Procedure

The individual Blue Swallows that were used in this study were adults involved with the breeding at a nest site with chicks on the nest at between 5 and 10 days old. As it entered the nest cavity, a single adult bird was captured in a small modified mist net. This offered some certainty that the captured individual was indeed a bird involved with the raising of the brood. The captured bird was placed into a small cloth bag prior to ringing. The switch on the radio tag was soldered closed, to start the tag pulsing and was tested to ensure that the tag was functioning. Thereafter, the switch on the tag was sealed with potting agent to prevent degradation from moisture. Although a magnetic reed switch on a radio tag would have been significantly faster to create a live tag, it was not considered an option due to the significant increase in tag weight that a reed switch mechanism would have caused on such a small tag (B. Cresswell, *pers. comm.*, 2003). The delay in creating a live tag with an in-field gas-operated soldering iron allowed the captured bird to become calm in the dark bird bag and this reduced capture stress.

The bird and bag was weighed using a 60 gm Pesola spring balance in 0.2 gm units. A standard Safring 2.3 mm aluminium ring was placed on the bird's right tarsus. All standard biometrics, such as the maximum cord wing length, tail and moult were gathered.

The radio tag was fixed onto the middle tail rectrix, using 'super glue' (cyanoacrylate) and a 'super glue' activator. The activator was applied to the tail feather of the bird and the glue was applied to the radio tag (Plate 8), ensuring that the radio tags were well bonded to the feather, so preventing tag failure resulting from premature tag detachment.

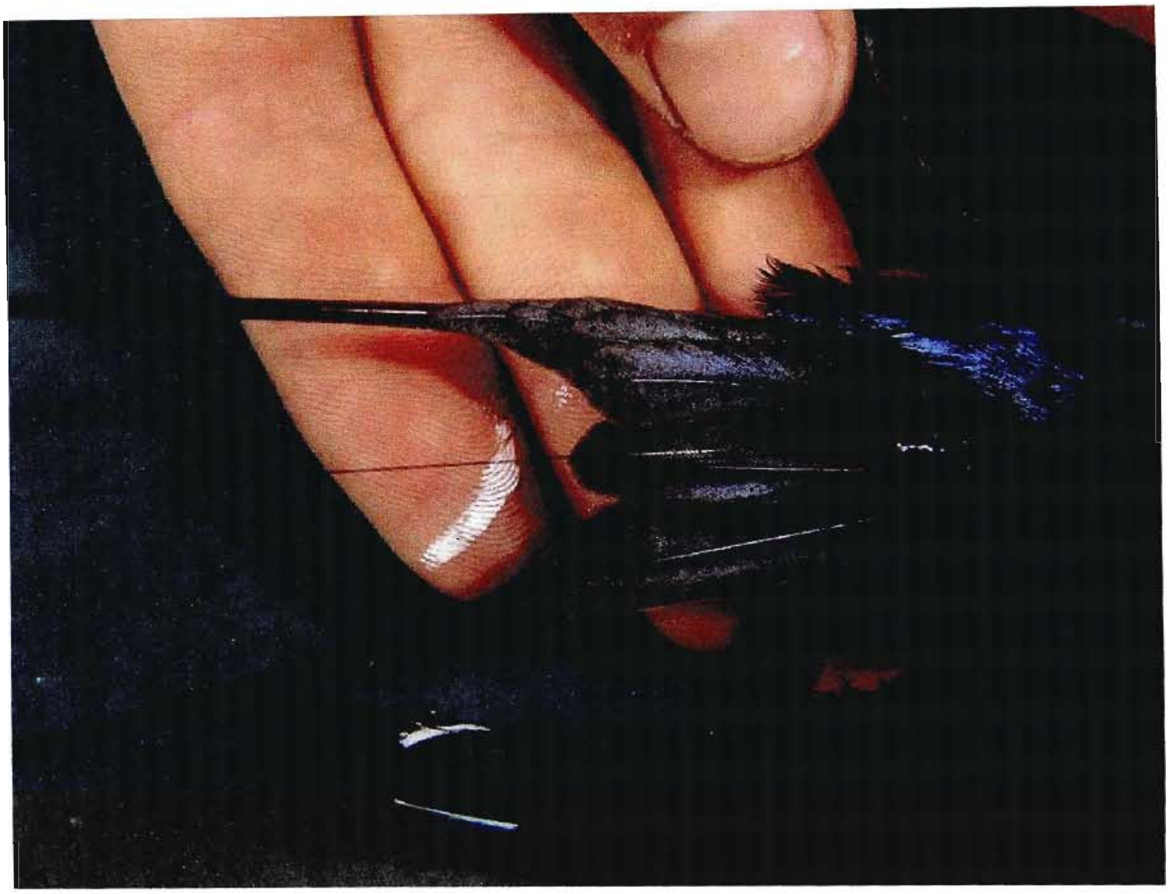

Plate 8. Tail-mounted radio tag on an adult male Blue Swallow *Hirundo atrocaerulea*.

4.5 Co-operative Breeding and Wing Marking

To positively identify co-operation in the breeding cycle of Blue Swallows it was necessary for individual birds to be identified. During the ringing and radio tagging procedure, each captured individual had the primary feathers uniquely marked with white correction fluid to facilitate easy field observation (T. Szép, *pers. comm.*, 2003), (Plate 9).

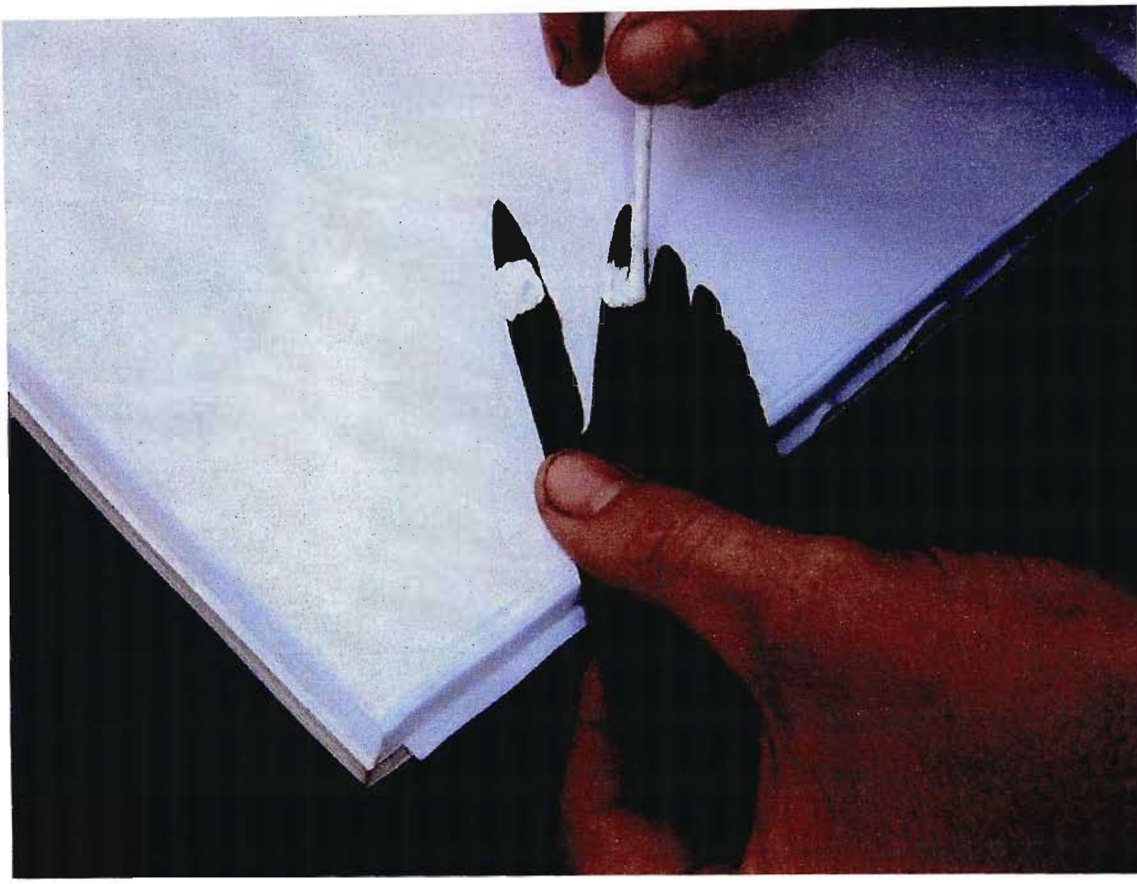

Plate 9. Uniquely wing marked Blue Swallow using correction fluid (photo by D. Hancock).

Using correction fluid, spot patterns were painted onto the dorsal side of the 8th and 9th primary feathers. These spot patterns were applied in different permutations. Many different permutations are possible depending how many marking locations are used. Due to the small size of the Blue Swallow, the speed at which it flies, and that only three individuals would be captured for this research and marked, it was decided to use only the dorsal wing tips in three clearly visible permutations (Fig. 4.1).

For marking, picric acid was recommended by Patterson (1978), due to the long-lasting effect the chemical has on marking bird feathers. However, due to the health hazard and toxicology report which highlighted the dangers associated with picric acid (http://www.setonresourcecenter.com/HMIS Msds/HMIS/080/CJTNM.HTM14/01/2003), correction fluid was used in instead.

1: Dip tank, Ad ♂ 2: Florida, Ad ♀ 3: Tafeni, Ad ♀

Figure 4.1. The different wing marks used to identify individual tagged birds.

4.6 Radio-tracking

Emphasis was placed upon obtaining reliable equipment that could withstand the wet climate of the study area. The equipment needed to be waterproof and easily transportable (B. Cresswell, *pers. comm.,* 2003; Kenward, 2001). Biotrack in the United Kingdom (UK) was chosen as the suppliers of all the radio-tracking equipment.

4.6.1 System Design and Implementation

In this section, an overview is provided of the basic VHF transmitting and receiving equipment used in this study. It also includes the development of the fixed point base stations.

4.6.1.1 Radio Receiver

The model of radio receiver used was the Sika, with a 256 programmable channel scanning manual and automatic gain control receiver. The receiver is supplied with a mains power supply but can also be charged from any 12v source such as a car battery. The Sika is fully waterproof (http://www.biotrack.co.uk) which proved essential because much of the field work undertaken during this study was in mist or rain (Plate 10).

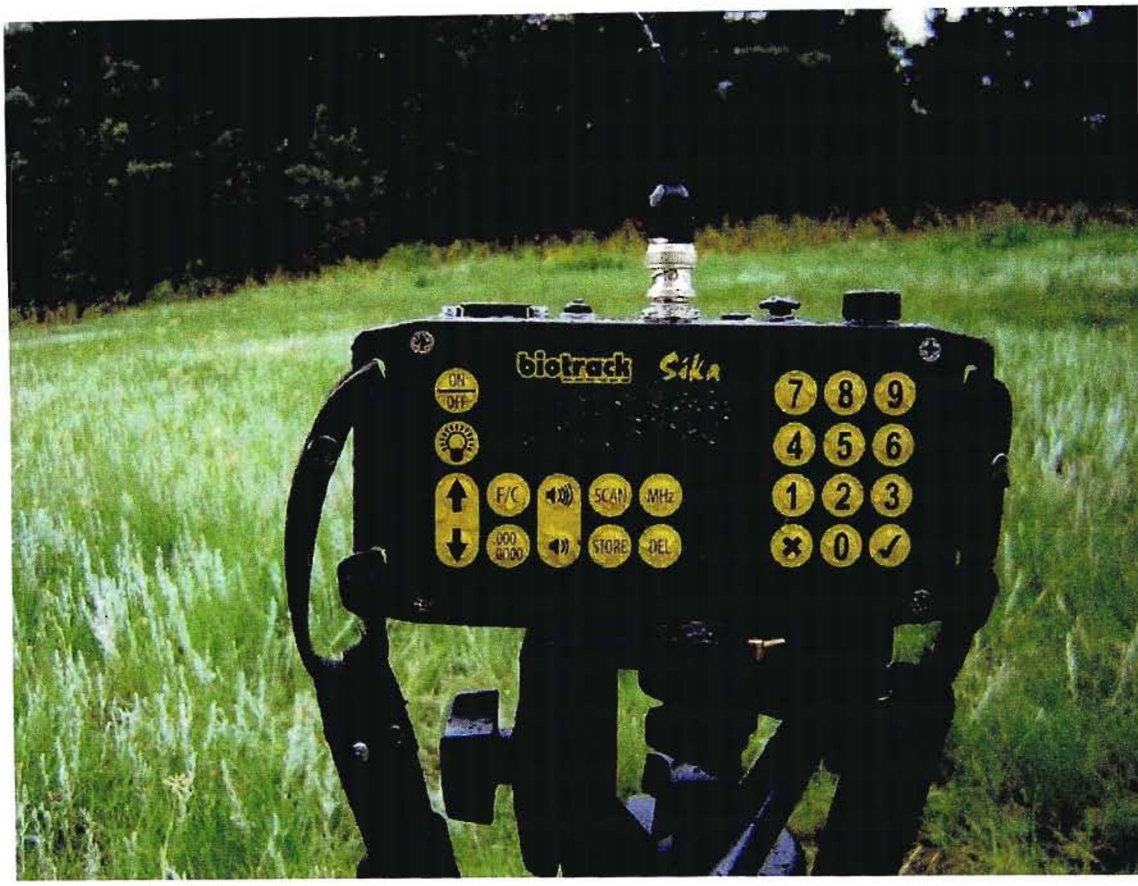

Plate 10. Using the Sika under wet conditions.

4.6.1.2 Radio Transmitting Device (Tags)

The tags used in this investigation, known as PIP3 tags, weighed between 340 and 360 milligrams (mg), (http://www.biotrack.co.uk). An Ag317 battery was used which delivered power to the tags for 14 days. The PIP3 tags contain a TW-4 transmitter circuit with surface-mounted crystals and operated at the 150 MHz frequency band. Tag masses were obtained using a Metler electronic balance. The whip antennas on the radio tags measured 116 mm in length (Plate 11).

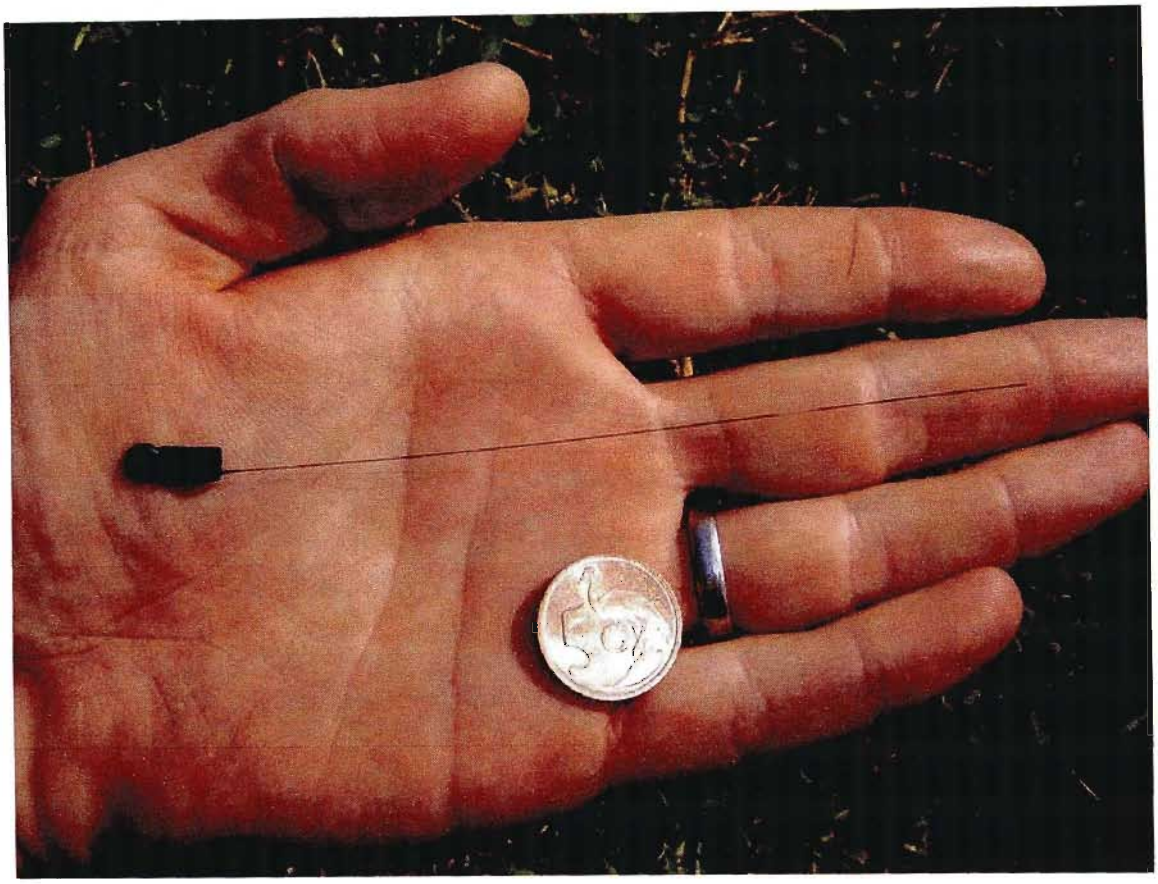

Plate 11. A 350 mg Biotrack manufactured PIP3 radio tag compared to a 5 cent piece. The coin is 20 mm wide and the tag antenna is 116 mm long.

4.6.1.3 Receiving Yagi Antenna

A flexible 3 element Yagi antenna, made by Lintec Antennas Ltd, a specialist antenna manufacturer, was used. This flexible antenna provides excellent performance and is lightweight and robust (B. Cresswell, *pers. comm.*, 2003). They are easy to pack away and transport as the elements are flexible and can withstand being bent. These antennas are matched to the standard 50 ohms input impedance of the radio-tracking radio receiver. The antenna weighed 500 gm and had a band-width of approximately 2 MHz, with a beam-width of 80° and a gain of 6 dB. The 'back to front' ratio was 18 dB (http://www.biotrack.co.uk; Biotrack, undated).

4.6.1.4 Base Station Development

Two independently located base stations for direction finding (Kenward, 2001), were set up for each site where Blue Swallows were tagged (Plate 12). Base station sites were chosen primarily for their proximity to the nest site and their visibility over the surrounding landscape. A 360° plastic compass was enlarged, scanned and laminated onto a Perspex board. This was fixed to the foot of the antenna stand. The base stations were in line of sight of each other to enable the correct base line zeroing (i.e. the 360° at the first base station faced the second base station and vice versa). A metal peg was driven into the ground at the 360° mark so that, if inclement weather prevented visibility between the base stations, an accurate and precise zero degree baseline could still be established. The readings were obtained by inserting a knitting needle through the base of the Yagi antenna stand which pointed to the direction, in degrees, that the Yagi antenna was aimed at (Plate 13).

Plate 12. Field assistant Mr Siyabonga Mkhize using the Sika at the fixed location radio telemetry base station in grassland habitat overlooking the Diptank nest site.

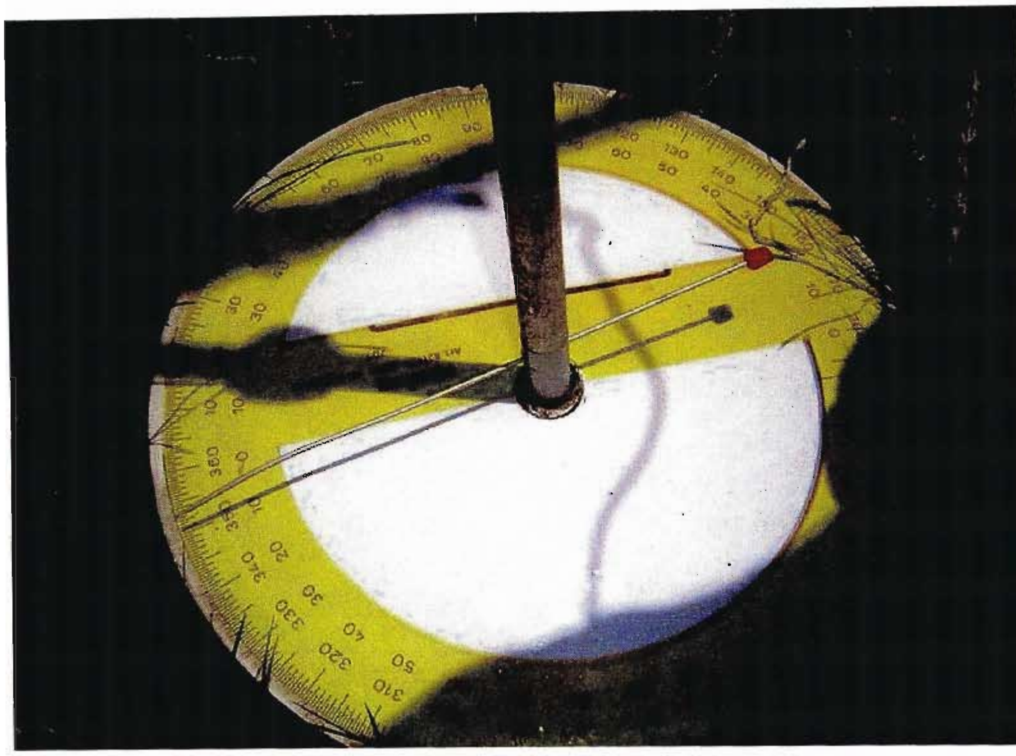

Plate 13. Compass fixed onto a Perspex board at the base of the Yagi antenna stand.

4.6.2 Fieldwork

4.6.2.1 Nest Site Selection

Nest site selection was based upon first, the age of the nestlings, and to a lesser degree, the availability of suitable base station positions. Suitability of base station positions was determined by the openness and visibility of the surrounding landscape (i.e. minimising 'dead' ground). Positioning of the base stations was crucial so that visibility of the surrounding landscape was maximised from as high a vantage point as possible (Kenward, 2001; White and Garrott, 1990). Positioning the base stations too close together could introduce errors and this became a trade-off between accuracy for triangulation and landscape visibility. Stations placed too close together could have resulted in low confidence being placed in the telemetry angles and thus the positional data. The ideal base station positioning would be to have the stations placed on the highest points, with the nest positioned between them at a suitable distance from the nest to avoid causing any disturbance.

4.6.2.2 Field Data Collection

Data concerning the positions of the base stations and the nest sites were collected using a differential Global Positioning System accurate to less than 1 m (http://www.trimble.com). These co-ordinates were recorded in Decimal Degrees using the Datum of WGS84, to facilitate entry into a GIS. The operators of the two base stations were able to keep in contact with each other using two-way radios. This allowed for both base stations to obtain a good fix on the radio-tagged bird and to take readings simultaneously. Only when both stations had high confidence in their directional fix were readings recorded on a data sheet (Appendix I). The time was also recorded off a digital wristwatch and any pertinent notes were made such as weather conditions, or bird location. The data collection forms were attached to a clip board which was protected with plastic sheeting. Any interesting observations made and useful notes were recorded in a small field notebook.

4.6.3 Post Fieldwork Processing and Analysis

The data on directional radio telemetry in the field, as collected by both base stations, were collated and stored in a spreadsheet format which was used to process the output co-ordinates into an appropriate GIS format. The tag location was calculated from the readings obtained from the base stations using basic geometry techniques (Appendix II).

4.6.4 Limitations of Radio Tagging

VHF radio tag signals are reliable only for line of sight (Kenward, 2001). In suitable Blue Swallow territory, the nature of the topography could be a limitation. As a result, only when the tag signal was strong and reliable were directions simultaneously recorded by both base stations. Weak tag signals were not used for establishing location data. This allowed for greater confidence in the collected locality data. Small discrepancies in determining the angle of tag direction can lead to erroneous data capture with accumulated error with an increase in distance from the base stations (Section 2.7.3). The example illustrated in Figure 2.2 demonstrates how an incorrect reading of 5° above or below the true bearing, increases the scale of error with an increase in distance between the radio tag and the base stations. An error of 5° is a realistic degree of error for the three element Yagi antenna.

In order to assess the accuracy of the triangulation system, error was randomly tested in the field with a live radio tag. A live tag was placed at random points (n=14), throughout the study area to simulate a Blue Swallow location. The exact location of the live tag was recorded using a differential GPS whilst the telemetry directions were recorded. The triangulated position was then compared to the exact tag locality and the error in the two positions was found to vary from 4 m at 75 m from the nest site to 92 m at 1045 m. This in turn could lead to erroneous attribute information being captured on habitat usage. This is particularly relevant where ecotones are used to distinguish preferential feeding areas between two habitats as is the case when one habitat is not selected as suitable forage habitat by the species. Nevertheless, error in radio telemetry plots the location within that habitat. Figure 4.2 displays the expected error of 5° for positional data plotted on the boundary between plantation and grassland, where the location of the point data cannot be precisely determined, but where error could be significant through assigning incorrect habitat attribute data to the dataset.

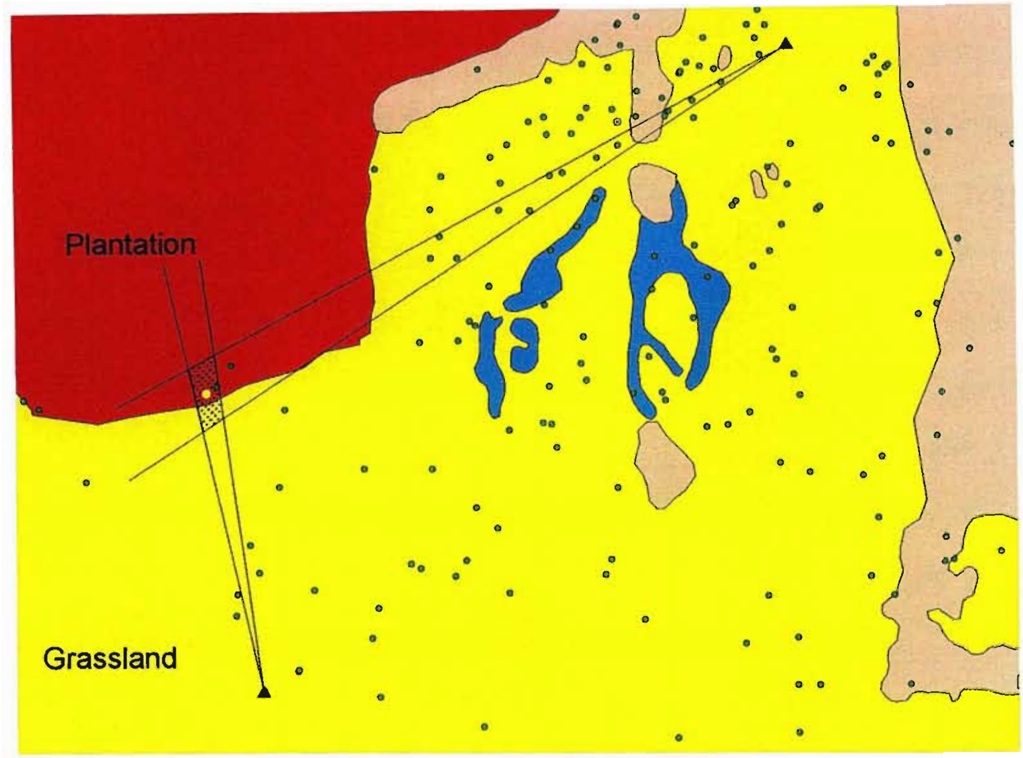

Figure 4.2. Illustration of the potential margin of error around a single telemetry point in plantation close to the boundary with grassland assuming a 5° error in telemetry. The margin of error around this point includes grassland and so the bird may have been in grassland and not plantation at the time the telemetry point was taken (▲ = base station).

It is reasonable to expect that the Blue Swallow, as a central place forager, would spend more time flying back and forward to the nest and hence the amount of time spent in the vicinity of the nest area would be relatively greater than time spent further away. This would have resulted in more telemetry point locations being obtained closer to the nest site, and possibly leading to erroneous interpretation in terms of location within a preferred habitat type.

4.7 Spatial Land Cover Data Capture

4.7.1 Land Cover Data Capture and Preparation

The nest data were obtained using a Global Positioning System (GPS), set up according to WGS84. These data were projected, using the Projector extension in ArcView, into Transverse Mercator in WGS84. Digital ortho-photos from the year 2000 were available from the Surveyor General for the study site in WGS84. Digital land cover coverages were digitised on-screen, and the digitised land cover data were stored as ArcView shape files in their original projection.

The digitised land cover data were cleaned in ArcView using the ArcView extension Edit Tools version 3.3. The cleaning process involved running both the 'clean and identify gaps', functions, which identified all overlaps and gaps generated during the digitising process. Edit Tools 3.3 subtracted the gaps and overlaps and formed them into individual polygons which were then either deleted or combined with adjacent polygons. The cleaned digitised land-use data were then overlaid with the positional data for each adult Blue Swallow that was tagged and tracked using radio telemetry techniques. Maps were printed using the layout function in ArcView and are to be found in Section 5.5.4.

In order to determine the portion of landscape visible from the base stations within each home range, a Digital Terrain Model was used to determine the habitat in line of sight from each base station which was then combined to create a 'view shed' for each nest site.

4.7.2 Definitions of Land Cover Categories

The land cover on and adjacent to the study site was digitised as polygons, and classed into a land cover type based upon the homogeneity of the physical attributes of the type of land cover. A simplified label was used to describe the classification of the land cover which simplified the attribute data within the GIS.

The following land cover classes were used;

- **Aliens** - Informal self-established stands of alien plants such as Black Wattle *Acacia mearnsii*, Amercian bramble *Rubus spp.*, and stands of Bugweed *Solanum mauritianum*.

- **Arable** - Land that is ploughed for annual cropping, subsistence or cash cropping.
- **Forest** - Wooded grassland and indigenous mistbelt forest.
- **Grassland** - Only unploughed, unplanted and not irrigated primary grasslands.
- **Orchard** - Established crop of fruit trees.
- **Plantation** - This category includes only commercial timber plantations in a regular array of trees.
- **Settlement** - All human settlement, formal and informal. This category includes the portion of land around a home-stead used as a living area.
- **Sugarcane** - This includes all forms of agricultural practices where ground is broken to plant sugar-cane as a crop.
- **Tea** - All forms of agricultural practises for the production of tea.
- **Waterbody** - All dams with standing water.
- **Wetland** - All areas where hydromorphic soils predominate. This habitat type is usually associated with sedges, reeds and other water-tolerant plants.

4.8 Dietary Study Sampling

Faecal sac analysis was not considered for use in this study. The decision was based upon the findings of Hawkes (2003). Dietary investigations were thus undertaken using a modified version of a Malaise trap.

4.8.1 Trap Design

A modified Malaise trap, whose design was based on the standard design of a 'dome tent', was used to trap insects that occurred within the forage range of Blue Swallows. The suggested maximum height is 1.2 m, ensuring that insects which fly above 1.2 m were not captured and included in the samples (Hawkes, 2003). The modified Malaise trap is self-supporting, and well suited for long sampling periods where most conventional designs would require frequent adjustments to ensure continued effective functioning (Hawkes, 2003). Flying insects are intercepted by the netting walls of the trap and channelled into a collecting jar whilst being prevented from escaping by a white nylon mesh covering the top of the inner mesh walls (Plate 14). The capture funnel ends in a container holding approximately 50 ml of 10% ethanol to water mixture, to which a small amount of dish-washing liquid was added to break the surface tension. Foam covered with foil was attached to the outside of the collection bottle, as a protective shield, to prevent the sun from damaging the insect samples (Hawkes, 2003).

A simple derivative of a modified Malaise trap was used to trap emerging insects from soil samples in an attempt to locate the source of suitable insect prey for the many aerial foraging birds using the tea plantation (Plate 15).

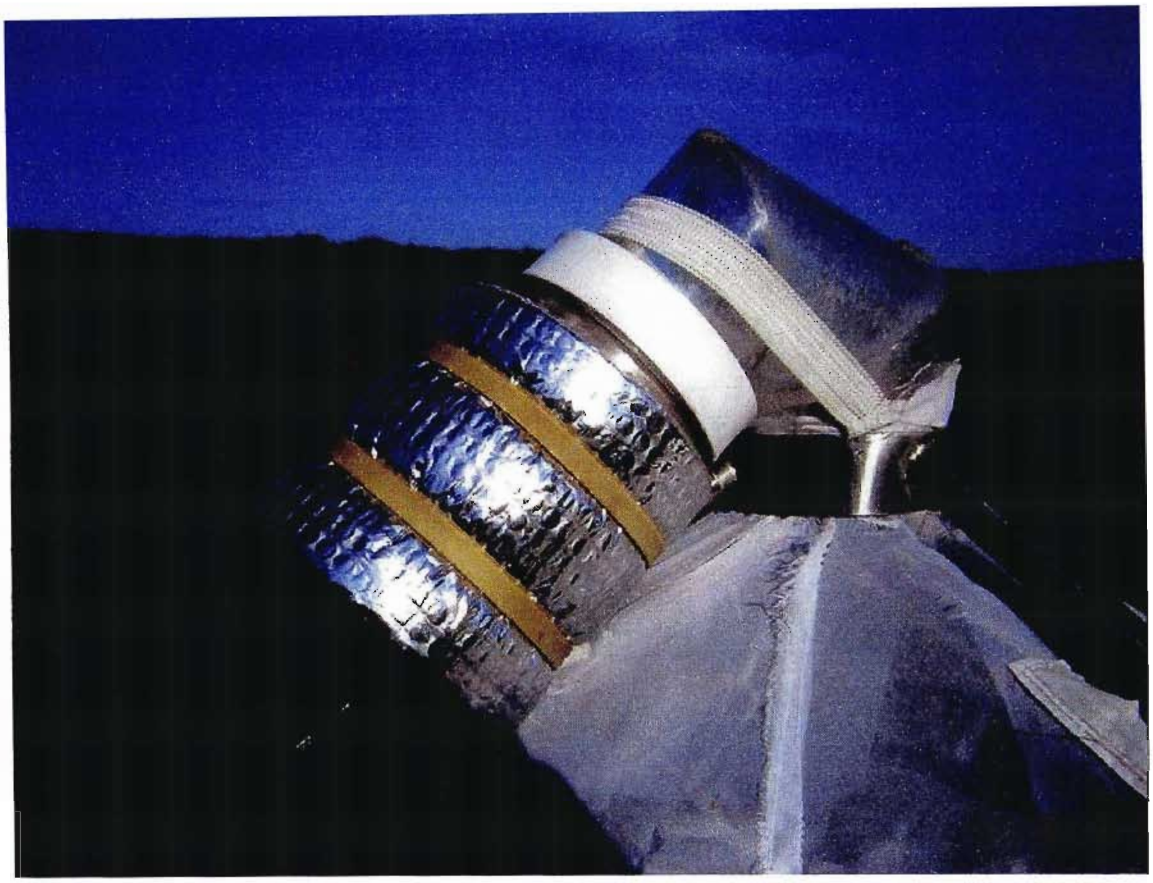

Plate 14. The insect collection bottle on a Malaise insect trap, containing an alcohol, soap and water mixture.

4.8.2 Trap Locations

A single trap was placed in each of the five habitat types surrounding the Florida nest site. Due to financial restrictions, more traps were unfortunately not available to increase the sample sizes. The Malaise traps were positioned in the following habitats: tea plantation, sugar-cane, wetland, grassland, and commercial timber plantation (Plate 16).

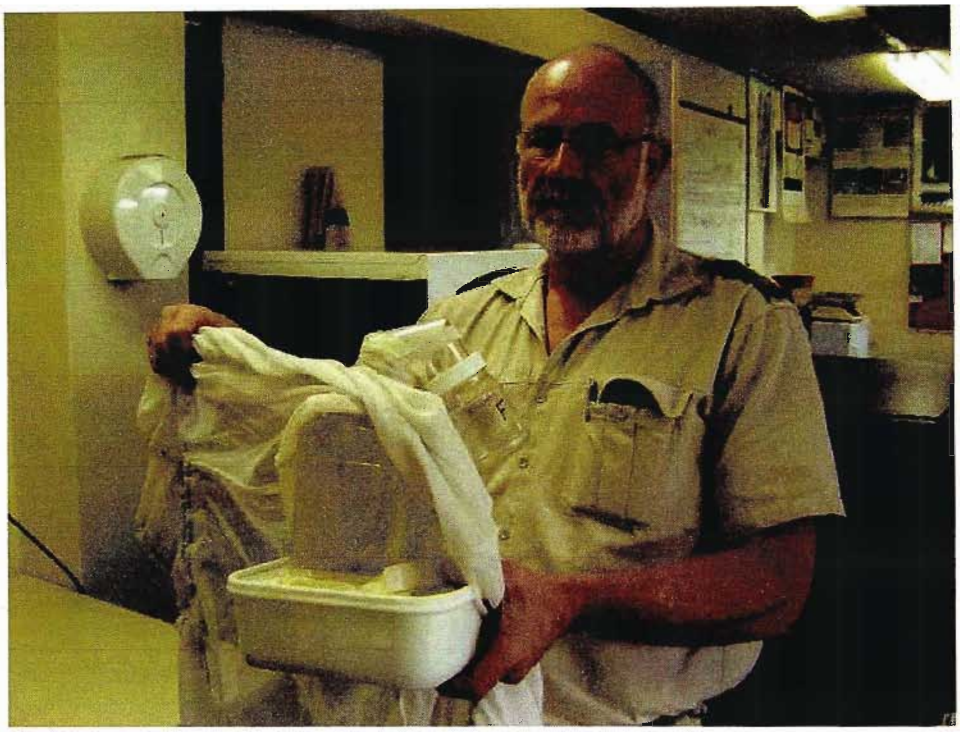

Plate 15. Insect trap designed to trap insects emerging from soil samples.

Plate 16. Malaise insect trap site within a field of tea, note the anchor guy-ropes.

4.8.3 Sample Collection

Each malaise trap was checked and emptied twice daily. A new bottle of solution was placed onto the funnel at 06H00 each day and was replaced at 12H00. This bottle was removed at 18H00 and the trap was left without a bottle overnight until the following morning at 06H00 when a new bottle was fitted onto the trap (Hawkes, 2003). The same order of setting the traps was followed for the duration of the sampling and the timing of setting the first trap was maintained as closely as possible on a daily basis to ensure that all traps operated for an equivalent period of time. The contents of the collection bottle were strained with a fine mesh tea strainer (Plate 17), and were transferred to a holding bottle containing a 70% ethanol and a 30% water mixture (Hawkes, 2003). Each bottle was labelled with the time and date and trap site (Appendix III).

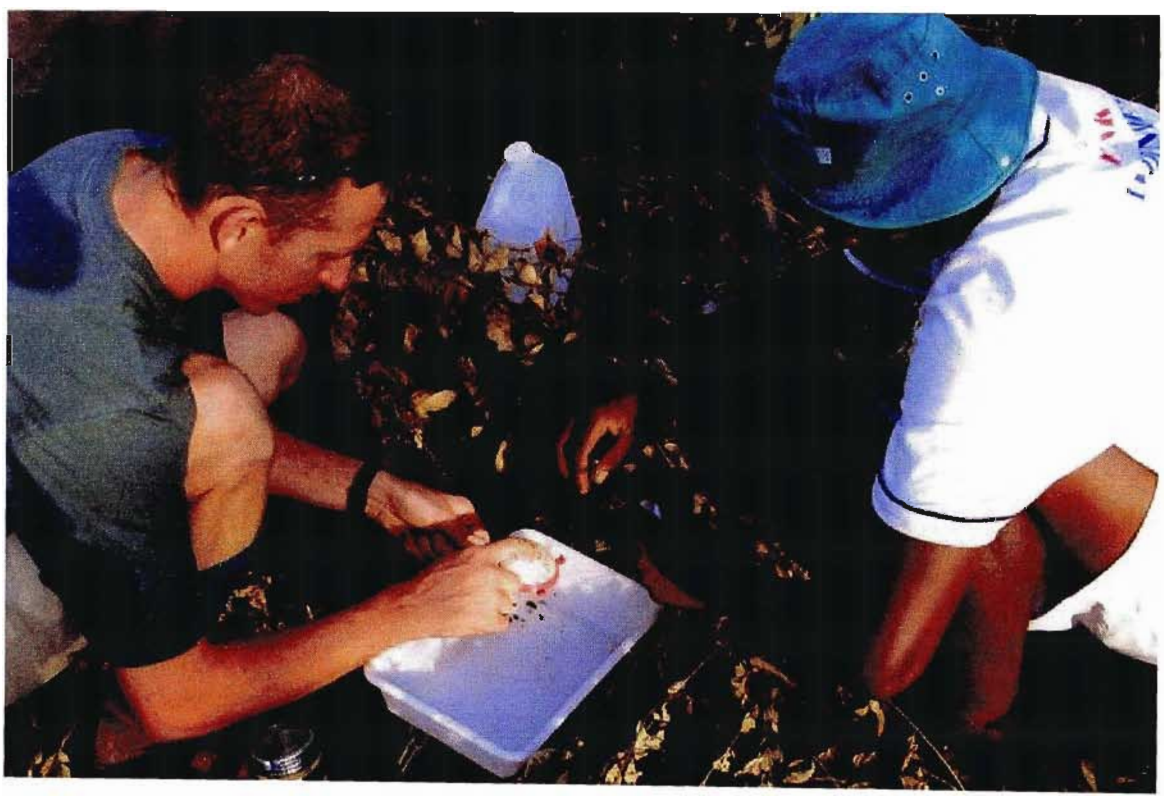

Plate 17. Insect sample collected from a Malaise insect trap (photo by D. Hancock, 2004).

4.8.4 Sorting and Weighing the Insects

In the laboratory, the contents of each collection bottle were removed and poured into a Petri dish where the insects were categorised and separated. Specimens of non-flying insects such as springtails (Collembola) that had climbed up the collecting chambers of the traps, as well as extremely large flying insects that were obviously not suitable prey items, were separated and categorised as potentially inedible. This resulted in two bottled samples for each trap for each sampling period of six hours. For each sample, the potentially edible and potentially inedible insects were grouped and classed according to insect order, dried on blotting paper, counted, and weighed in milligrams (mg) using a Metler balance (Plate 18).

Analysis was made of which habitats produced the most insects, and of the ratio of inedible to edible insects. This aspect of the dietary study was considered to be potentially important for energetic reasons as the Blue Swallows might expend energy through specific prey avoidance (P. Hawkes, *pers. comm.,* 2005). Identification was made with assistance from a professional entomologist, Dr Adrian Armstrong, and with the use of an insect field guide (Picker, Griffiths and Weaving, 2002). The insects were then returned to the collection bottle for safekeeping. Each sample was analysed separately, and the data entered onto a spreadsheet and graphically represented.

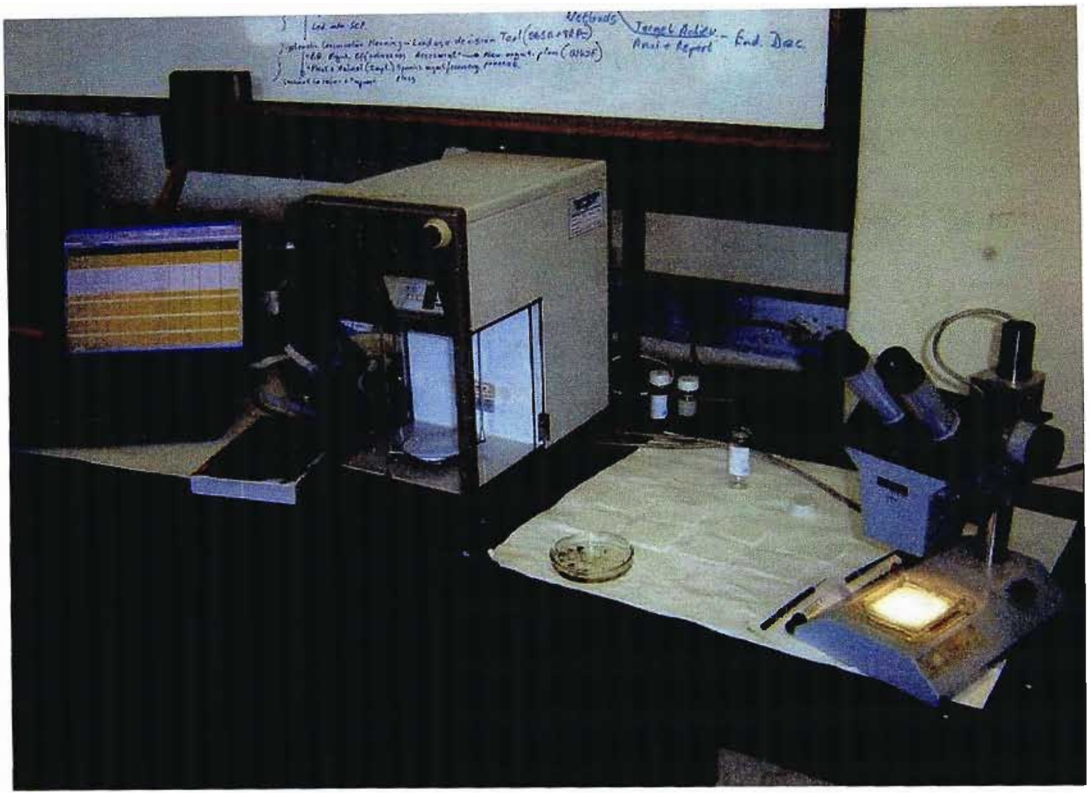

Plate 18. Insect processing station, with the Metler balance used for weighing insects.

4.9 Environmental Factors

Two HOBO® data logging units (Onset Computer Corporation, Bourne, MA, USA) were used to measure temperature and relative humidity. The sensor is accurate to approximately 0.7 °C and has a temperature resolution of 0.4 °C (http://www.onsetcomp.com/Products/Product_Pages). A HOBO® Temp datalogger consists of a thermostat temperature sensor enclosed in a plastic box containing a small battery and electronics to keep time and store temperature data. The HOBO® sensor is not resistant to moisture damage and therefore cannot be placed unprotected directly into the environment. The sensor needs to be put inside a weatherproof protective housing which prevents moisture damage, but allows for uninhibited air circulation so that precise readings can still be obtained (M. Savage, *pers. comm.*, 2004). The housing was manufactured from a series of inverted plastic camping plates, in which a cavity was made into which the HOBO® sensor was placed. This protective housing could then be placed in any desired location. Two HOBO® sensor units were used in this study: one was placed next to an active Blue Swallow nest (Plate 19) inside the underground nest cavity and the other was placed inside the weatherproof housing, in close proximity to the nest cavity entrance above-ground (Plate 20).

The sensor unit has a standard operating temperature range between -20 °C and 70 °C and its dimensions are 60 mm by 50 mm by 20 mm and thus are easily concealable (http://www.onsetcomp.com/Products/Product_Pages). The HOBO® data logging units were calibrated by the user with a computer programme called Boxcar, to record temperature and relative humidity at 10 minute intervals for a period of 17 days. Thereafter, the temperature and humidity data from the HOBO® data logging units were transferred to a laptop computer for analysis and display.

Plate 19. HOBO® sensor attached to the cavity wall just below the nest of a Blue Swallow inside a sinkhole at the Florida nest site.

Plate 20. HOBO® sensor was placed inside this weatherproof housing.

4.10 Statistical Analysis

Non-parametric statistical analyses were made of all data-sets. These included the Chi-square test (X^2). The X^2 is a statistical method for determining the significance of differences between two independent groups (Siegel and Castellan, 1988; Hammond and McCullagh, 1974). This test was used to determine the significance between the radio telemetry point dataset and the number of expected locality points occurring within each of the various habitat types.

To determine i) whether there were genuine population differences between insects, ii) environmental variables and habitats, and iii) the kinds of variation that can be expected from random samples from within the same population, the non-parametric Kruskal-Wallis analysis of variance (ANOVA) by ranks and median test was used (Hammond and McCullagh, 1974; Siegel and Castellan, 1988; Statsoft Inc, 2001; Zar, 1984). A Pearson Product-Moment 2 table correlation test was applied to the environmental data. This test assumes that the two variables are measured on interval scales, and determines the extent to which values of the two variables are proportional (Statistica for windows, 1994; StatSoft, Inc, 2001).

In addition, Formal Inference-based Recursive Modelling (FIRM) was used as an alternative to multiple regression or multiway analysis of variance to identify the best predictor of habitat using mass and numbers of insects per insect order (R. Emslie, *pers. Comm.*, 2005; Hawkins, 2005). The significance level at which the model automatically stopped calculating was set to 95%. Only groupings having more than 10 cases were considered further for splitting into independent categories as predictors, the model stopped automatically from splitting groups having 10 or fewer cases.

CHAPTER FIVE

RESULTS

5.1 Blue Swallow Capture and Biometrics

In order to fit the radio tags and obtain measurements, Blue Swallows had to be captured. This proved to be an impossible task using traditional mist netting techniques as the birds saw the nets and avoided them easily. As a result, a very fine (110d) single panel mist net was placed inside the nest cavity and this worked well. This also ensured that the Blue Swallow that was captured was one that was actively involved in feeding chicks. Disturbance was kept to a low level and it was observed that the trapped swallow continued feeding the chicks within an average of 25 minutes of being released (n=3; 18, 28 and 29 minutes). All the nests that had adult Blue Swallows captured and tagged fledged their chicks and returned to breed and fledge a second clutch in the same breeding season.

Table 5.1. A comparison of Blue Swallow biometrics. Mass is shown in gm and wing and tail measurements in mm

	n	Spottiswoode, 2005	n	Wakelin, 2003	n	This Study
♂ Mass	1	13.1	3	14-15 (14.3)	1	15.8
♂ Wing	47	103.5-119.5 (113.4)		No data	1	118
♂ Tail	44	92.6-155.2 (131.7)		No data	1	144
♀ Mass		No data	5	13-14 (13.6)	2	12.5-13.8 (13.1)
♀ Wing	19	101-111 (107.4)		No data	2	108-110 (109)
♀ Tail	18	60-81 (71.4)		No data	2	70-78 (74)

All the biometrics for the Blue Swallows captured and handled were included in this study. All recorded biometrics were found to be similar to those found by Spottiswoode (2005), (Table 5.1).

5.2 Co-operative Breeding

The investigations into co-operative breeding are secondary to this study and therefore the breeding system was not investigated in detail. However, during the preliminary phase of this research, Mr D. Hancock, in 2003, videoed Blue Swallows at a nest at Impendle Nature Reserve. The film footage was carefully examined and by measuring slight variation in tail streamer length, it was revealed that at least 3 different (presumably adult female) Blue Swallows were involved with the incubation of eggs and the feeding of chicks. From the film footage it was noted that an adult male Blue Swallow was also involved in feeding of the chicks. However, it was impossible to verify whether or not the male was the same individual during each feeding session because the streamer length did not vary measurably. This indicated that the male bird was either the same individual during the nest visits or that tail streamer length in males is less variable and therefore less obvious, which appears not to be the case (Table 5.1).

With the aid of visual markers, observations made during the summer of 2004/5 at Roselands indicated that a similar situation existed to that recorded at Impendle Nature Reserve. All the active nest sites (Diptank, Florida and Tafeni) that were investigated had more than one adult female Blue Swallow involved in the breeding system. The average sex ratio noted of birds provisioning at the nest was 1♂ : 3♀, n=3 (Table 5.2). The fact that eggs are laid sequentially over a period of days and not on a single day (H. Mattison, *pers. comm.*, 2003), supports the notion that a single female was involved in the breeding and not polygyny where one male mates with more than one female (Cockburn, 2004). There was also no evidence to suggest that a single fledgling was fed exclusively by a single adult bird, as the wing marked adult female birds showed no selection for specific individuals. It was also noted that there was an excess of adult males that flew in smalls groups numbering 2 to 3, which could potentially be a result of a lack of suitable breeding sites or available adult female birds. The breeding system used by Blue Swallows could possibly be a true monogamous mating system that uses helpers.

Inter-nest visits are common, for example, on 2/12/2004, the Diptank adult male arrived at the Florida nest site with at least five other Blue Swallows, who spent a timed 10 minutes investigating the Florida nesting cavity and close surrounds. During this period, a group of at least 11 Blue Swallows socialised in the vicinity of the Florida nest site. Without wing marking, it would have been impossible to determine the origin of the Blue Swallows that arrived at the Florida nest site. This was not an isolated event as the Diptank male continued to visit regularly with other unmarked Blue Swallows until the Florida chicks fledged on 8/12/2004. As a result of the wing markings on the female Blue Swallows, it was easier to count the number of female birds with careful observation when they foraged in and around the vicinity of the nest.

Table 5.2. The number of female and male Blue Swallows involved in the breeding system on Roselands per active nest site

Nest Site	No. of Males	No. of Females
Diptank	1	2
Florida	1	4
Tafeni	1	3

5.3 Radio-tracking

The height of the tagged bird off the ground affected the strength of the radio signal. Consequently, during the warmer periods of the day, normally between 11H00 and 14H00, the Blue Swallows socialised and gathered in groups which resulted in much stronger tag signals. During this period, the height at which the birds flew was substantially greater than during the active forage sessions, affecting tag signal positively. However, obtaining reliable signals from afar was limited by topography, which is evident with the positional data obtained from the tagged female bird from the Tafeni nest, which frequently disappeared in a southerly direction toward the tea estate where radio tag signal was concomitantly lost (Fig. 5.1). Occasionally, the signal was recovered but not for long enough periods to obtain an accurate positional fix. The loss of signal, due to terrain, is clearly evident in the spatial distribution maps of the Tafeni female who spent considerable time over the tea plantation during the warmer periods of the day. However, it was not possible to obtain any positional data for this area simply due to the nature of the terrain.

5.3.1 Summary of Positional Data

A total of 1001 positional points were gathered from the radio-tracking field work over a continuous 22 day period for the entire study area for three nest sites (Table 5.3). Using a minimum convex polygon for each of the three nests, the overlap between the positional points obtained for the tagged Blue Swallows is obvious (Fig. 5.1).

Table 5.3. Summary of sampling statistics for three adult Blue Swallows at Roselands farm, KZN

Bird ID	Age and Sex	Days Sampled	Total Data Points	View Shed Data Points	Notes
Dip Tank	Ad ♂	5	289	272	Nest collapsed due to excessive rainfall
Florida	Ad ♀	8	309	276	Chicks fledged
Tafeni	Ad ♀	9	403	392	Chicks fledged
		22	**1001**	**940**	

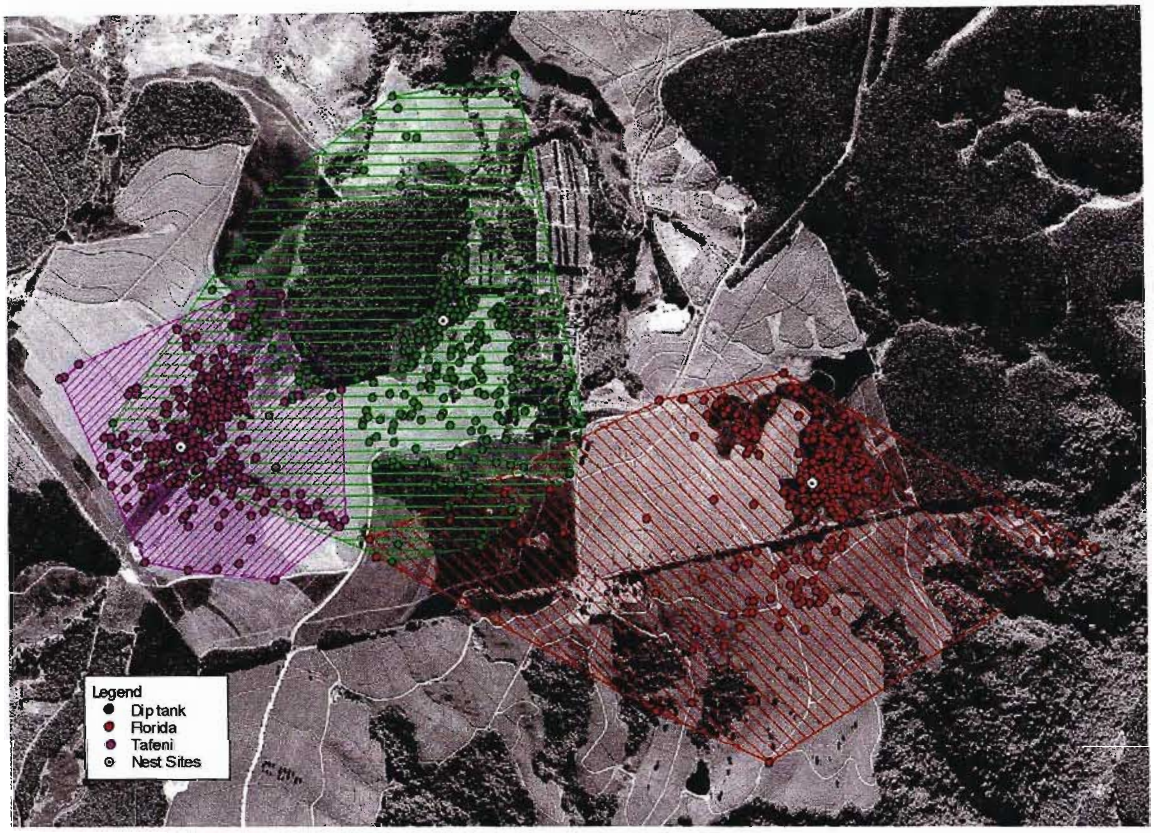

Figure 5.1. Overview of the distribution of all radio telemetry points obtained for three radio-tagged Blue Swallows on the farm Roselands. The shaded areas indicate the minimum convex polygon for each radio-tagged Blue Swallow.

5.3.2 Summary of Positional Data for Each Nest per Land Cover Class

The land cover type for the positional data points was summarised (Table 5.4), and is shown as a percentage of the total composition of land cover they occurred within per nest view shed (Fig. 5.2).

Of the 940 positional data points obtained, grassland habitat was the highest habitat type represented across all three nesting sites with a total of 708 points (75.3%), (Table 5.4). As a land cover, commercial timber plantations were well represented at all three nest sites, but only represented 0.7% of the total recorded point localities for all three nest sites and all were from the Diptank nest site. The habitats classified as arable, orchard and settlement were not represented with any location point data within the view shed areas. The number of positional points per habitat type alone does not indicate habitat preference by the Blue Swallow, because the areas of the different habitats vary in size.

In order to determine the habitat preferences of the Blue Swallow, significance was tested by comparing observed frequencies to the expected frequencies in relation to the ratio of land cover class area within the view shed area (Appendix IV). The calculated Chi-square values were, for Diptank (X^2 = 123.9 df = 5 p < 0.0001), Florida (X^2 = 338.1 df = 6 p < 0.0001), Tafeni (X^2 = 168.3 df = 4 p < 0.0001). When the three view shed areas were combined and the radio-tracking data for the three nest sites were combined per land cover class, the observed versus the expected frequencies were also found to be significant (X^2 = 601.6266 df = 9 p < 0.0001). The individual and combined Chi-square and p values were statistically significant, suggesting that Blue Swallows actively selected their preferred feeding habitat.

Table 5.4. Summary of positional and land cover data for the view shed for Diptank, Florida and Tafeni nest sites indicating % of points per habitat type

Land Cover	Diptank			Florida			Tafeni		
	Area (ha)	Telemetry Points	Points/ habitat (%)	Area (ha)	Telemetry Points	Points/ Habitat (%)	Area (ha)	Telemetry Points	Points/ Habitat (%)
Aliens	26.33	51	18.8%	4.44	1	0.4%	1.66	6	1.5%
Forest	0.47	0	0%	1.73	2	0.7%	0.71	9	2.3%
Grassland	103.78	204	75.0%	33.20	191	69.2%	59.21	313	79.8%
Orchard	4.46	0	0%	0	0	0%	0	0	0.0%
Plantation	30.19	7	2.6%	16.25	0	0%	17.62	0	0.0%
Settlement	1.29	0	0.0%	0	0	0%	0	0	0.0%
Sugarcane	29.98	4	1.5%	39.36	17	6.2%	19.29	40	10.2%
Tea	0	0	0%	7.42	32	11.6%	0	0	0.0%
Water	0.52	0	0%	1.31	0	0%	0.23	4	1.0%
Wetland	0.73	6	2.2%	3.10	33	12.0%	1.19	20	5.1%
	197.74	272	100%	106.81	276	100%	99.91	392	100%

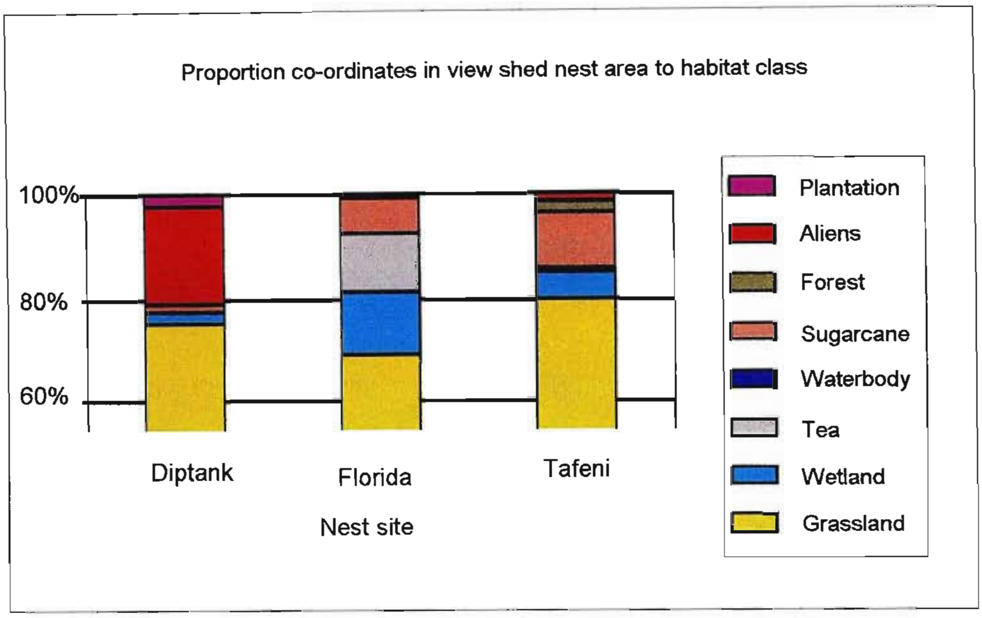

Figure 5.2. Telemetry point localities shown per habitat, shown per nest as a %.

Only brief periods of time were spent by Blue Swallows actively feeding over the sugar-cane, but they frequently flew over the sugar-cane to get from one point to another. It was observed that when the Blue Swallows foraged over sugar-cane, they generally chose to fly just above-ground level down a grassed contour road inside the block of cane as opposed to over the top of the block. Plate 6 shows quite clearly the secondary scrub growth that exists on the margins of the blocks of cane and in particular along the road network. These scrub margins have the potential benefit of increasing insect abundance (Frouz and Paoletti, 2000), which could possibly be the reason the swallows use these areas along the road.

Tea plants stand at approximately 1.2 m high, and are regularly pruned to produce a flush of new tea leaves for harvesting. The pruned portions of tea bush are piled into the areas between the rows of tea where they are left to decompose. During the warmer periods of the day (11H00 to 14H00), the plantation of tea was well used by foraging Blue Swallows where it was chosen preferentially over other habitats. During this time, many bird species that feed on aerial insects could be seen congregating over the tea plantation. Initially it was not obvious from where the insectivorous birds were obtaining suitable prey items because the tea bush itself has an extremely high tannin content that prohibits many insects from feeding upon the plant itself (S. Germishuizen, *pers. comm.*, 2005). The tea plantation is also free of all other plant species and is maintained strictly as a monoculture. It was noted that the insectivorous bird species were feeding very close above the cut tea bushes, but there was no sign of insect use of the tea plant. With the fledging of each nest of Blue Swallows, the adult birds brought the new fledglings onto the tea plantation where the young birds sat perched, while the adults gathered food and fed them (Plate 21).

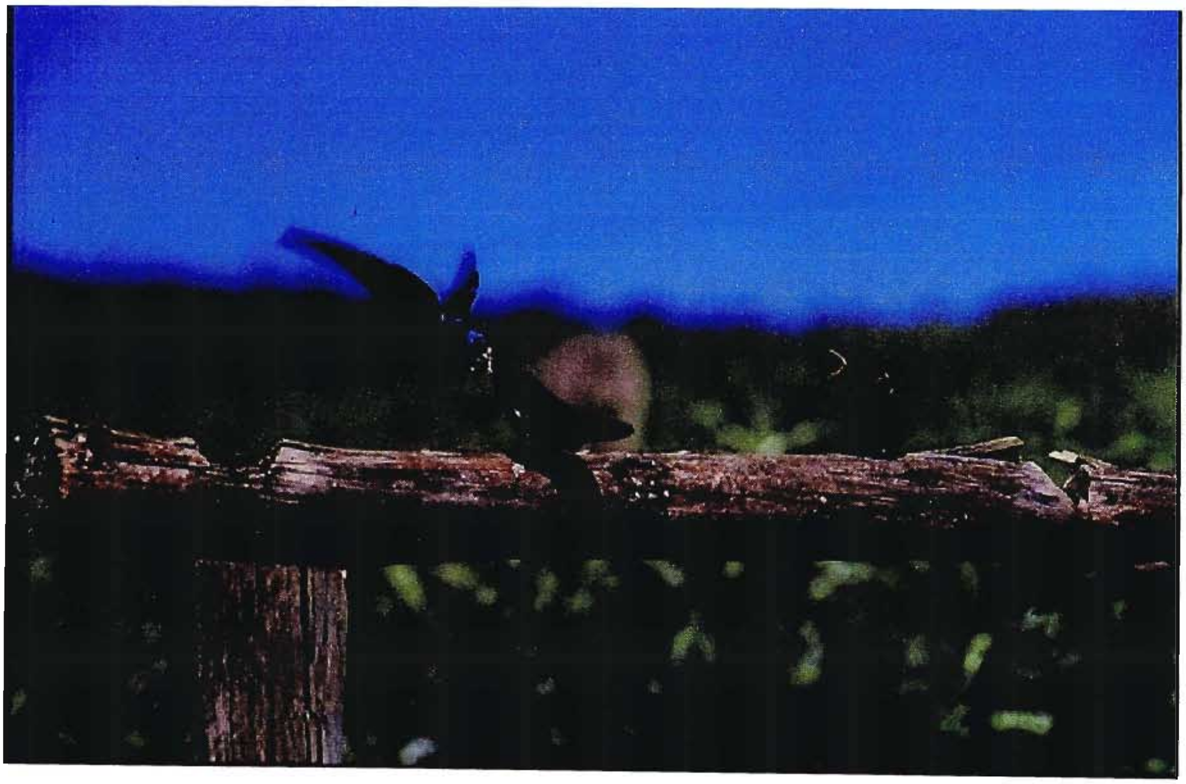

Plate 21. Two newly fledged Blue Swallow chicks being fed by an adult male Blue Swallow in the tea estate; note the long tail streamers.

As a result of this interesting observation a 2 litre soil sample was collected from the inter-rows below the decaying plant matter to ascertain the origin of the winged insects. Using a derivative of a malaise trap (Plate 15), within two days seven winged insects (Diptera), emerged from the soil sample and were trapped. This finding indicated that insect occurrence in the tea plantation was a result of a high humic content in the soil (Plate 22).

Plate 22. High humic content in the soil between the inter-rows of the tea plantation. The insert depicts large inter-row brushpiles.

5.3.3 Spatial Representation of the Study Site and Positional Data

The territory around each nest site is indicated separately (Figs. 5.3 to 5.5). For each nest site, the data are displayed in relation to the background orthophoto from which the land cover information was obtained. Each nest has the potential home range plotted (525 ha) with a radius of 1296 m from each nest site (Section 5.3.4). The maximum potential forage range for breeding Blue Swallows was assumed to be the maximum distance obtained using radio-tracking for a Blue Swallow tied to its active nest site. The recorded distance of 1296 m by the Florida bird was assumed to be the maximum range. As a result, a circular area of 525 ha was calculated as the potential feeding habitat around an active nest site, using 1296 m as the radius. These circular forage areas, comprised of mixed land cover, were termed the 'maximum potential home range'.

The view shed analysis boundary is depicted by a single outline and varies according to each nest site (Section 4.7). The actual positions for the telemetry base stations are indicated for each nest site, as well as the nest site itself. The radio-tracking positional data, for each radio-tagged Blue Swallow, are plotted for the entire home range (Figs. 5.3 to 5.5). The view shed areas for both Diptank and Florida slightly exceeded their calculated home range boundary of 1296 m radius. The small areas created outside the home range by the view shed boundaries were excluded from the habitat area calculations because no radio telemetry points were located within these outlying areas.

5.3.4 Distance of Positional Points from Land Cover Ecotones

It was noted that Blue Swallows appeared to increase their activity along the boundaries between two habitat types, and in particular along the boundaries between grassland and wetland habitats. In order to corroborate this observation, the distances of the points to an ecotone of a habitat were determined for the 940 radio telemetry points (Fig. 5.6). The distances of 940 randomly generated points (Fig. 5.7), were then compared to the distances of the 940 observed points.

It was found that 58% of the total observed locations occurred within 20 m of all habitat boundaries and 69% within 30 m. In contrast to these findings, the randomly generated expected frequencies delivered 31% and 43% respectively. The Chi-Square test produced highly significant findings ($p=0.0001$) between the observed and expected frequencies indicating that Blue Swallows preferentially select ecotones for foraging (Appendix V). Clearly, Blue Swallows preferentially used grassland and wetlands and actively chose the ecotone between the two.

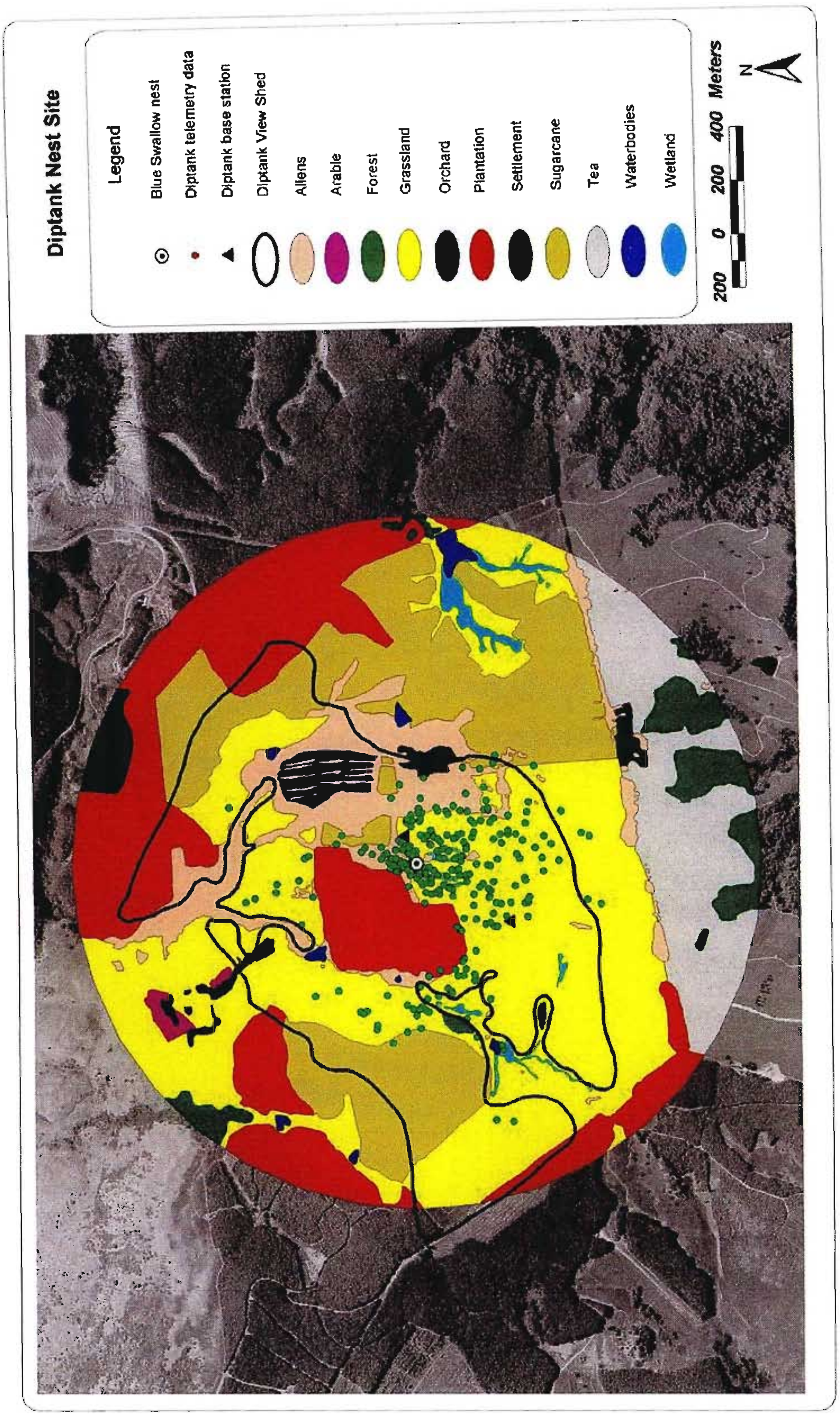

Figure 5.3. Spatial representation of the Diptank nest site indicating home range, view shed area and the complete set of radio telemetry positions.

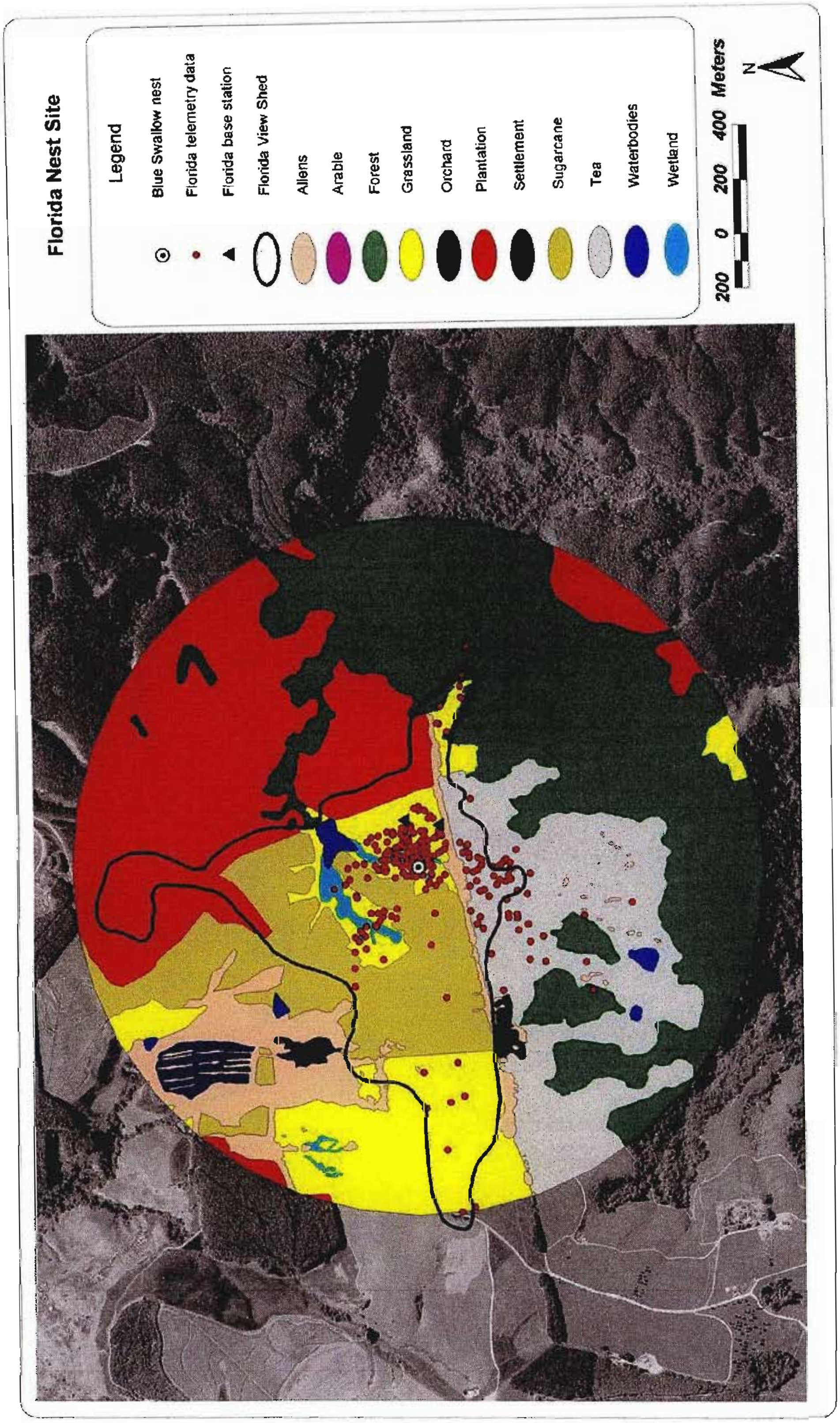

Figure 5.4. Spatial representation of the Florida nest site indicating home range, view shed area and the complete set of radio telemetry positions.

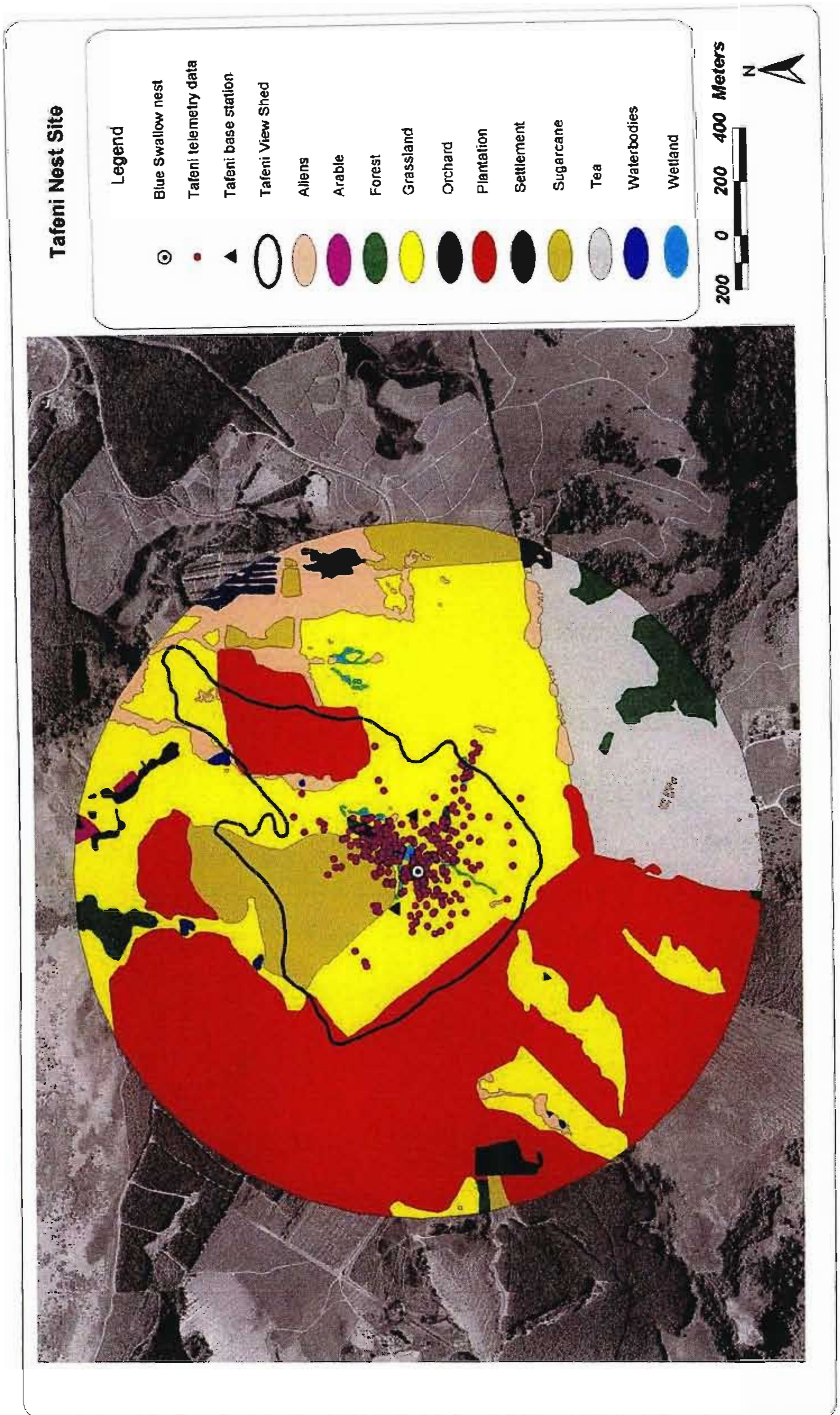

Figure 5.5. Spatial representation of the Tafeni nest site indicating home range, view shed area and the complete set of radio telemetry positions.

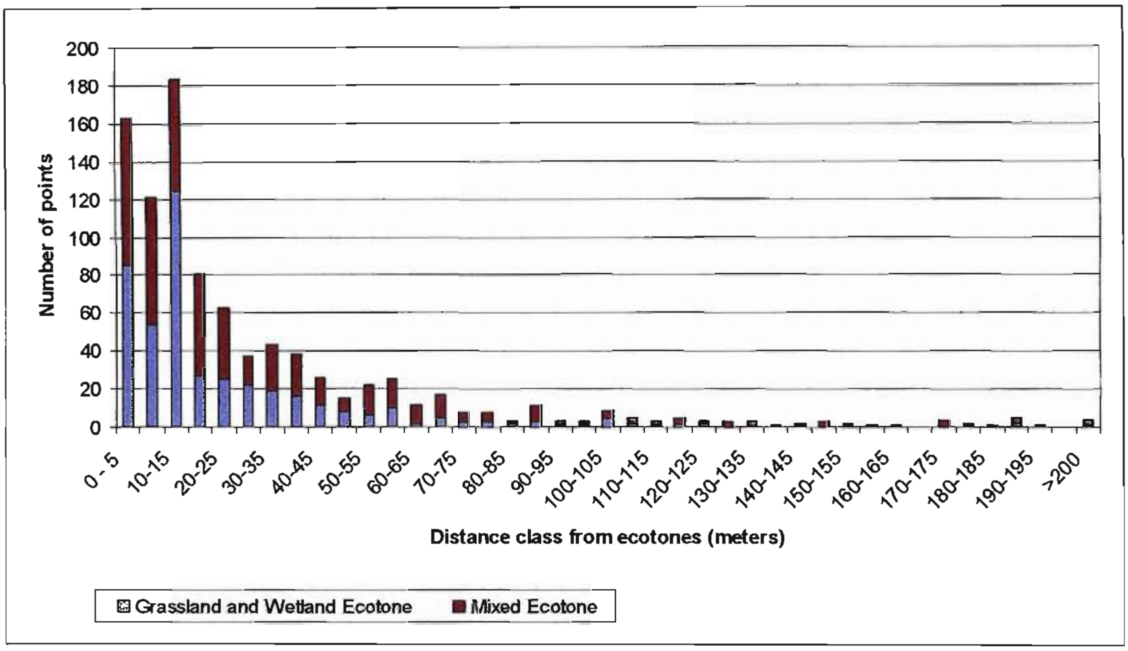

Figure 5.6. Illustration of the distance of the 940 observed locations, obtained from radio-tagged Blue Swallows, from different habitat ecotones at 5 meter interval classes within the viewshed areas for Tafeni, Diptank and Florida nests.

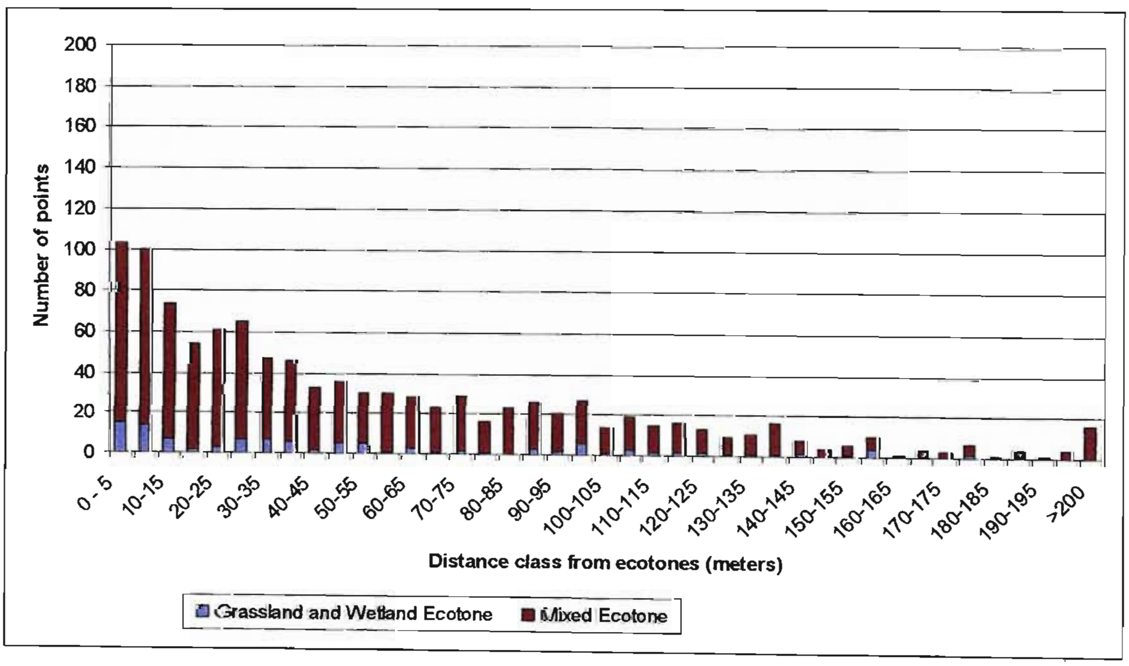

Figure 5.7. Illustration of the distance of the 940 randomly generated point locations, from the different habitat ecotones at 5 meter interval classes within the viewshed areas for Tafeni, Diptank and Florida nests.

5.3.5 Key Distance Findings from Positional Data

The furthest distance recorded of a radio-tagged Blue Swallow, was 1296 m (Table 5.5), which was the adult female Blue Swallow from the Florida nest. Clear overlap existed between the breeding Blue Swallows (Fig 5.1). Owing to wing marking, it was possible to make observations of inter-nest visits by the male from the Diptank nest. These were not limited only to the male of the species because unmarked females were also present in the visiting groups (*pers. obs.*). The furthest recorded telemetry location obtained for Diptank was 1030 m but frequent nest visits were made between the Diptank and Florida nests which are 1167 m apart (Table 5.6). Terrain prevented obtaining regular fixes on these kinds of distances on the radio-tagged birds due to the loss of line of sight where the landform obscured the tag signal. Therefore, the maximum distance (1831 m) between the Roselands nest sites (Table 5.6), provides an indication of the minimum distances (radius) that breeding Blue Swallows are capable of covering from their own nest sites. A radius of 1831 m amounts to an area of 1053 ha adjacent to the active nest site.

Table 5.5. Furthest distance flown by a radio-tagged swallow from its active nest site

Tagged Bird	Age and Sex	Furthest Distance From Nest (m)
Diptank	Adult ♂	1030
Florida	Adult ♀	1296
Tafeni	Adult ♀	524

Table 5.6. Distance in metres between the active Blue Swallow nest sites at Roselands

Nest Site	Distance (m)
Diptank to Florida	1167
Florida to Tafeni	1831
Tafeni to Diptank	842

5.4 Spatial Land Cover Data

5.4.1 Summary of Spatial Composition of the Home Ranges

The following summary tabulates the patch number of the respective habitats for each nest site home range (525 ha) investigated. These data are shown as a percentage in Figure 5.8.

Table 5.7. Summary of the spatial composition of the home ranges for Diptank, Florida and Tafeni nest site areas

Land Cover	Diptank Home Range		Florida Home Range		Tafeni Home Range	
	No. of Patches	Area (ha)	No. of Patches	Area (ha)	No. of Patches	Area (ha)
Aliens	49	46.6	55	33.1	63	26.9
Arable	2	1.8	0	0.0	2	0.8
Forest	8	17.0	6	161.1	7	13.6
Grassland	8	187.1	8	65.5	9	178.9
Orchard	1	4.5	1	4.5	1	2.0
Plantation	5	105.8	4	117.5	4	198.6
Settlement	11	9.9	3	3.2	11	6.7
Sugar cane	5	98.1	4	59.2	6	39.5
Tea	1	46.6	1	74.7	1	55.2
Waterbody	9	2.7	6	2.6	8	1.0
Wetland	11	4.9	7	3.6	8	1.8
	110	525	95	525	120	525

5.4.2 Summary of Spatial Composition of the View Shed Areas

Of the 11 different land covers represented in the home ranges, 10 were represented in the combined view shed areas, with only the arable habitat class not represented. The total area of the combined view shed areas amounted to 404.5 ha (Table. 5.8), and is shown as a percentage in Figure 5.9.

Table 5.8. Summary of the combined view shed area for all three nest sites indicating land cover, area and patch number

Land cover	Combined View Shed Area (ha)	No. of Patches	% Contribution of Land Cover Class
Aliens	32.440	73	8%
Arable	0.000	0	0%
Forest	2.911	7	0.7%
Grassland	196.188	15	48.5%
Orchard	4.456	1	1.1%
Plantation	64.063	9	15.8%
Settlement	1.286	4	0.3%
Sugarcane	88.623	8	21.9%
Tea	7.416	1	1.8%
Waterbody	2.064	8	0.5%
Wetland	5.016	13	1.2%
TOTAL	**404.463**	**139**	**100%**

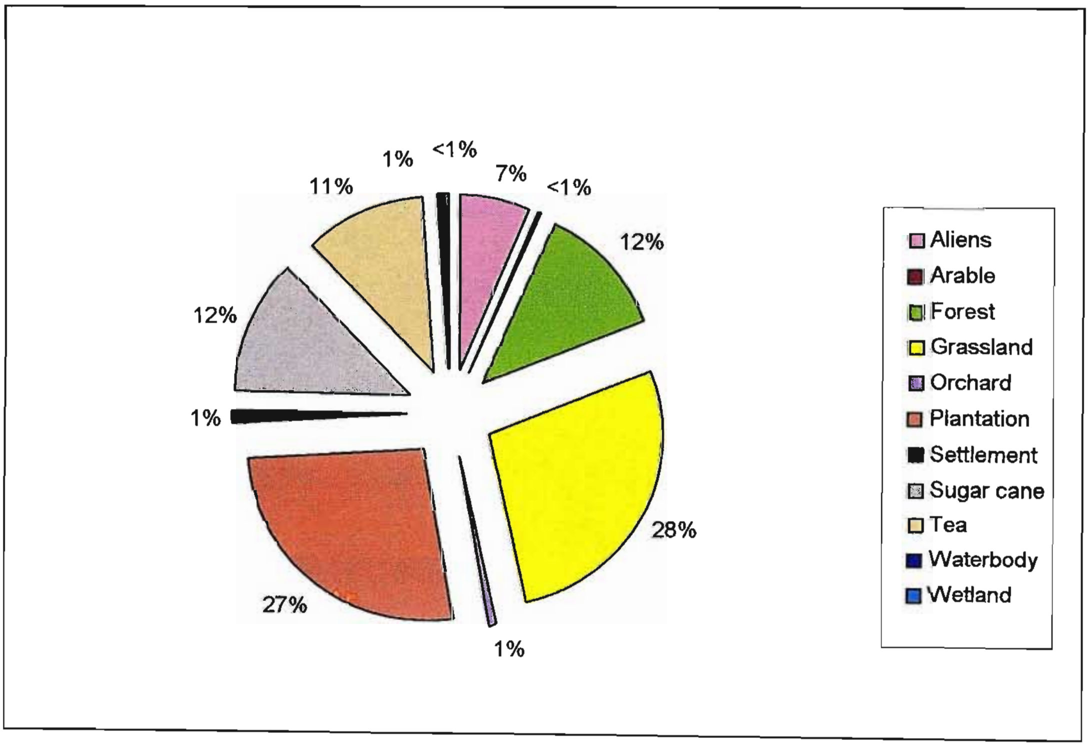

Figure 5.8. Summary of the total land cover (%), for the combined home ranges.

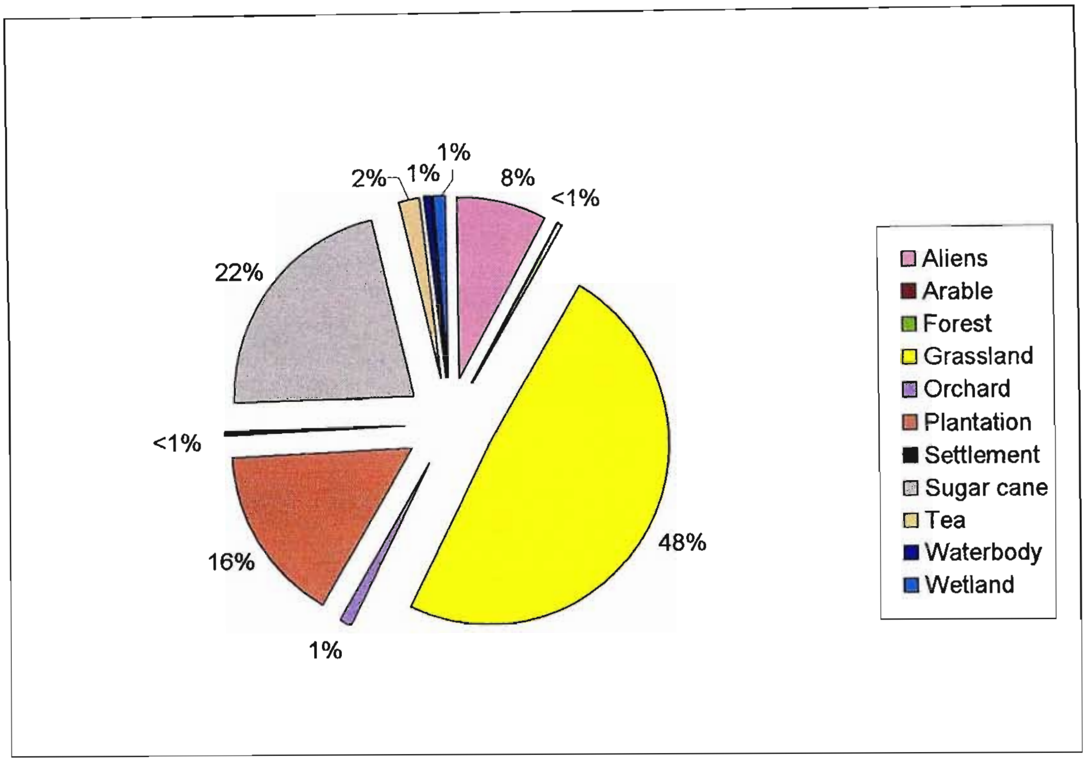

Figure 5.9. Summary of the total land cover (%), for the combined view shed areas.

5.5 Dietary Study Sampling

A list of the insect orders used in this study is tabulated in Appendix VI. The detailed statistical tests for the data are summarised in the following subsections and tabulated in Appendix VII.

5.5.1 Total Mass and Number of Edible and Inedible Insects per Habitat

A detailed analysis was made of the potentially edible insect mass and number per habitat type (Table 5.9), as well as the ratio of potentially inedible insects to potentially edible insects (Section 4.8.4), (Appendix VIII).

Table 5.9. Summary of the comparison between edible and inedible insect numbers and mass (gm) per land cover

Land cover	Edible Mass (gm)	Edible No.	Inedible Mass (gm)	Inedible No.	Inedible Mass Proportion	Inedible Number Proportion
Tea	2.620	1510	3.921	59	59.9%	3.8%
Sugar cane	2.066	1653	2.084	117	50.2%	6.6%
Wetland	5.195	2608	0.868	93	14.3%	3.4%
Grassland	4.838	2126	0.677	173	12.3%	7.5%
Plantation	4.207	4924	5.037	1582	54.5%	24.3%

Assuming that total insect mass is comparable across the different habitats and is directly proportional to insect availability, 'wetland' produced the highest mass of potentially edible insects (5.195 gm). 'Wetland' also showed the lowest ratio of potentially inedible to edible insect number (3.4%), and 'plantation' the highest (24.3%), (Table 5.9). The data from both 'wetland' and 'tea' indicated that inedible insects were few, but comparably large (Table 5.9).

Using the Kruskal-Wallis test, ANOVA by ranks, the variation between the total combined inedible insect mass per habitat was found to be significant ($p = 0.0028$). Using the same set of statistical tests for significance testing of the variation between habitat and total potentially inedible insect numbers this was also found to be highly significant ($p = 0.0001$). These statistically significant findings indicate that the different habitats investigated support potentially inedible insects in varying mass and numbers.

The relation between potentially edible and inedible insect numbers shows 'plantation' with the highest mean and variation compared with the remaining habitats, which themselves were comparable with similar means at the lower end of the scale ($p = 0.0001$), (Fig. 5.10). It is evident that 'plantation' also holds the greatest inedible insect mass and variation, 'tea' and 'sugar' second and third respectively (p =0.0458), (Fig. 5.11). 'Grassland' and 'wetland' feature at the lower end of the scale with comparable means and variation, indicating that the mass of inedible insects in the transformed habitats is greater than that found in untransformed habitats. 'Tea', with the lowest number of inedible insects and the second highest inedible insect mass, indicates that the average size of inedible insects was comparably larger than in other habitats investigated (Table 5.9).

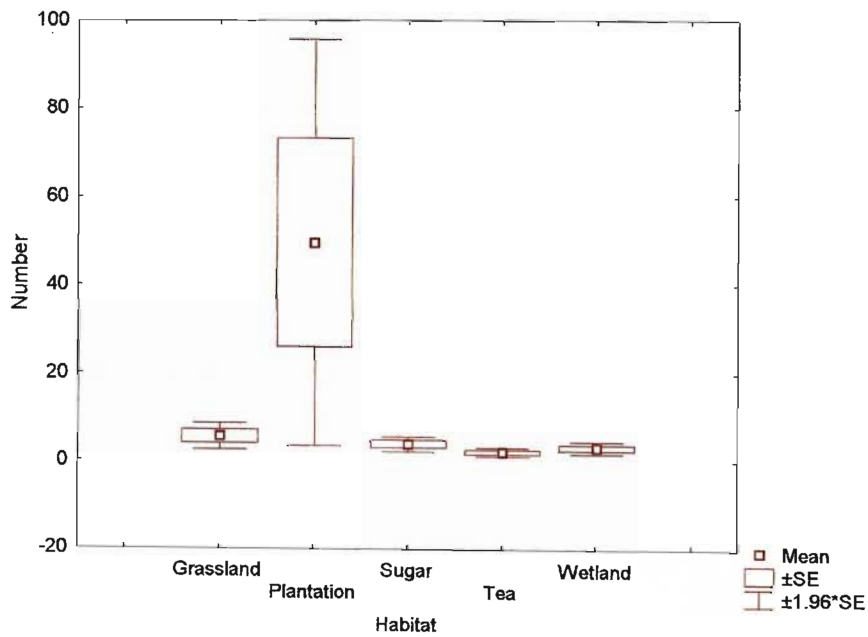

Figure 5.10. Variation in the numbers of potentially inedible insects caught in the Malaise traps in five different habitats.

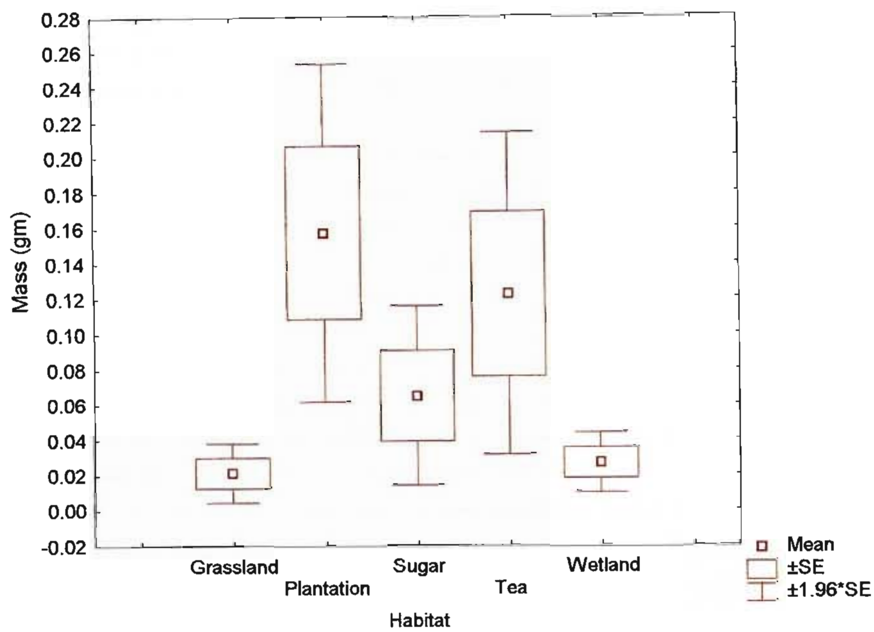

Figure 5.11. Variation in the mass of potentially inedible insect mass caught in the Malaise traps in five different habitats.

High insect numbers and lower mass in 'plantation' indicate lower mean insect mass, while low insect numbers in 'wetland' and 'grassland' with high mass indicates larger insects (Table 5.9). Using the Kruskal-Wallis ANOVA test by ranks, the variation in the number of edible insects between the different habitat types was highly significant (p = 0.0001), (Fig. 5.12). Similarly, the mass of edible insects was also highly variable between land cover types (p = 0.0001), (Fig. 5.13). Overall average potential edible insect mass per insect order per habitat (Table 5.12) shows a different pattern where average edible insect mass was the highest in 'grassland' followed by 'tea', with the greatest variability, and then 'wetland', with 'sugar' and 'plantation' represented much lower down the scale. (p = 0.0001), (Fig. 5.14).

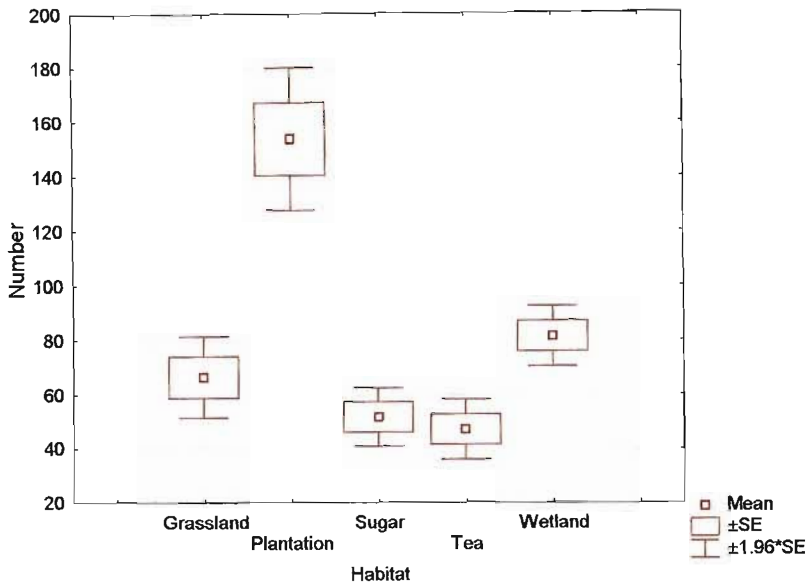

Figure 5.12. Variation in the numbers of potentially edible insects caught in the Malaise traps in five different habitats.

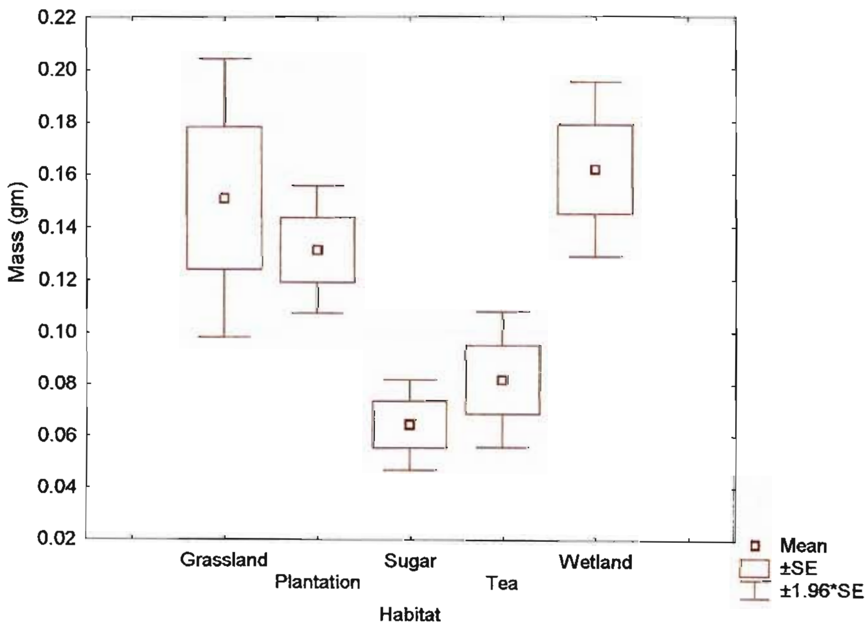

Figure 5.13. Variation in the mass of potentially edible insects caught in the Malaise traps in five different habitats.

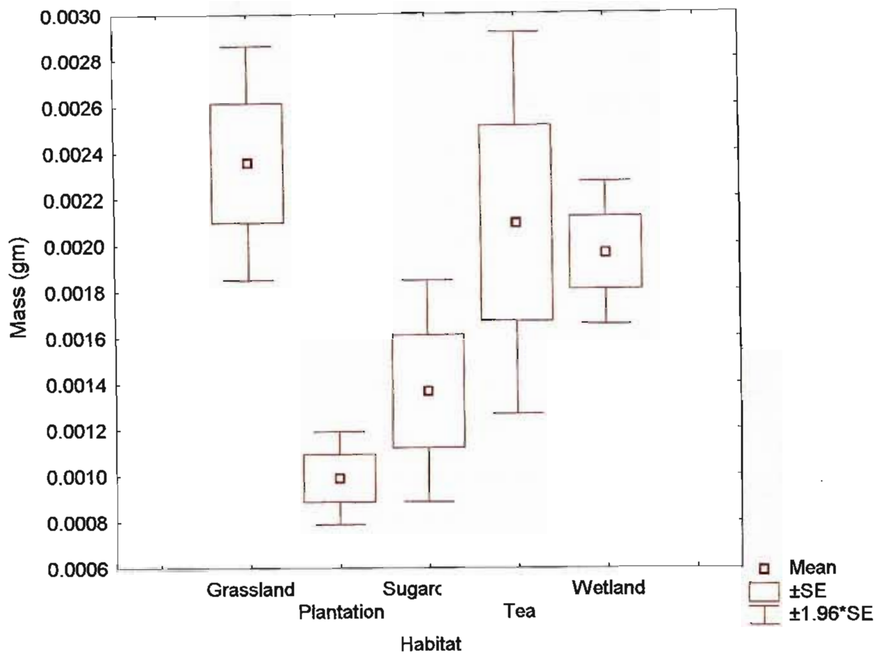

Figure 5.14. Variation in the average mass of potentially edible insects caught in the Malaise traps in five different habitats.

5.5.2 Total Mass and Number of Edible and Inedible Insects per orders

The overall mass of the potentially inedible insect orders was dominated by the Coleoptera (beetles) at nearly 6.4 times greater than the next closest insect order, the Lepidoptera (butterflies and moths). Coleoptera made up 69% of the mass of inedible insects category. However, in terms of the numbers of inedible insects, the insect order Collembola (springtails) was by far the highest taxa represented with 1635, yet these flightless insects made up only 1.3% of the total inedible insect mass (Table 5.10).

The majority of the edible insects trapped represented the insect *order* Diptera (true flies). The mass was four and a half times more than the next insect order (Coleoptera), and exceeded the combined total of Coleoptera, Hymenoptera (ants, bees and wasps) and Isoptera (termites). The mass and numbers of Isoptera was fourth and fifth highest in the insect orders represented. Isoptera totalled 30.6% of the total mass of the edible insects trapped within the grassland habitat (Table 5.12).

Table 5.10. Summary of the potentially inedible insect numbers and mass (gm) per insect order

Potentially Inedible	Mass (gm)	No.	% Total Mass
Diptera	0.304	1	2.6
Hemiptera	0.000	0	0.0
Ephemeroptera	0.000	0	0.0
Isoptera	0.000	0	0.0
Embiidina	0.004	16	0.0
Coleoptera	8.143	29	69.0
Lepidoptera	1.282	16	10.9
Trichoptera	0.000	0	0.0
Hymenoptera	0.643	257	5.4
Araneae	0.124	37	1.0
Orthoptera	1.156	20	9.8
Collembola	0.154	1635	1.3

Table 5.11. Summary of the potential edible insect numbers and mass (gm) per insect order

Potentially Edible	Mass (gm)	No.	% Total Mass
Diptera	10.781	9521	57.0
Hemiptera	1.772	2048	9.4
Ephemeroptera	0.040	5	0.2
Isoptera	1.539	204	8.1
Mecoptera	0.056	6	0.3
Coleoptera	2.434	468	12.9
Lepidoptera	0.489	152	2.6
Trichoptera	0.052	21	0.3
Hymenoptera	1.758	393	9.3
Plecoptera	0.005	3	0.0

Table 5.12. Average mass (gm) of edible individual insects per order for each habitat

Habitat	Diptera	Hemiptera	Isoptera	Coleoptera	Hymenoptera
Tea	0.0016	0.0008	0.0080	0.0071	0.0019
Sugarcane	0.0012	0.0007	0	0.0029	0.0040
Wetland	0.0016	0.0017	0.0054	0.0065	0.0070
Grassland	0.0019	0.0007	0.0076	0.0023	0.0036
Plantation	0.0005	0.0005	0	0.0058	0.0051

The difference in variation between the potentially edible insect numbers, from the order Coleoptera and the different habitats, was highly significant ($p=0.0001$), (Fig. 5.15). The same relation was exhibited for edible Coleoptera mass per habitat ($p = 0.0001$), (Fig. 5.16).

Of the potentially edible Coleoptera, it is clear that 'plantation' showed the highest insect numbers and mass, followed by 'wetland' in both numbers and mass. 'Grassland' had the next highest Coleoptera numbers but displayed the second lowest insect mass. 'Sugar-cane' featured with both the lowest number and mass of beetles (Fig. 5.15 and Fig. 5.16).

A significant difference in variation exists ($p = 0.0003$), between the average potentially edible insect mass (mg) from the order Coleoptera and the different habitats (Fig. 5.17), and demonstrates that 'wetlands' produced the highest mean mass and with the greatest variation.

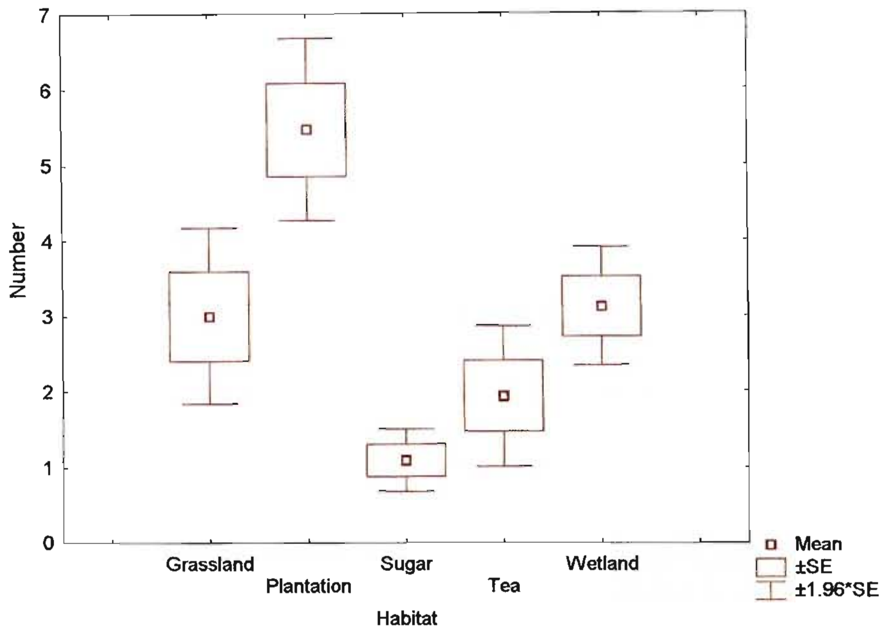

Figure 5.15. Variation in the numbers of potentially edible Coleoptera (beetles), caught in the Malaise traps in five different habitats.

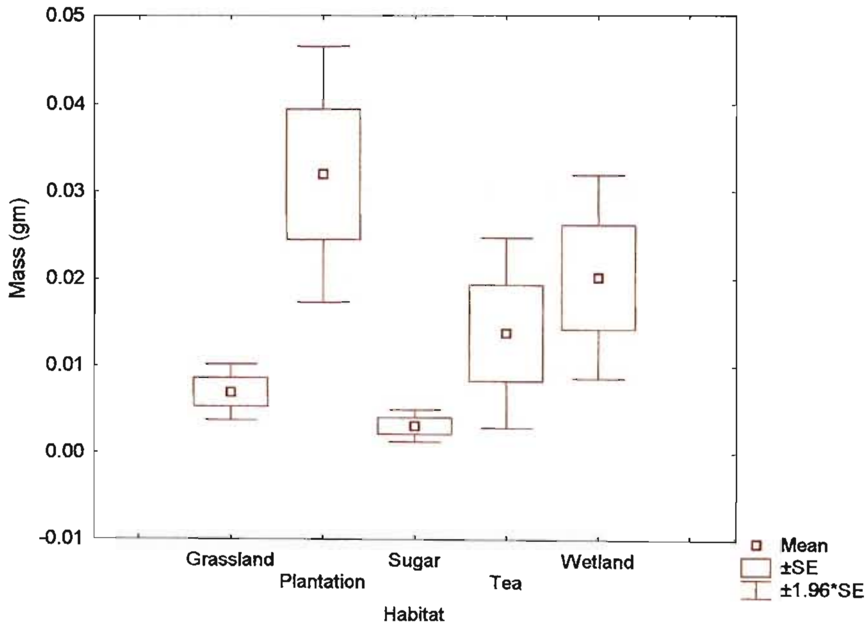

Figure 5.16. Variation in the mass of potentially edible Coleoptera (beetles), caught in the Malaise traps in five different habitats.

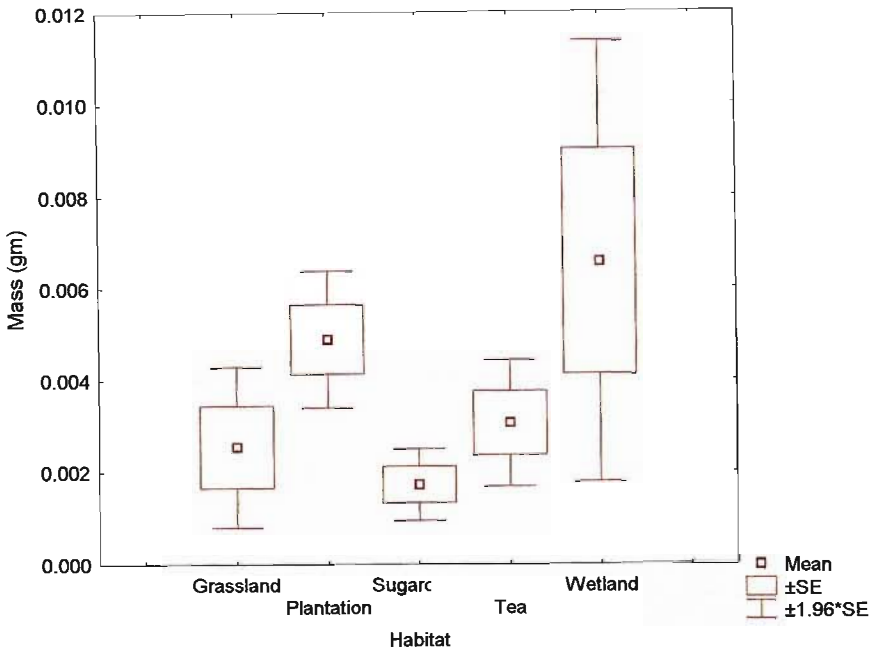

Figure 5.17. Variation in the average mass of potentially edible Coleoptera (beetles), caught in the Malaise traps in five different habitats.

With the highest mass and number of edible insects (Table 5.11), the insect order Diptera (true flies), demonstrated a highly significant variation between the different habitats and edible insect numbers (p = 0.0001), (Fig. 5.18). Similarly, Diptera mass showed a highly significant variation between the different habitats (p = 0.0001), (Fig. 5.19). 'Plantation' showed the highest edible Diptera number and the third lowest mass after both 'grassland' and 'wetland', indicating a significant difference in average insect mass, with 'plantation' having the smallest average Diptera mass. 'Grassland' and 'tea' showed proportionally larger average Diptera mass than the remaining three habitat types, with 'plantation' at the lowest end of the scale (p = 0.0001), (Fig. 5.20, Table 5.12).

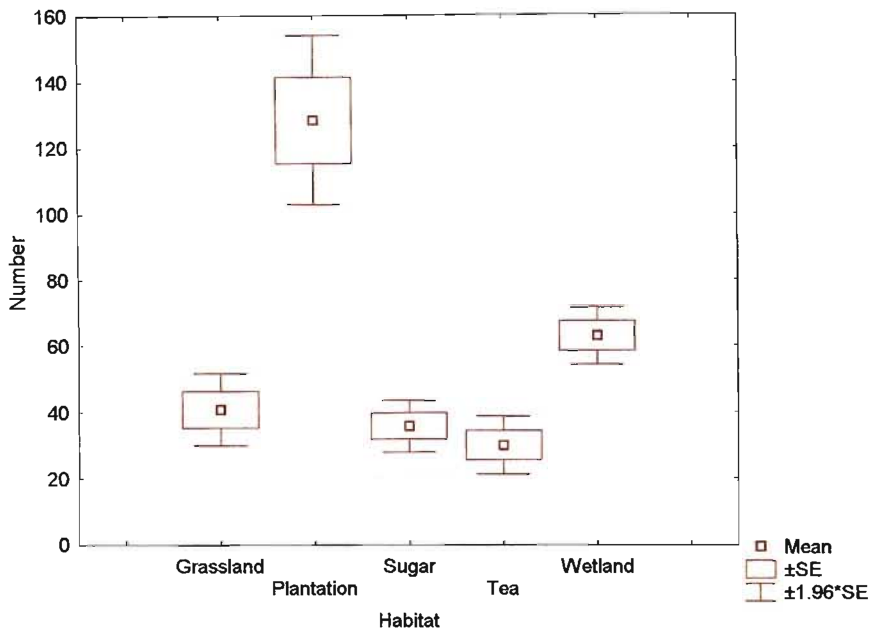

Figure 5.18. Variation in the numbers of potentially edible Diptera (true flies), caught in the Malaise traps in five different habitats.

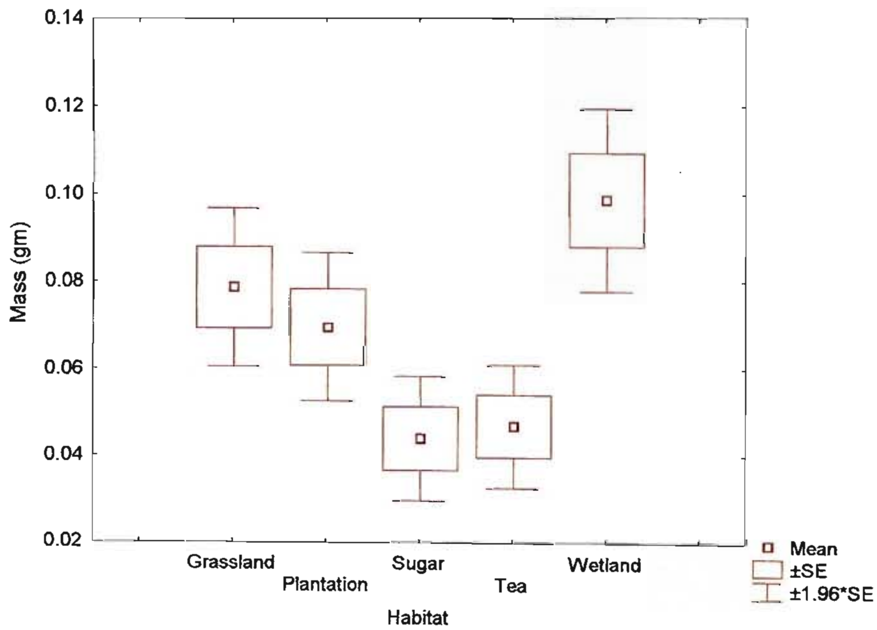

Figure 5.19. Variation in the mass of potentially edible Diptera (true flies), caught in the Malaise traps in five different habitats.

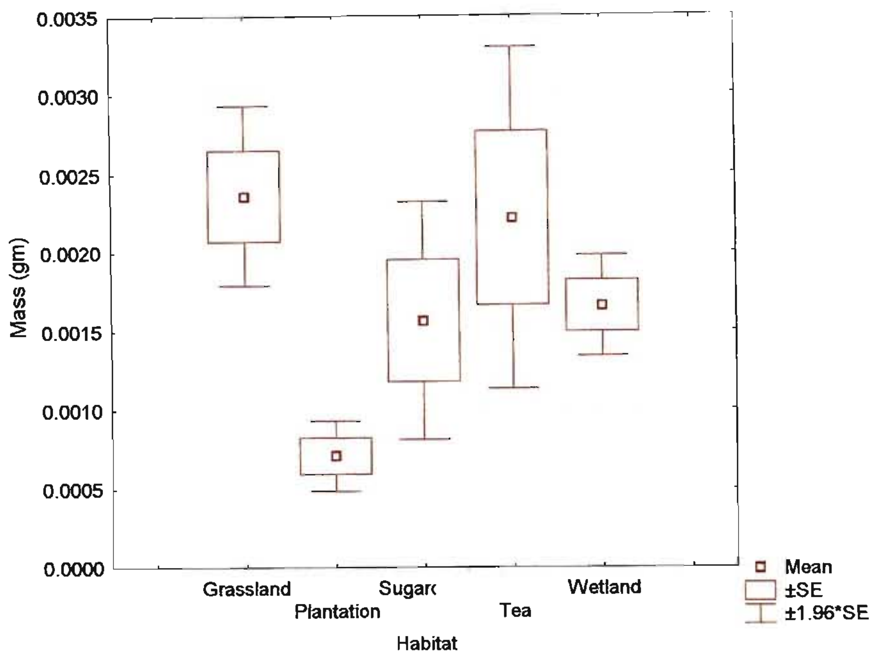

Figure 5.20. Variation in the average mass of potentially edible Diptera (true flies), caught in the Malaise traps in five different habitats.

In the Hemiptera (bugs), 'plantation' showed the highest mean represented by numbers. 'Wetland' was most noticeable as second lowest just greater than 'tea', but with the lowest standard error and mean (p = 0.0051), (Fig. 5.21). When compared to potentially edible Hemiptera mass, 'plantation' depicted the lowest variation and mean. 'Wetland' was most noticeable by displaying the highest mass, clearly exceeding the other four habitats (p = 0.0360), (Fig. 5.22). 'Grassland' featured with the second highest edible Hemiptera numbers, behind 'plantation', but only just showing a higher mass that the three transformed habitats. Average Hemiptera mass (Fig. 5.23) indicates that 'wetland' with the highest average insect mass is well clear of the standard error of the next highest class that of 'tea'. 'Tea' featured as the habitat class with the lowest mass, but in terms of average insect size, 'tea' contains the second largest class.

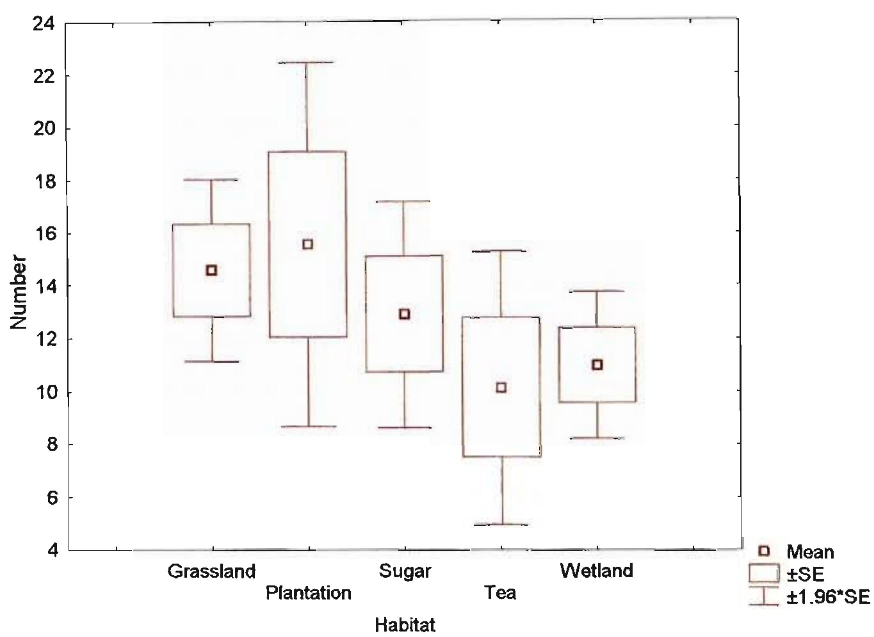

Figure 5.21. Variation in the number of potentially edible Hemiptera (bugs) caught in the Malaise traps in five different habitats.

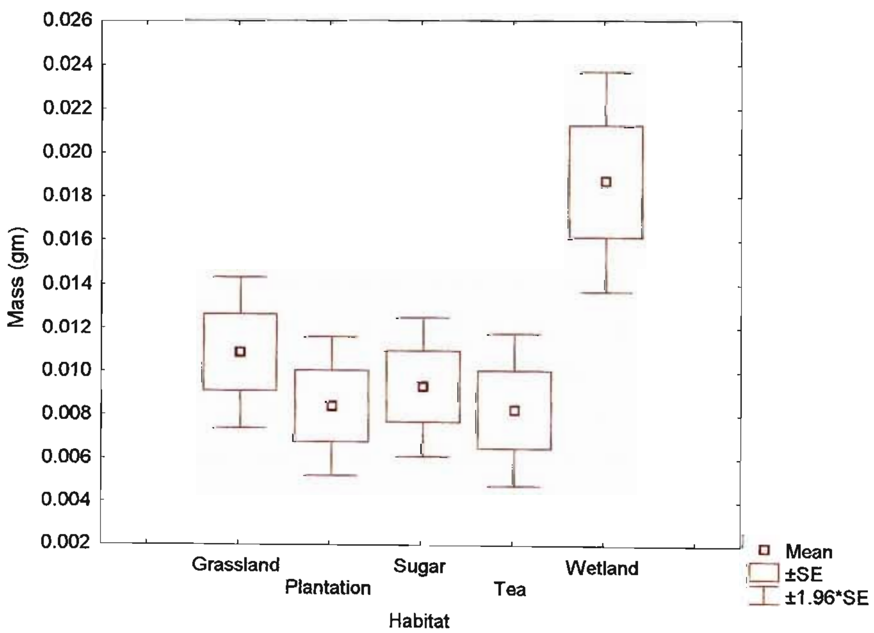

Figure 5.22. Variation in the mass of potentially edible Hemiptera (bugs), caught in the Malaise traps in five different habitats.

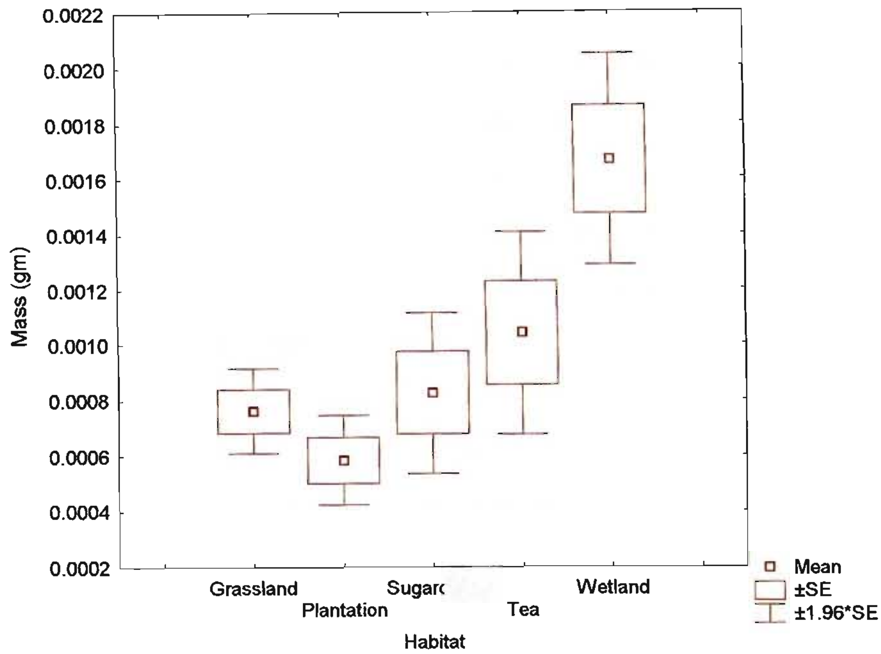

Figure 5.23. Variation in the average mass of potentially edible Hemiptera (bugs), caught in the Malaise traps in five different habitats.

Edible Hymenoptera (bees and wasps) were well represented within the five habitat types. 'Plantation' produced the highest number with means comparable in 'wetland' and 'tea' ($p = 0.0732$), (Fig. 5.24). Variation in mass between the different habitats was significant ($p = 0.0191$), where 'wetland' showed the greatest overall mass and variation. 'Tea' showed comparably a similar variation in edible Hymenoptera numbers to 'wetland'. However, proportionally 'tea' produced the smallest average Hymenoptera edible insect mass (Fig. 5.25). The average edible Hymenoptera insect mass per habitat did not vary in trend from actual mass (Fig. 5.26), nor were the differences in variation significant ($p = 0.1154$).

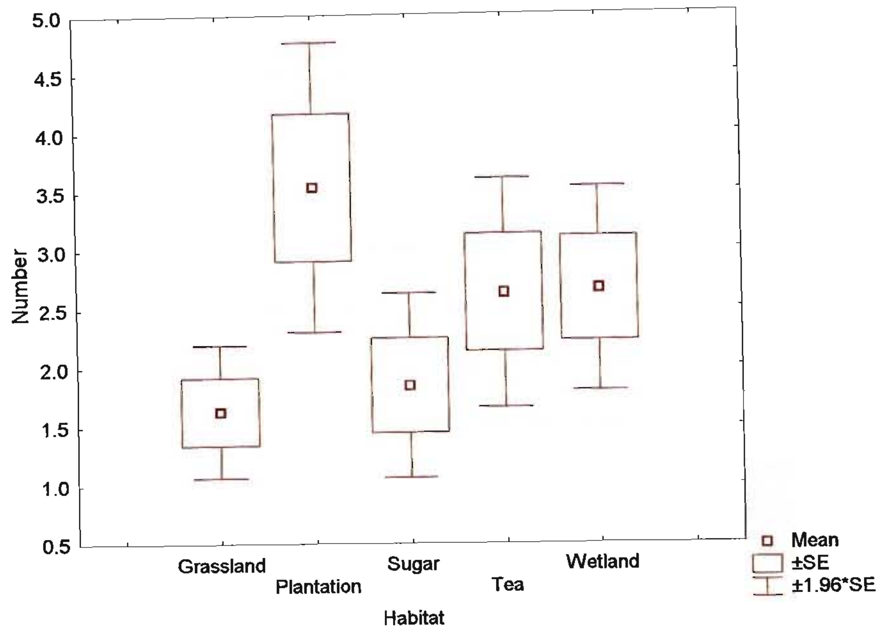

Figure 5.24. Variation in the number of potentially edible Hymenoptera (bees and wasps), caught in the Malaise traps in five different habitats.

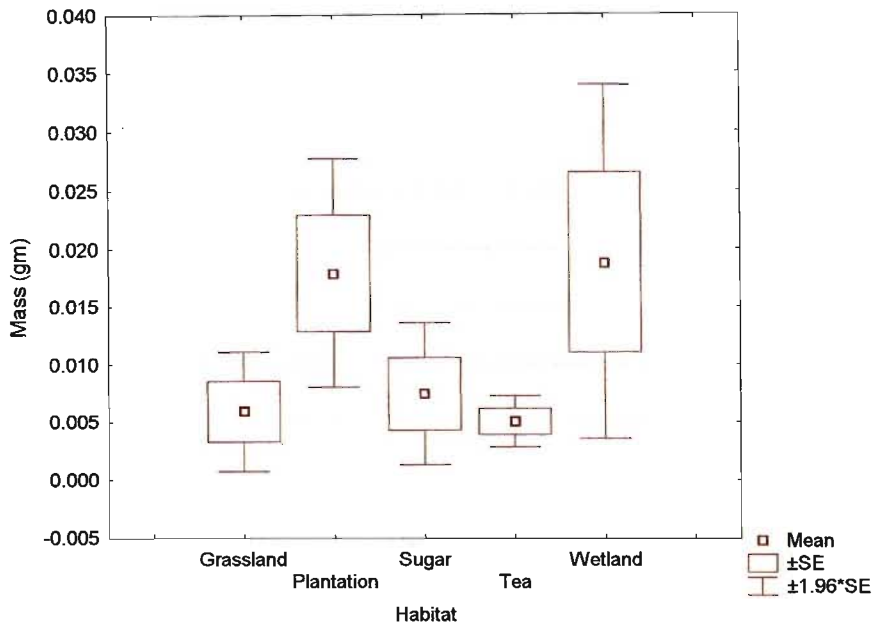

Figure 5.25. Variation in the mass of potentially edible Hymenoptera (bees and wasps), caught in the Malaise traps in five different habitats.

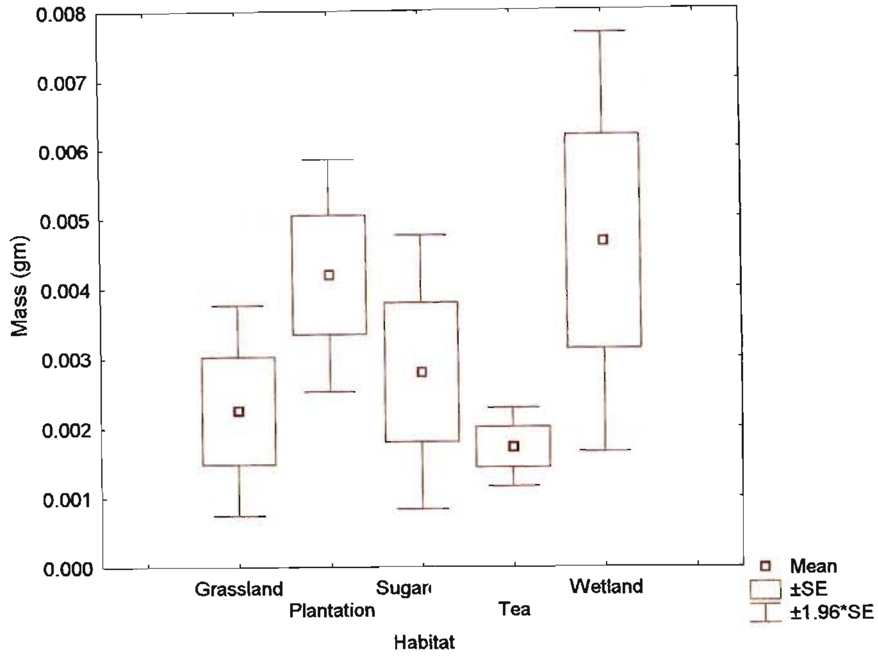

Figure 5.26. Variation in the average mass of potentially edible Hymenoptera (bees and wasps), caught in the Malaise traps in five different habitats.

Isoptera (termites) featured as the insect class with the lowest overall mass out of the five insect orders investigated, contributing only 8.1% to the total combined edible insect mass collected for the duration of the study (Table 5.11). Isoptera were represented in numbers only in three habitats (grassland, wetland and tea) but were particularly well represented in only one habitat class, namely 'grassland' where the variation was significant, (p = 0.0001), (Fig. 5.27). Within 'grassland', Isoptera represented 30.6% of the total mass of edible insects trapped and collected and the difference in variation of Isoptera between habitats was highly significant (p = 0.0001), (Fig. 5.28). The difference in variation between the average Isoptera mass and the different habitats was not significant, nor were any new trends evident (p = 0.0732), (Fig. 5.29).

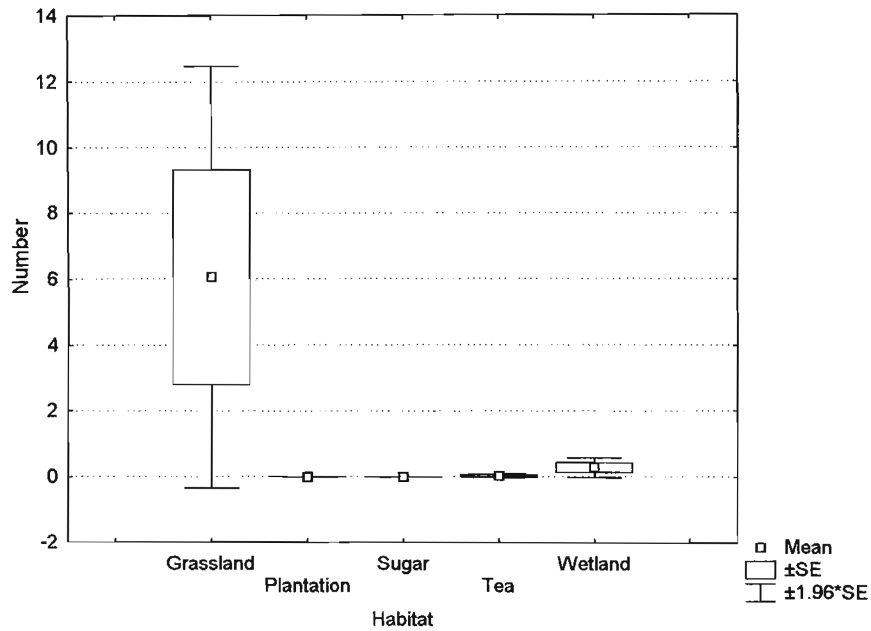

Figure 5.27. Variation in the number of potentially edible Isoptera (termites), caught in the Malaise traps in five different habitats.

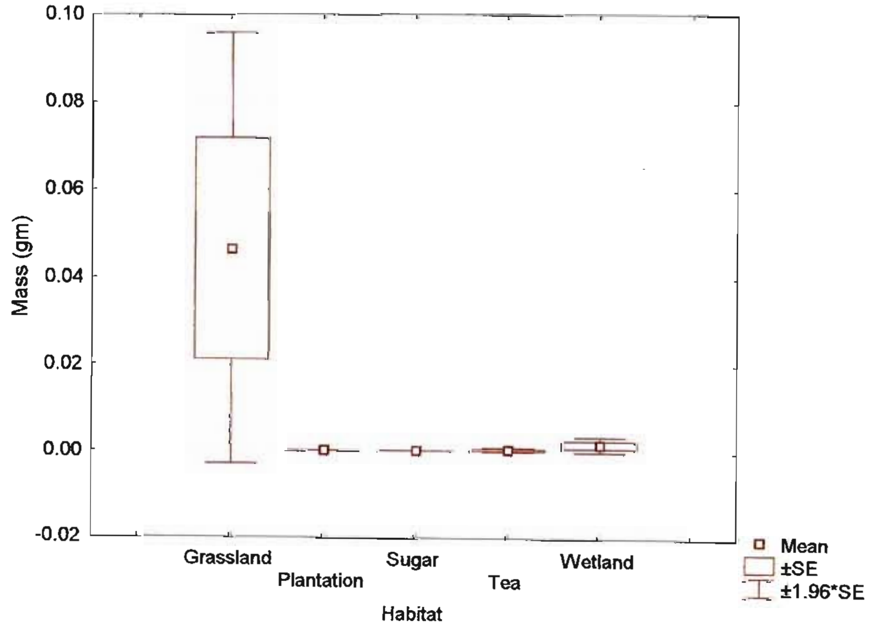

Figure 5.28. Variation in the mass of potentially edible Isoptera (termites), caught in the Malaise traps in five different habitats.

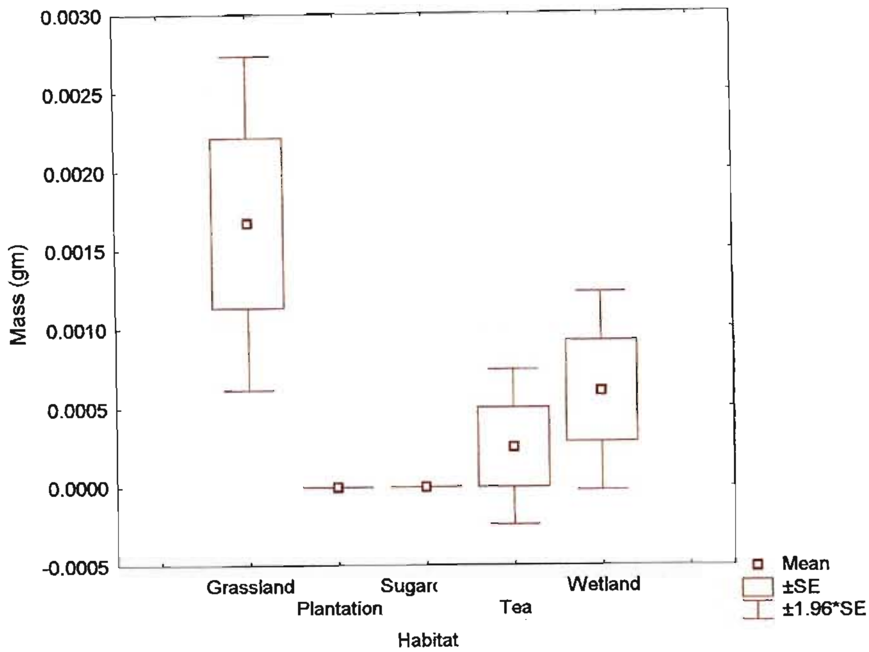

Figure 5.29. Variation in the average mass of potentially edible Isoptera (termites), caught in the Malaise traps in five different habitats.

5.5.3 Formal Inference-based Recursive Modelling

Formal Inference-based Recursive Modelling was performed as an alternative to multiple regression or multiway analysis of variation (Hawkins, 2005), (Appendix IX).

It was shown that habitat was best characterised by Diptera numbers. The model grouped and separated three classes of Diptera insect numbers; less than 63 (n=103), between 63 and 110 (n=34) and greater than 110 (n=23). These group numbers and categories indicate the trends and groupings within the insect order Diptera that was sampled. However, due to limited sample sizes and because of the concern about pseudo-replication (R. Emslie, *pers. comm.*, 2005), the formal inference-based recursive modelling process was considered to be heuristic and the results of this model were not regarded as positive and the statistical model was abandoned.

5.6 Environmental Factors at the Nest Site

Temperature and humidity levels differ greatly at a Blue Swallow nesting cavity, when above and below-ground variables are compared. These findings show that the underground cavity has a moderating effect on the environmental variables, which would support the theories of Hardy (1979) and Powell and Logan (2005) who state that a moderated environment is necessary for the survival of certain species.

5.6.1 Temperature (˚C)

The most obvious trend regarding the above and below-ground temperature data-sets is the cyclic nature of the daily data ranges (Fig. 5.30). This rise and fall of the temperature graph coincides with the heating from the sun. Weather conditions were observed and recorded on a regular basis throughout the day for the duration of the study period. Cold frontal systems have been indicated on the figure and are clearly discernable during the periods 27/11/2005 to 28/11/2005; 30/11/2005 to 1/12/2005 and 8/12/2005 to 10/12/2005.

A comparison of the full ranges of both the below (14.5 to 23.6 ˚C) and above (8.6 to 38.3 ˚C) ground temperatures, indicates that below-ground temperature is heavily moderated by the nesting cavity (Fig. 5.30). On average, below-ground temperatures were 2.3 ˚C cooler than the above-ground temperatures. Below-ground temperatures were also more constant, being 7.6 ˚C cooler at the maximum, and 5.9 ˚C warmer at the minimum end of the temperature scale. This result is not unexpected as a moderated temperature range is required for bird nestlings (Primault, 1979), particularly in a variable climatic zone like that in the Mistbelt Grasslands.

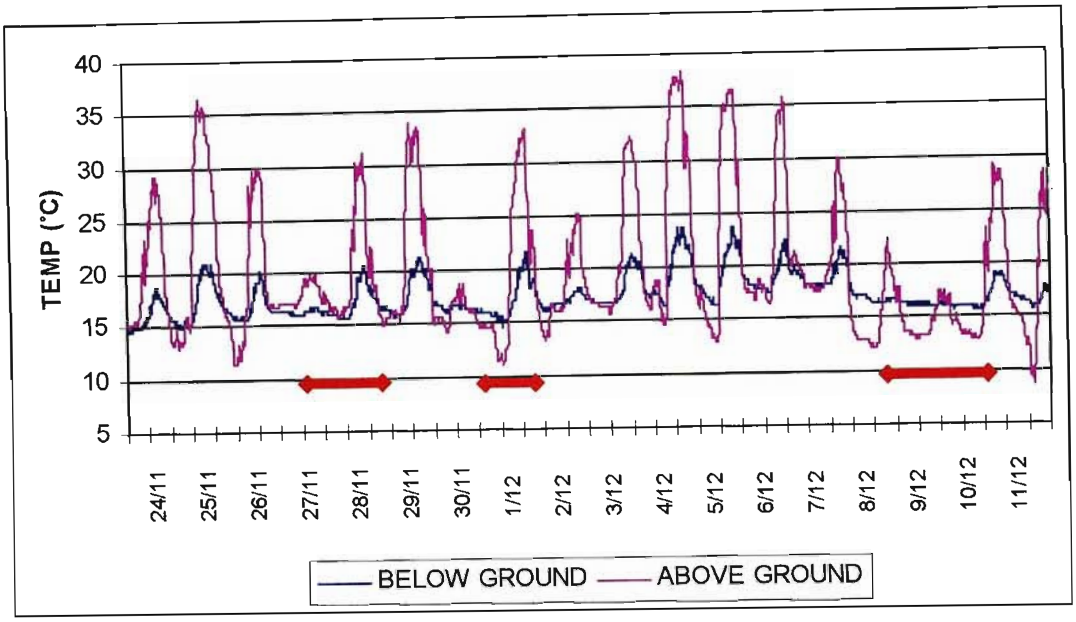

Figure 5.30. A comparison between below-ground and above-ground temperature (°C) showing that conditions were moderated and were less variable below-ground next to the nest. The red arrows indicate the dates and duration of the cold, wet, inclement weather.

5.6.2 Absolute Humidity (gm/m³)

Absolute humidity was not moderated at both ends of the humidity scale as was the case for temperature. There was an increase in below-ground absolute humidity in comparison to that above-ground (Fig. 5.31).

The highest absolute humidity was recorded below-ground at 19.9 gm/m³ as compared to an above-ground reading of 24.3 gm/m³. At the lower end of the scale, minimum values below-ground attained 12.2 gm/m³ while those above-ground went as low as 8.4 gm/m³. In general, the average absolute humidity above-ground (13.9 gm/m³), was marginally lower than the humidity underground (14.8 gm/m³), (Fig. 5.31). The three cold frontal systems have been indicated and are clearly noticeable, in particular the third which showed very low humidity levels. Personal field observation notes made during this period indicate that the frontal system caused heavily overcast but dry conditions.

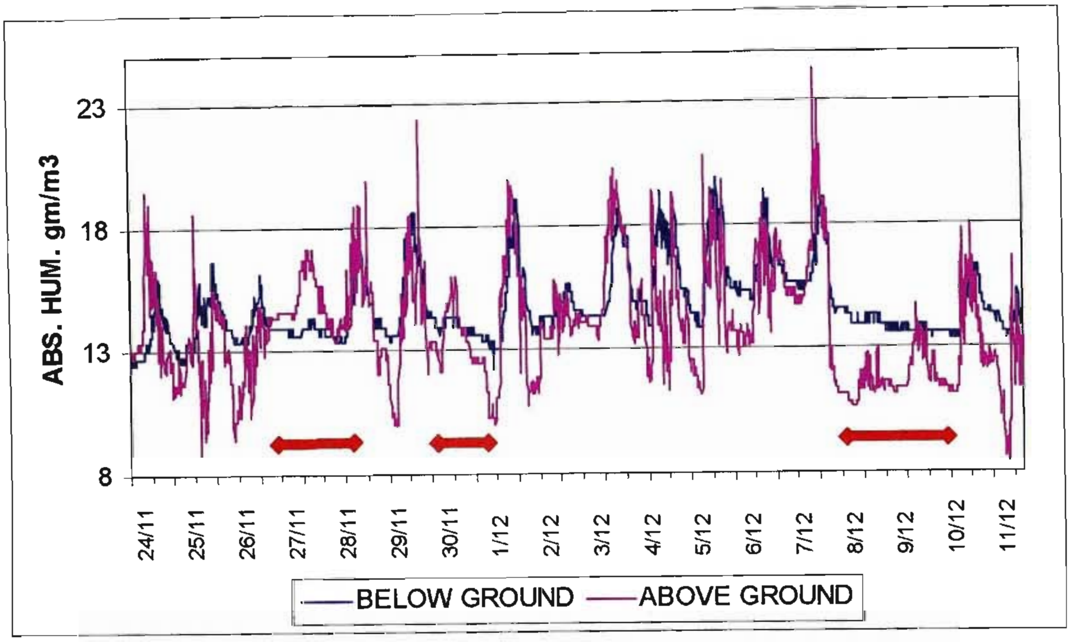

Figure 5.31. A comparison between below-ground and above-ground absolute humidity (gm/m³), indicating that below-ground conditions were more humid. The red arrows indicate the dates and duration of cold, wet, inclement weather.

5.6.3 Relative Humidity (%)

These data-sets confirm the results obtained using absolute humidity as a measure. Below-ground moisture levels were higher than the above-ground levels. Below-ground the lowest relative humidity reading was 77.2%, as opposed to the above-ground relative humidity reading of 24.4% (Fig. 5.32). Over the 17.5 day sampling period, the relative humidity, measured below-ground, dropped to less than 100% on only 8 occasions, while the relative humidity readings above-ground dropped below 100% every single sampling day (n=17). The relative humidity readings below-ground only dropped below 100% in very dry conditions when above-ground humidity dropped to as low as 49.9% (10/12/2004). The average value of the relative humidity readings taken from below-ground were 99.1%. Those taken from the above-ground HOBO® sensor averaged 84.7%, indicating a 14.4% difference. During the period of the first two cold fronts (27/11/2005 to 28/11/2005 and 30/11/2005 to 1/12/2005), the relative humidity increased with the rain and heavy mist that was recorded. However during the period 8/12/2005 to 10/12/2005, the frontal system brought no rain and the weather remained dry and cool. These observations are clearly corroborated by the readings obtained from above-ground (Fig. 5.32).

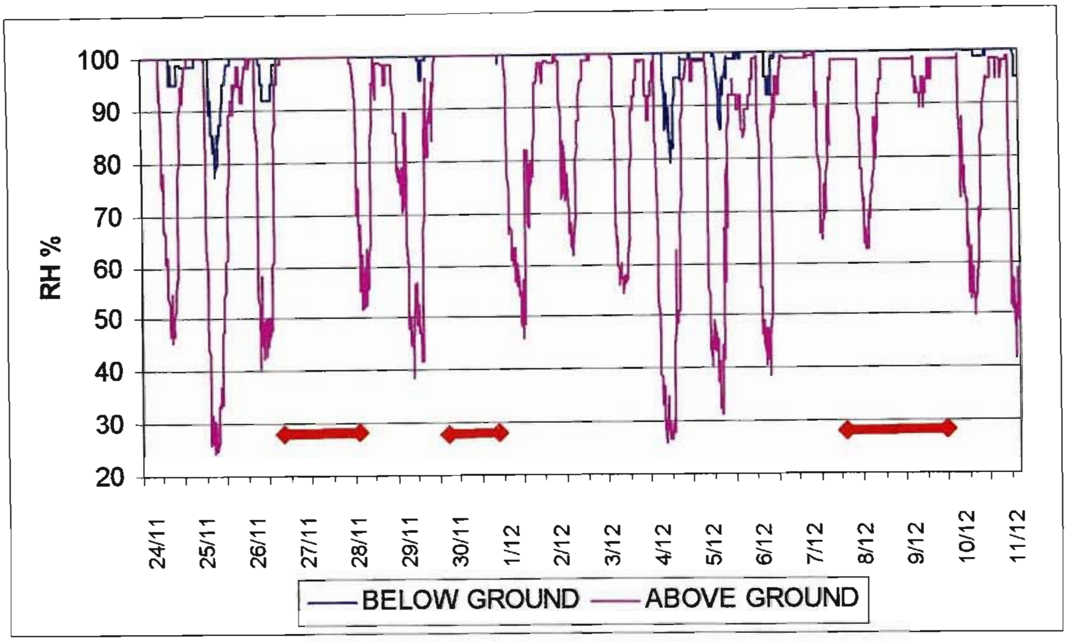

Figure 5.32. A comparison between the below-ground and above-ground relative humidity (%) showing that below-ground humidity was more moderated and humid. The red arrows indicate the dates and duration of the cold, wet, inclement weather.

5.7 Environmental Factors and Insect Mass and Numbers

Using a Pearson Product-Moment 2 table correlation test (StatSoft Inc, 2001), the environmental variables of temperature (°C), relative humidity (%), absolute humidity (gm/m³) were correlated with the numbers and mass (gm) of insects, both as a total and per individual insect order (Table 5.13), (Appendix X). Significant relations (<p=0.05) are either related positively or negatively and are indicated in red print.

Table 5.13. A Pearson Product-Moment correlation indicating the r values, between environmental variables, measured next to the nest, and mass (gm) and number of insect order across all five habitat types for two 6 hour periods (06H00 to 12H00, 12H00 to 18H00) for a 16 day period (from 12H00 on 24/11/04 to 12H00 on 11/12/2004) total n=160

Correlations (Stat data 13 Nov05)
Marked correlations are significant at p < .05000
N=160 (Casewise deletion of missing data)

Variable	EdGm	EdNum	DipGm	DipNum	HemiGm	HemiNum	IsoGm	IsoNum	ColeGm	ColeNum	HymGm	HymNum
MinTemp	0.22	0.18	0.05	0.12	0.15	0.12	0.13	0.13	0.18	0.22	0.15	0.23
MaxTemp	0.33	0.29	0.17	0.18	0.33	0.31	0.12	0.12	0.22	0.32	0.21	0.43
AvgTemp	0.29	0.23	0.11	0.12	0.31	0.30	0.12	0.12	0.20	0.33	0.24	0.46
MinRH	-0.32	-0.26	-0.13	-0.15	-0.33	-0.29	-0.13	-0.13	-0.24	-0.33	-0.18	-0.43
MaxRH	-0.13	-0.13	0.02	-0.08	-0.10	-0.11	-0.11	-0.09	-0.13	-0.14	-0.10	-0.23
AvgRH	-0.27	-0.19	-0.07	-0.08	-0.31	-0.29	-0.12	-0.12	-0.21	-0.32	-0.21	-0.48
MinAH	0.03	0.07	0.06	0.09	0.01	-0.03	-0.05	-0.03	-0.01	0.00	0.13	-0.07
MaxAH	0.23	0.22	0.18	0.16	0.19	0.19	0.08	0.10	0.12	0.18	0.10	0.14
AvgAH	0.18	0.22	0.16	0.19	0.17	0.17	0.02	0.03	0.07	0.14	0.17	0.12

EdGM = Total edible insect mass (gm)
EdNum = Total edible insect number
DipGm = Diptera mass (gm)
DipNum = Diptera number
HemiGm = Hemiptera mass (gm)
HemiNum = Hemiptera number
IsoGm = Isoptera mass (gm)
IsoNum = Isoptera number
ColeGm = Coleoptera mass (gm)
ColeNum = Coleoptera number
HymGm = Hymenoptera mass (gm)
HymNum = Hymenoptera number

Apart from Isoptera (termites), all the individual insect orders showed statistical significance to one or more environmental variables. The most significant positive correlation between total potentially edible insect mass and number was with maximum temperature (°C), which fact is supported by Woods (2002). The most significant negative correlation was between minimum relative humidity and the individual insect orders, supporting the theory that low humidity is generally stressful for most insect species (Edney, 1979). Correlations between environmental factors and insect order were variable and in some case indeterminate, but generally the correlation results using the insect orders were comparable to those with the total potentially edible insect numbers and mass, where maximum temperature and minimum absolute humidity were all significant (<p=0.05). The only exception in the insect orders was Isoptera, where mass and numbers showed no significant correlations with any of the environmental variables investigated. Interestingly, this concurs with the findings of Hawkes (2003).

5.8 Insects and Environmental Factors.

The results obtained substantiate the findings of Hawkes (2003), Turner (2004) and Woods (2002), who found that changes in both temperature and humidity affect the availability of insects. Obvious trends exist where changes in humidity and temperature where brought about through frontal weather systems (Figs. 5.33 and 5.34). During the period 27/11/2005 to 28/11/2005, temperature decreased and humidity increased substantially. This frontal system brought rain and heavy mist, and interestingly, available insects continued to decrease with an increase in humidity. During the period 30/11/2005 to 1/12/2005 (24 hours), the cold frontal system reduced both temperature (Fig. 5.33) and humidity, which in turn substantially reduced the available insects (Fig. 5.33 and Fig. 5.34). Insect availability was affected just as severely during fronts that were dry, cold, and of long duration (8/12/2005 to 10/12/2005), where humidity declined with temperature reducing insect mass considerably.

These results support the hypothesis proposed by Hawkes (2003), which suggests that the mortality of Blue Swallow nestlings could increase as a result of an increase in extended periods of mist and rain. Furthermore, Hawkes (2003) is of the opinion that mist limits visibility, and thus hampers successful foraging by the adult Blue Swallows, further aggravating an already difficult situation for the nestlings that have to cope with reduced available insect prey as a direct result of unfavourable weather conditions. Interestingly, in the afternoon of the 29/11/2006, a heavy mist covered the study site after a hot sunny day. During this period the movements of the adult Blue Swallows, from the Diptank nest site, were being tracked. When visibility was reduced to less than approximately 6 metres, the tag signal was lost. A faint signal was relocated a short while later, indicating the position of the tagged bird in the direction of a known grassland patch at a much lower altitude. The measured humidity at this time was 16.41 gm/m^3, which was the highest recorded humidity since the start of the study.

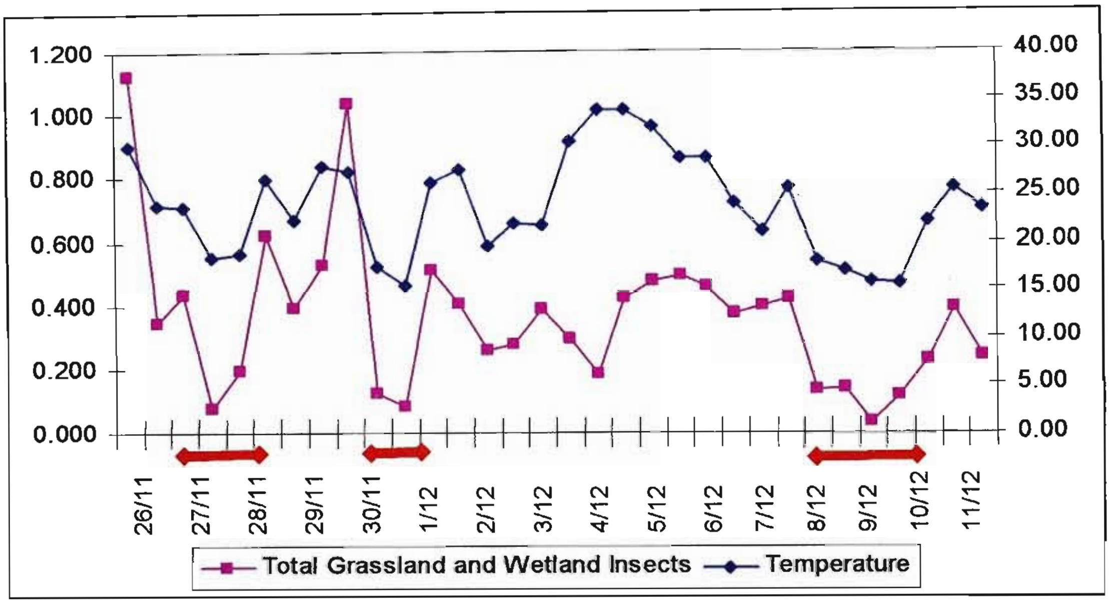

Figure 5.33. A comparison between the total insect mass (gm) collected in Malaise traps in grassland and wetland habitats and the average temperature (°C). The red arrows indicate the dates and duration of the cold, wet, inclement weather.

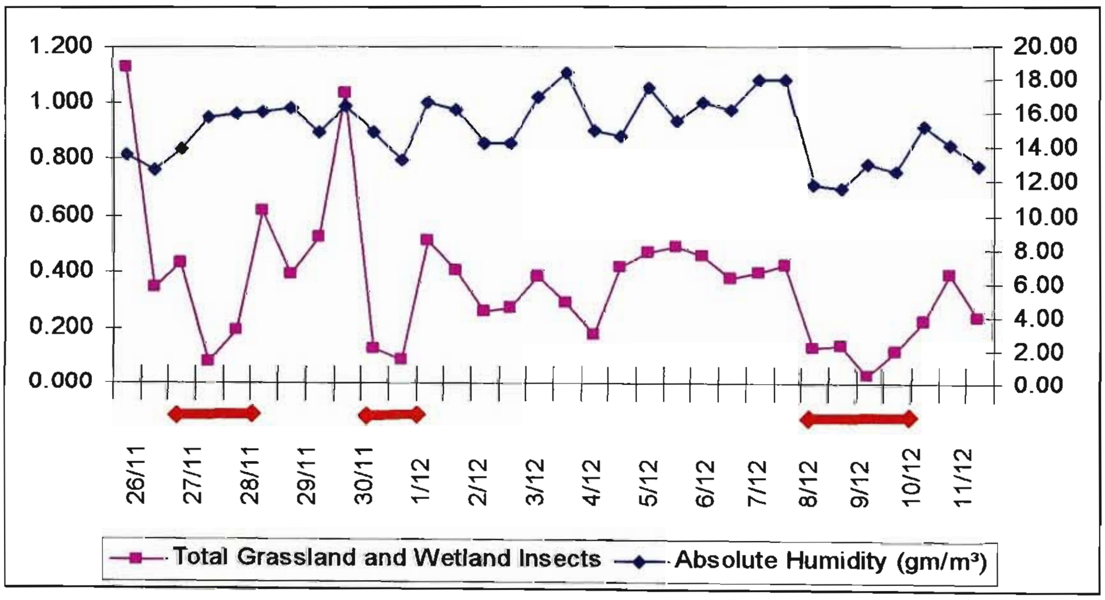

Figure 5.34. A comparison between the total insect mass (gm) collected in Malaise traps in grassland and wetland habitats and the average absolute humidity (gm/m^3). The red arrows indicate the dates and duration of the cold, wet, inclement weather.

CHAPTER SIX
DISCUSSION

6.1 Introduction

This chapter is divided into sections in which three main themes are discussed: first, habitat selection for foraging by Blue Swallows linked to insect abundance; second, environmental moderation; third co-operative breeding and the Blue Swallow.

Due to the low number of radio-tagged Blue Swallows (n=3) used in this study, the concern was raised that the sample size was too small and consequently low in statistical power. If so, this could result in a type II error which would lead to the acceptance of the null hypothesis when in fact the hypothesis was false (Siegel, 1956). In addition, concern was raised that the small sample size would be inadequate to provide an accurate indication of trends within the KwaZulu-Natal Blue Swallow population. However, the data obtained from the three active nest sites used in this research amount to a sample size of over 12% of the total known and confirmed breeding sites for the South African Blue Swallow population.

6.2 Habitat Use and Selection by the Blue Swallow

The radio-tagged birds spent 80% of their forage time over 'grasslands' and 'wetlands' and the remainder over 'tea' and 'sugar-cane' plantations. When insect abundance and mass (Section 5.5.1) for 'grasslands' and 'wetlands' are compared with the other land cover types, the choice of habitat by the Blue Swallow is clear. Of concern to conservation is the fact that wetlands and grasslands make up only 14.8% of the total study site area, compared to transformed habitats, not used by the Blue Swallow, such as commercial timber plantations, which make up 44% (Table 5.7). Furthermore, increases in fragmentation and perimeter increase the negative edge effect of the transformation (Camargo and Kapos, 1995). This in turn reduces habitat availability for the swallows through reducing suitable forage range. Originally, grasslands in the study site region were a single contiguous patch interspersed with indigenous forest and wetlands (Acocks, 1988; Camp, 1997). The grassland remnant now exists in only 22 isolated fragments, with these fragments having the third longest perimeter of all the habitats in the study area (Table 5.7). Other land cover types, such as settlement exist in higher fragment numbers (n=26). However, the category of settlement is a developed land cover that transformed the original grassland extent, and thus is not a good example. It is noteworthy that settled areas were avoided by the Blue Swallows. Only two land cover classes other than grassland are natural, namely wetland and indigenous forests. As in the case of grassland, natural wetland habitat would have been lost through the construction of dams (Begg, 1991), thus reducing a choice habitat for Blue Swallows, which habitat is a mosaic of grassland and wetland habitat (Evans *et al.,* 2003; Spottiswoode, 2005).

Extended field observation and results from data obtained in this study (Section 5.3.2) confirmed that Blue Swallows forage preferentially over grassland and wetland habitats, possibly as a result of the increased individual insect mass in these habitats (Fig. 5.14). However, within these habitats, Blue Swallows were regularly recorded and observed feeding on or near to the ecotone (Section 5.3.3). The findings outlined in Section 5.3.3 indicate clearly that the Blue Swallow is a species that uses ecotones preferentially as forage zones. The use of ecotones was clearly noticeable at nest sites such as Tafeni (Fig. 5.5) where the margins of small forest patches and wetland edges were frequently used. Wetland and grassland ecotones are used more than any other ecotone combination (Fig. 5.7). These areas would be used preferentially only if insects were more abundant and more available in these areas. According to Frouz and Paoletti (2000) insect diversity and abundance is increased on the ecotone between two habitats and could be the explanation of this feeding behaviour exhibited by the Blue Swallow.

It appears that soil humic content plays an important role in insect production (Section 5.3.2). The observation of the use of unburnt and ungrazed grassland habitat by Blue Swallows adjacent to the Florida nest site supports this notion because an unburnt and ungrazed portion of grassland was foraged over more frequently and for longer periods than the portion that had been recently burnt that year, indicating that fire had possibly negatively affected the quantity of insects available (Callaham *et al.*, 2003; Hanula and Wade, 2003). It would appear that soil humus plays a pivotal role in determining the abundance and occurrence of insects (Callaham *et al.*, 2003; Holland, 2004), which could explain the reduced selection by Blue Swallow of the sugar-cane fields which are burnt every 18 months for harvesting, leaving the soil bare and devoid of humus and plant litter.

Radio-tagging showed that plantations were clearly avoided by the Blue Swallows (Table 5.4). Only 0.7% of all the point locations that were plotted fell within this land cover type. Of the 0.7%, the majority of fell just onto the edge of existing plantations and here it is conceivable that the points plotted within plantations are possibly a result of error bias during triangulation (Figs. 2.2 , 2.3 and 4.2; Section 4.6.4). In support of this finding, it was observed that Blue Swallows avoided plantations even though wind direction could have been blowing insects from inside the plantation into the grassland areas. However, M. McNamara (*pers. comm.*, 2006) has observed Blue Swallows flying along plantation edges in Mpumalanga province, South Africa. As insect biomass and numbers (Table 5.9) cannot fully explain why the Blue Swallows do not regularly use commercial timber plantations as forage areas, there must be other plausible reasons. The most likely explanation is that plantations are aerially cluttered habitats and structurally do not allow fast flying aerial foraging birds like swallows an unobstructed and safe forage opportunity.

Alternatively, Blue Swallows, as habitat specialists, could possibly use ecotones within the interior of natural untransformed habitats rather than the periphery of these natural habitats which have transformed sections. If this is the case, then transformation and habitat fragmentation of the preferred grassland and wetland habitats could have significant conservation implications for the persistence of the species, where fragmentation increases patch number and perimeter length but reduces available core habitat with suitable interior ecotones (Bruna, Vasconcelos and Heredia, 2005; Kareiva and Wennergren, 1995; Yahner, 1996).

Clumps of wattle *Acacia mearnsii*, categorised as aliens, were not ignored by the Blue Swallow as a source for insects. The Blue Swallows at the Diptank nest site spent time foraging around small clumps of wattle, and in particular in the lee of these clumps when a wind was blowing. These small clumps of wattle trees were well augmented by indigenous undergrowth. Nevertheless, in time, the situation could change when these wattle clumps might outgrow the protective function that they currently provide to the indigenous species that have established beneath them and begin to outgrow them (Galatowitsch and Richardson, 2005).

Waterbodies also played a major role in the foraging of the Blue Swallows which bathed frequently on the wing, almost fully submerging themselves. Faecal sacks were also often deposited into the dam by the Tafeni birds. The Blue Swallows that emerged with faecal sacks from the Florida nest site flew toward the dam, but unfortunately distance prevented one seeing whether these sacks were also disposed of into the dam or not.

6.2.1 Summary of Spatial Composition of the Study Site

Loss of suitable natural forage and breeding habitats for the Blue Swallow is cause for serious concern (Evans *et al.*, 2003; Wakelin 2001). Transformed land comprises 71% of the entire combined home range areas (Fig. 5.8). This figure includes 12% of indigenous forest which has limited use for Blue Swallows as only the ecotones are used for foraging. In effect, there remains intact approximately 29% of grassland and wetland mosaic for the Blue

Swallows to breed in and forage on within their active home range areas (Fig. 5.8).

Considering the small and highly fragmented nature of the natural habitats that remain intact, some transformed habitats, such as the tea plantation, are fulfilling an important surrogate role for foraging (Section 5.3.2). Loss of these areas to other land covers less suitable for the Blue Swallow could potentially reduce the availability of forage to below the critical threshold which could lead to local extirpation of the species. Loss of the tea plantation as a habitat, if transformed to a timber plantation, would be one example where a simple change in land cover from one transformed habitat to another could potentially have significant impacts on the Blue Swallow. In this regard, the role of fragmentation and nature thereof within a landscape is therefore of importance (Martin *et al.*, 2006).

6.2.2 Key Distance Findings from Positional Data

The furthest distance travelled by a radio-tagged Blue Swallow was 1296 m (Table 5.5), which was recorded from the adult female bird known as Florida. Inter-nest visits were made by the male swallow from the Diptank nest; the visits were confirmed by means of the unique wing marks (Fig. 4.1). These inter-nest visits were not limited to the male of the species only, as unmarked females were also present in the visiting groups. Therefore, the distance between the nests (Table 5.6) provides an estimate of maximum distance flown. The furthest recorded telemetry location obtained for the male Blue Swallow from the Diptank nest site was 1030 m; however, this male bird made frequent visits to the Florida nest which is 1167 m away. The nature of the terrain prevented obtaining accurate location data on the radio-tagged birds at these ranges due to the tag signal being obscured. The distance between the Florida nest and the Tafeni nest is 1831 m, which as a radius, amounts to a potential home range size of 1053 ha. What remains unknown is whether or not the Blue Swallows flew directly between the nests for visits, and hence were able to cover a greater distance in a straight line, or whether the birds foraged out to this distance regularly. It would be naïve to think that that Blue Swallows would never venture beyond a presumed maximum distance from their nest site; however, it is probably reasonable to assume that the majority of the forage activity would take place within 2 km from their nest site while bound to the nest site because of chick rearing activities. Verification of this distance with radio telemetry equipment would only be possible if the line of sight was not inhibited by terrain.

Interestingly, the area covered by the adult male Blue Swallow from the Diptank nest appeared to be greater in comparison to the areas recorded for the two female birds (Figs 5.3 to 5.5). From many examples it is known that the male of a species ranges over a larger area than the female (Chandler, Ketterson and Nolan, 1997). This increased range could be associated with the male bird seeking extra-pair copulations which has been noted to be the case in other Hirundines (Turner, 2004). Increased movement could be in response to many factors including increased testosterone levels (Chandler *et al.*, 1997), food availability, body mass and population density (Benson, Chamberlain and Leopold, 2006). An increase in sample size is needed to confirm these observations concerning Blue Swallows.

6.2.3 Dietary Study Sampling

Food availability is a major determinant in species distribution (Benson *et al.*, 2006; Christiansen and Pitter, 1997). Therefore, insect diversity, abundance and distribution are potentially the major influence in the use of habitat by Blue Swallows. Dietary investigations are of importance as they guide appropriate habitat management that could influence habitat use by the Blue Swallow. Because of small sample sizes in this study, recursive modelling techniques failed to produce useful information on insect orders as a predictor of preferred habitat. The preliminary use of recursive modelling techniques indicated that potential exists for future investigation into dietary studies of this nature (Annexure IX).

As single point sampling locations within the different habitat types were investigated using Malaise insect traps, there were inherent problems associated with this approach to data collection as a result of pseudo-replication. The results could also be biased by the placement of the trap. To reduce these problems, increased replication of sampling per habitat type is required (R. Emslie, *pers. comm.,* 2005; Siegel 1956; Siegel and Castellan, 1988).

6.2.4 Mass and Number of Edible and Inedible Insects per Land Cover Type

If Blue Swallows select habitats based upon total available edible insect mass alone (Table 5.9), one would expect the descending order of total mass of edible insects to habitat to match the order of habitat selection obtained from the radio-tracking data (Table 5.4) – which is not the case. In terms of total edible insect mass, the order of selection was 'grassland', 'wetland', 'plantation', 'tea' and 'sugar-cane'. 'Plantation' was the only habitat type out of order, which should be placed last and not third, when compared with the order of habitat selection (Table 5.9).

Although plantations produced the third highest mass of edible insects, as a land cover they stood out clearly above the others in terms of the high numbers and mass of inedible insects produced (Table 5.9). Almost one quarter of all insects trapped in this habitat were considered to be unsuitable as prey for the Blue Swallow; and more than half the total mass of insects captured in plantation comprised of inedible insects. Given the general avoidance of plantations by Blue Swallows (Figs. 5.3 to 5.5), it is possible that the ratio of inedible insects to edible insects could play a role in this avoidance. Food item selection on the wing by Blue Swallows must be a difficult undertaking considering the speed at which they fly (Evans *et al.,* 2003) during foraging sessions. Apart from the obvious structural issue in plantations, habitat avoidance could possibly be a function of the ratio of inedible to edible insects based upon the principles of energetics, where the energy benefits of feeding in these areas does not outweigh the costs. Outmanoeuvring inedible prey items in the path of flight could prove to be difficult for aerial foragers and therefore costly in terms of energy expenditure simply for insect avoidance as the gape size of a bird sets the limit for the largest insect prey that can be consumed (Sherry and McDade, 1982). 'Plantations' differed in this regard from all the other habitats in that there were high numbers of inedible insects that correspond to high inedible mass which means high number of average sized inedible insects (Table 5.9). Tea plantations, on the other hand had the second highest mass of inedible insects with the lowest corresponding insect numbers, indicating that the inedible insects in tea plantations were large and possibly easily avoidable in flight. Prey size could be of great importance because it appears that not only birds are prey size selective, but that predatory insects have been found to actively select prey of the most suitable size (Rashed *et al.*, 2005). Turner, (2004), found that the type and size of the insect prey varies widely with Hirundines, but they remain very selective feeders about which prey they choose to pursue. Different species of Hirundines avoid competing for food with other insectivores by feeding at different heights and on different insects (Turner, 2004).

6.2.5 Mass and Number of Inedible and Edible Insects per Insect order

In order to identify the critical insect relation to habitat type, insect mass and numbers were investigated further in relation to insect order. The most significant finding was that average insect mass per order, which was correlated closely to habitat type ($p=0.0001$), matched the order of positive habitat type selection by the Blue Swallows ($p=0.0001$), (Table 5.12). These findings demonstrated a high level of statistical significance and suggest that average insect mass could be one of the main influences behind the habitat selection by Blue Swallows. With larger edible insects, it is thought that Blue Swallows would have to spend less time actively foraging to gather fewer insects, as opposed to feeding on higher numbers of smaller insects, which would take relatively more time and effort for the same nutritional mass and intake. Average insect size is thus crucial in this context (Britschgi, Spaar and Arlettaz, 2006; Schoener, 1966; Vézinal, 1985). Tea plantations, with low edible insect numbers had the second highest overall mean mass for edible insects produced (Table 5.9), possibly explaining why the Blue Swallows spend a significant period of time foraging over tea plantations. Tea plantations, as a cover type for forage, are exceptionally important considering that each time a Blue Swallow nestling fledged successfully, the adult birds took the fledgling onto the tea to forage.

6.3 Environmental Factors and Insect Mass and Numbers

Woods (2002) and Hawkes (2003) found a clear indication that insect numbers increase with an increase in temperature; these findings are supported by those of Heinrich and Casey (1973) and Heinrich (1993). The present study supports these findings, because the highest strongest positive relations were correlations between edible insects and maximum temperature, implying that insect numbers and mass increase with an increase in temperature (Table 5.13). Furthermore, when the variables in average temperature were plotted with changes in the mass of insects collected in Malaise traps in grassland and wetland habitats, clear trends are noticeable (Fig. 5.33 and Fig. 5.34), where a decrease in average temperature resulted in a decrease of grassland and wetland insect mass.

The highest negative correlations were between edible insects and minimum relative humidity (Table 5.13). Relative humidity, in effect, is related to temperature because relative humidity refers to the amount of water that is present in the air compared to the greatest amount it would be possible for the air to hold at that temperature. Thus, the amount of water vapour that will saturate the air increases with a rise in temperature. Therefore, it is to be expected that temperature is inversely related to minimum relative humidity.

Considering these correlations, it can be expected that insect numbers and mass will decline with a reduction in temperature and with a reduction in relative humidity which corresponds to follow the results obtained (Fig. 5.33 and Fig. 5.34). Long periods of either cold and or dry weather periods would therefore quite conceivably, negatively influence insect abundance and in turn Blue Swallow well-being. Jones (1987) found that inclement weather has a significant effect upon swallows' being able to feed and recorded a 9% decrease in body mass of an adult female Barn Swallow *Hirundo rustica* in only a six-hour period. In support of these findings, Hawkes (2003) stated that humidity was not the only factor responsible for changes in insect populations, unless rain and mist continued for extended periods of time (>3 days). Interestingly, Hawkes (2003) stated that cloud cover affected insect populations significantly. It is presumable that cloud cover would reduce radiation and decrease ambient temperature which supports the trends shown in this study (Fig. 5.33 and Fig. 5.34).

The underground cavity used as the nesting site of choice by Blue Swallows experiences a greatly moderated climate in the range of critical environmental factors compared with those experienced above-ground (Section 5.6). Because the performance of animals, in general, is critically dependent on local microclimates, which are and of particular importance for the young of animals (Primault, 1979), a moderated environment is a clear advantage for the Blue Swallow chicks.

6.4 Co-operative Breeding

It was evident that the Blue Swallow is a very social species during breeding and the birds make frequent nest visits to neighbouring nesting sites, contrary to the findings of Turner (2004). The same behaviour was apparent at the Tafeni nest site, where groups of many unmarked birds were noted. The adult male bird from the Diptank nest site also spent time intermittently in the vicinity of both the Florida and Tafeni nest sites.

Through the use of visual markers (Fig. 4.1) and video footage (Section 5.2), it is clear that Blue Swallows breed with a number of adult birds at one nest. The recorded average sex ratio was 1♂ : 3♀ (Table 5.2). The relationship between the extra adult females within the breeding system is not known, and it is not inconceivable that the helpers participate in egg laying as well, considering that they do participate in the incubation of the eggs (Section 5.2). Brown (1987) described this breeding strategy as 'joint nesting'. Even though Cockburn (2004) stated that true fidelity in monogamy is limited to only a few species, it seems the most likely breeding system in the case of the Blue Swallow, as eggs are laid sequentially over a number of days (H. Mattison, *pers. comm.,* 2003; Section 5.2). Brown (1987) named and described this type of breeding system as 'singular nesters'.

Even though climatic variables have low predictive power to predict co-operative breeding (Ligon and Burt, 2004), co-operation in the Blue Swallow breeding system could be a result of a variable climate and the concomitant rapid variation in insect numbers and abundance (Fig. 5.33 and Fig. 5.34). This could be a factor of adult Blue Swallows taking advantage of the relatively short periods of increased availability of insects during periods of rapid weather change. Understanding that the best predictors of co-operative breeding are related species (Ligon and Burt, 2004), the Blue Swallow appears to be unique. Because, according to Turner (2004), there are no members of the Hirundinidae that are currently known to breed co-operatively (Walters *et al.*, 2004). The notion exists that Blue Swallows could participate in co-operative breeding strategies as a result of difficulties with reduced visibility when foraging (R. Porter, *pers. comm.,* 2005). Turner (2004) supports this belief, stating that Hirundinidae may be unable to feed at all during periods of adverse weather conditions, but adds that the Blue Swallow is the exception with its specially adapted body feathers being more effective in repelling water droplets than those of most other bird species, and is therefore well adapted to feeding in these conditions. In addition, these special adaptations support the idea that mist and rain would have less influence on the feeding patterns of the species compared to other Hirundinidae and hence the influence of weather on insect numbers would probably be relatively more important. A shortage of suitable nest sites and habitat (Evans *et al.*, 2003), could be a possible reason why Blue Swallows breed co-operatively.

6.5 Conclusions

In South Africa, there are insufficient formally protected grassland areas suitable for Blue Swallow habitation. With the exception of the Impendle Nature Reserve, under the management of KZN Wildlife, it appears that the future of the Blue Swallow lies in private land ownership, outside any form of formal protection. Ultimately, the Blue Swallow is therefore far from secure and there is a great need to address Blue Swallow conservation and its preferred montane grassland habitat. This is a difficult task, considering that economic imperatives are the greatest cause of land-use changes (O'Callaghan, 1996). Habitat selection by Blue Swallows was important for the species, where the grasslands and wetlands were the preferentially selected habitats. Ecotones between the different habitats were also preferentially selected. Tea plantations were selected as the next most important habitat type and timber plantations were avoided.

Malaise insect traps gathered suitable insect samples for analysis, revealing that significant differences occur in insect order, numbers and mass between habitat types. Average insect mass per insect order, was correlated closely to habitat type, which matched the decreasing order of positive habitat type selection by the Blue Swallow. These findings showed a high level of statistical significance and it is suggested that this relation is the main factor behind habitat selection by Blue Swallow, based upon the principles of energetics. Humic content within the habitat was important for availability of insects, which has important habitat management implications.

Even though the investigations into co-operative breeding were subsidiary to this research, preliminary findings indicate that the Blue Swallow breeds co-operatively. However, the breeding system requires more investigation so that is can be defined clearly.

CHAPTER SEVEN
CONCLUSIONS

7.1 Introduction

The aim of this dissertation is to determine the critical habitat requirements of breeding Blue Swallows in KwaZulu-Natal. In this chapter, the research undertaken will be evaluated against the four objectives outlined in Section 1.3, all of which were fulfilled. The strengths and weaknesses and key findings of each of the approaches will be highlighted and used to identify further research needs.

7.2 Conclusions

> *Objective 1. To determine habitat use of breeding Blue Swallows during foraging by using radio-tracking in order to investigate habitat selection.* (It is important to investigate the usage of Blue Swallow habitat in order to determine the habitat preferences of the species so that any further habitat loss can be prevented).

This study showed that radio-tracking can be used to determine habitat selection by small birds. Disturbance caused by this research appeared to have minimal impact, as in all the nest sites where adult birds were captured and radio-tagged they successfully fledged their chicks. These birds all continued into their second breeding cycle where they all subsequently fledged their second clutches as well - this being the ultimate measure of success (T. Hill, *pers. comm.*, 2005).

In Chapter 5, the radio-tracking findings are presented which indicated that strong habitat selection by Blue Swallows exists. The most significant finding was that grassland, wetland, tea and forest habitats were selected in that order of preference. Negative habitat selections of significance were timber plantation, sugar-cane, aliens, orchard and settlement. Blue Swallows also preferentially selected ecotones for foraging, which could not be correlated to insect abundance and diversity as insect samples were not gathered from any ecotones. The most important habitat for Blue Swallows is the mosaic of wetland and grasslands, and the ecotones between these habitats (Section 5.3).

> *Objective 2. To investigate insect abundance and diversity within five habitat classes and to correlate these findings to Blue Swallow habitat usage and to changes in temperature and humidity.* (It is hypothesised that insect prey is a major factor in determining habitat use; if this is the case improved and focused habitat management could benefit the Blue Swallow by means of improved insect production. The notion that inclement weather negatively affects Blue Swallow forage will also be investigated).

The techniques employed to collect insect samples were successful and these samples revealed that significant differences occur in insect order, numbers and mass between the different habitats (Section 5.5). The classification of insects into categories and orders allowed for the development of appropriate data-sets by which correlations were investigated between insects and habitat type. The most significant finding is that average insect mass per order, which was correlated closely to habitat type, matches the order of positive habitat type selection by the Blue Swallows. These findings demonstrated a high level of significance and suggest that the principles of energetics could be the main factor behind habitat selection by Blue Swallows (Fig. 5.14). Clear correlations were noted between a decrease in temperature and a resulting decrease in insect numbers and total mass (Section 5.7). Although a reduction in humidity shows a similar result, the relation was not always constant.

Objective 3. To investigate the protective role played by the nesting cavity and its regulation of temperature and humidity. (To better understand the protective role played by the nesting cavity. Insight may also be offered into the breeding system employed by the Blue Swallow by better understanding the role and function of the nest cavity).

The use of Hobo® sensors was effective in delivering the required information on the climatic variables underground at the nest site of a Blue Swallow. In Chapter 5, details are given of the moderating effect the nest cavity has on the environmental variables of temperature and humidity, which provides a suitable nesting environment for the Blue Swallow within a variable climate.

Objective 4. To undertake preliminary investigations into the breeding system used by the Blue Swallow and to estimate the number of individuals involved. (Understanding the breeding system of the Blue Swallow is crucial in order to gain insight into and an understanding of effective population and recruitment potential).

In Chapter 4, details are given of the method of wing marking Blue Swallows which assisted with the identification and confirmation that more than two adult Blue Swallows were involved in breeding at a single nest site. Visual markers proved invaluable as a technique and were easy to apply, cost effective and highly visible. In addition, they complemented the more advanced radio-tracking methods, by assisting to identify tagged adult birds once the tag battery was dead. However, there remains a very clear need to investigate the relationship and role of co-operative breeding helpers to the Blue Swallow nestlings, in addition to understanding the factors that underpin the Blue Swallow breeding system.

7.3 Recommendations

Recommendations have been divided into four sections as follows.

7.3.1 Ethics

The capture and handling of Blue Swallow as a Critically Endangered bird species requires experience and understanding of the species. It is not recommended that the species be targeted by the Causal bird ringer, using the methods outlined in this research because these techniques took significant periods of time to perfect. People ringing Blue Swallows should receive training and guidance in the appropriate ringing methods. Nestlings should undergo ringing at an appropriate age only after guidance and training (Evans, 2004).

7.3.2 Research Methods

The negative side of using advanced techniques is that sufficient training is required to ensure that they are implemented appropriately to achieve plausible information (Kenward, 2001). Training of assistants is critical for achieving confidence in data obtained from radio-tracking. The techniques are time-consuming and not always a simple alternative to intensive field-based sampling or observations.

A clear understanding of the limitations of radio-tracking is required prior to deciding on the suitability of the technique to answer the biological question under investigation (Kenward, 2001; Mech, 1983; White and Garrott, 1990). This is so, particularly if the interpretations of the findings are beyond the capabilities or scale of the technique or the data captured (Kenward, 2001).

Reliable radio-tracking equipment is essential (Kenward, 2001); unreliable equipment will just cause frustration and will result in a waste of time and money (B. Cresswell, *pers. comm.,* 2003). It is therefore critical to use the correct equipment for the correct application (Kenward, 2001). The supplier used in this study produced high quality equipment which was user-friendly and which functioned faultlessly. The equipment was also very durable and stood up to the harsh conditions it was subjected to. Most importantly, the supplier offered good advice at purchase and a reliable technical backup service following purchase.

If resources were not limited, a third base station would have been the most appropriate change or addition to the radio-tracking technique used. This would have decreased the error and increased the area of landscape visible from the base stations (Kenward, 2001).

The value of visual markers to this study cannot be overstated. They were simple, cheap to use and simple to apply (T. Szép, *pers. comm.*, 2003) and added value to this study.

If budgets had allowed, the number of Malaise insect traps would have been increased. In hindsight, it is thought that samples needed to be collected on habitat ecotones to verify the hypothesis that increased insect numbers in these areas influence the habitat selection of the Blue Swallow.

It was suggested that replications and sample number of the insect investigations made in this study, be increased for future studies of a similar nature. Random plots within each habitat type should be undertaken to prevent pseudo-replication and to obtain an improved overview of the relation between average insect mass and habitat (R. Emslie, *pers. comm.*, 2005). Further investigation into the impact of climatic variables on insect abundance would be valuable.

7.3.3 Science

Extrapolation and application of the distance findings should be applied with caution. Each nest sites had its unique habitat mosaic and set of ecosystem variables that would need to be fully understood in terms of impact on forage range and post fledging dispersal (Benson *et al.*, 2006). The usage of the tea plantation by the Blue Swallows is a good example of a totally unexpected factor being found to influence their behaviour.

7.3.4 Conservation Action

Cloven-hoofed animals can damage the plant species found within the Mistbelt Grassland by trampling and over grazing, which reduces plant diversity and basal cover (R. Scott-Shaw, *pers. comm., 2005*) and reduces infiltration by rain and increases susceptibility to erosion (Pietola, Horn and Yli-Halla, 2005). Therefore, in natural grasslands, grazing of the new growth which is stimulated by fire, should be avoided because the resultant accelerated erosion causes the loss of humus (Pietola, Horn and Yli-Halla, 2005) which supports insect populations (Callaham *et al.*, 2003; Hanula and Wade, 2003). Grassland management should therefore be carefully redefined for Blue Swallow breeding sites in order to maximise insect production. Grassland adjoining Blue Swallow nest sites should be managed in a mosaic of different age blocks of burnt grassland with the oldest patch of unburnt grassland not exceeding four years. Grazing of the newly burnt grassland must be avoided. To prevent trampling of the veld by livestock, low densities of grazing animals over long periods of time in a single area should also be avoided. It is preferable to stock areas with high animal numbers over very short time periods so that the livestock do not have time to graze selectively. Grazed grasslands must also be adequately rested to facilitate recovery of the herbs and forbs.

Although not the key focus of this study, information on insects was important: it is clear that insect abundance and overall mass is strongly related to the humic content of the soil (Callaham *et al.*, 2003; Hanula and Wade, 2003). Habitat management, therefore, can have a direct influence on the overall abundance and mass of available insects for Blue Swallows.

Consequently, the protection and maintenance of the humic content of the soils within the various habitat types, within a radius of two km of the nest sites, should be a key objective of habitat management. Although in conflict with some of the findings of O'Connor (2002), recommendations of simple management practices such as reduced burning and grazing could have positive benefits for insect diversity and density for the Blue Swallow. Guidance is thus needed to inform the management of natural and transformed habitats so that the maximum insect abundance possible can be maintained during difficult weather conditions.

The concept and implications of maintaining an adequate buffer distance from active Blue Swallow nest sites are far-reaching. All inappropriate land cover and land-use change should not be allowed within two km of any active nest sites. But restricting landowners from undertaking certain land-use activities has serious economic and social implications. Marginal agricultural operations could be forced into bankruptcy, and landowners of Blue Swallow nesting sites could be alienated by conservation officials, with far-reaching implications for Blue Swallows. Uneconomical farms could be sold and subdivided for inappropriate development, thus reducing the opportunity to safeguard the breeding Blue Swallows and their habitat. Therefore, it is strongly recommended that all custodians of Blue Swallow breeding sites should be contracted into an incentive and compensation-based agreement with the provincial conservation agency, ensuring that the remaining breeding habitat is appropriately managed. Information on key habitat range is still needed so that this information can be used by the planning and decision-making bodies on land cover and land-use change; otherwise, decisions could be made without the necessary supporting information, thus jeopardising existing Blue Swallow breeding sites.

The observations in this study of the cooperative breeding system employed by the Blue Swallow have important conservation management implications.

Walters *et al.* (2004) believe that cooperative breeding birds are more likely to be adversely impacted by habitat loss and fragmentation due to their unusual dispersal behaviour. If this is the case with Blue Swallow, the continuing habitat fragmentation could have dire consequences for the species persistence. However, Walters *et al.*, (2004) hypothesised that small populations of cooperative breeders with helpers are more likely to persist than those species that do not breed cooperatively, due to the ability of helpers to buffer demographic and environmental stochasticity.

In addition to the issues involving population dynamics, there are consequences for cooperatively breeding Blue Swallows with respect to their genetic population structures, as neighbourhoods of cooperative breeding birds have a high degree of genetic relatedness. As a result, the potential for inbreeding in cooperative breeding birds is great (Walters *et al.,* 2004). Furthermore, if cooperative breeding is normal for the Blue Swallow, the assessment of effective population size of breeding adult birds will be seriously over-estimated. For these reasons a comprehensive understanding of the Blue Swallow breeding system is urgently required as proposed in section 7.5.2.

7.4 Reflections on Research

Researching the Blue Swallow turned out not to be merely a scientific matter: personalities and professional jealousy were very obvious and consequently hindered the research. This is unfortunate because the species is in critical need of research investigation (Evans *et al.*, 2003, Wakelin 2001) if it is to have any chance of survival. A current concern voiced by many conservationists, is that the species is simply being monitored to its extinction, with lack of any real conservation action or intervention.

Concern is also raised at the lack of capacity and resources within conservation agencies to adequately deal with issues pertaining to the conservation of the

Blue Swallow. A decline in effectiveness of the relevant provincial conservation agencies would without doubt lead to a lack of focus on conservation action for flagship species such as the Blue Swallow. This would result in more and more support required from non-governmental organisations such as the Endangered Wildlife Trust, which would have to fill these needs without a legal mandate to do so.

7.5 Future Conservation Priorities

7.5.1 Ethics and Research

Considering the Critically Endangered conservation status of the Blue Swallow (Barnes, 2000), it is suggested that all proposed research be submitted to the mandated provincial conservation agencies for approval. Although no evidence of disturbance was noted as a result of this research, access to active Blue Swallow nest sites must also be in accordance with the requirements of both the Endangered Wildlife Trust – Blue Swallow Working Group and the provincial conservation agencies.

7.5.2 Research Required

What remains of significant importance is to undertake an investigation into the genetic heterozygosity of the Blue Swallow populations (Evans *et al.*, 2003). This is considered to be the most important research required, especially considering that Austin Roberts originally described the Blue Swallow genus as *Natalornis,* and a superspecies of the central African Black and Rufous Swallow *Hirundo nigrorufa* (Turner, 2004). This is particularly important when considering sexual dimorphism and co-operative breeding displayed by the species.

Next most important would be to attempt to identify the migratory paths and final destination of the southern African Blue Swallows (Evans *et al.*, 2003). Without this information, the southern African Blue Swallows are at serious risk for half of their lives even if 100% habitat protection is achieved in

Southern Africa (Nasirwa and Njoroge, 1997; Wakelin, 2001). Conservation action in southern Africa would be futile without collaboration with conservation authorities further north in Africa (Evans *et al.*, 2003). The application of trace element analysis on feather samples from first year birds trapped on the over-wintering grounds in east and central Africa (Szép *et al.*, 2003), could be the most appropriate technique. Trace elements from foreign samples could be compared to those obtained from nestlings in southern Africa and could give an indication of migratory movements (T. Szép, *pers. comm.,* 2003).

Third, the roles of the Blue Swallow helpers and breeders at a nest site need to be defined. It is suggested that a 'clock in, clock out' micro-chipping system be used, where a micro-chip is attached to individual Blue Swallows and this allow their movements in and out of the nest to be recorded (S. Piper, *pers. comm.,* 2003). In terms of defining the ecology of the breeding Blue Swallow, the use of video cameras could be considered to view the nest discreetly without causing any disturbance (McQuillen and Brewer, 2000; Stake and Cimprich, 2003).

7.5.3 Science

Important questions remain unanswered about paternity, pair fidelity and helper relationships and sex. These unanswered questions which all pertain to the Blue Swallow breeding system, could be answered using genetics (Ligon and Burt, 2004), which would require assistance from a professional geneticist.

7.5.4 Conservation Action

Conservation action is an important priority and should include recommendations from this research. Strong lobbying for the introduction of incentives and fiscal relief for private landowners who manage habitat around active Blue Swallow breeding sites is also needed. Expecting landowners, at their expense, to maintain Blue Swallow breeding habitat, purely for the benefit of the species, is over-optimistic. The following five steps are strong recommendations made as a result of this study. These recommendations are compared and integrated with suggestions made in the International Blue Swallow Action Plan (Evans *et al.*, 2002) and the Blue Swallow population and habitat viability assessment (PHVA) (Evans *et al.*, 2003).

1. A set of habitat management guidelines for the Blue Swallow should be developed. These should focus on land management that maximises the production of suitable insects for Blue Swallows, and maintain nest sites while ensuring that grazing and fire systems are appropriately controlled. This document should form the basis of the contractual agreement between landowners and the conservation agencies. Although further research was identified as one of the most important goals for Blue Swallow conservation in the PHVA (Evans *et al.,* 2003), this specific recommendation was unaccountably not identified as a priority conservation action. The International Blue Swallow action plan, (Evans *et al.*, 2002) states that stringent measures must be applied with respect to land management, but does not identify the need to develop the habitat management guidelines, which this study suggests is a priority. The suggested development of these guidelines will allow for improved and more appropriate and specific habitat management for Blue Swallows.

2. The contractual agreement between the landowner and the conservation agency should provide a suitable financial reward to the landowner for maintaining or even improving Blue Swallow habitat. It was suggested in Evans *et al.*, (2002), that important Blue Swallow sites be listed according to the various international conventions such as Ramsar, in addition to listing them as Important Bird Areas. Unfortunately neither of these processes will afford the landowner any form of fiscal support nor afford any formal long-

term protection to the land. However, the need for incentives was highlighted in the Blue Swallow PHVA as an important solution and goal for the conservation of the Blue Swallow, although they were not defined (Evans *et al.,* 2003).

3. All Blue Swallow nesting sites should be prioritised according to the threat that alien plants pose to the nest's integrity and their immediate surroundings. There should be access to registered herbicides and government support teams (e.g. Working for Water), specialised in the clearing of alien vegetation, to control the alien plants and safeguard the breeding sites. The clearing and control of alien vegetation should be undertaken only outside the breeding season, to minimise the risk of disturbance, i.e. May to September. The issue of habitat loss and degradation was identified as being of great importance in both the International Blue Swallow Action Plan (Evans *et al.*, 2002) and the Blue Swallow PHVA (Evans *et al.,* 2003). However, as suggested in this study, a more specific focus is needed for each known nesting site.

4. Securing the over-wintering habitat used by the Blue Swallow is critical for the long-term conservation of the species. It would be futile if conservation effort was focused upon the breeding grounds alone. In this respect, negotiations with BirdLife International should be initiated immediately to ensure the formal conservation of the species on their over-wintering grounds. The suggestion that relevant Blue Swallow habitat be listed as Important birds Areas and as Ramsar sites, is an important goal in this respect (Evans *et al.*, 2002).

5. It is strongly suggested that a Blue Swallow recovery plan for all the breeding sites throughout the species' range needs to be developed. This recommendation concurs with that made in the International Blue Swallow action plan (Evans *et al.*, 2002), where rehabilitation of former suitable

breeding habitat was suggested as a method of increasing the size of isolated Blue Swallow populations. The proposed Blue Swallow recovery plan must identify the breeding sites where breeding attempts consistently fail, or produce few fledglings. Intervention at these sites should be planned, mapped and prioritised. Without this focus, and considering the dwindling habitat (Scott-Shaw, 1999), it seems likely that the population could never grow to the goal population (Evans *et al.*, 2003).

7.6 Conclusions

The habitat preferences of the Blue Swallow have been here determined. This satisfies one of the most important goals set in the Blue Swallow PHVA (Evans *et al.,* 2003). In addition, this study improves knowledge of the species, and will benefit conservationists involved with Blue Swallow population and habitat management.

This study successfully developed and refined techniques which have increased the knowledge of the ecology and biology of the Blue Swallow, particularly with respect to habitat use, the influence of insects as food and the breeding biology of the species. The findings of this study also indicate that the Blue Swallow breeds co-operatively and is a social species with specific ecological requirements, which can be provided for by means of appropriate habitat management and which in turn will have practical conservation action implications.

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Appendix I

Telemetry Data Collection Form.

DATE	
TIME	
NEST SITE	
SWALLOW NAME	
PAGE NUMBER	

TAG SENDER UNIT DIRECTION

TIME	BASE 1	BASE 2	NOTES

Appendix II

Point Data Algorithm

For illustrative purposes, the base stations for the Diptank nest site are used in the following example.

For the Dip tank site, the co-ordinates for the two base stations were:
Dip tank Base 1 (D1) = S29° 55' 06.6" E29° 54' 53.9"
Dip tank Base 2 (D2) = S29° 54' 53.9" E30° 09' 01.0"

To determine the linear relationship between these two points, the location of the points in metres was required. Therefore these localities where projected from decimal degrees to metres using the following parameters. Transverse Mercator, spheroid WGS84, central meridian 31.

D1: $y1 = -3311384.89484$ South
$x1 = -82382.22462$ East

D2: $y2 = -3310991.36474$
$x2 = -82057.84050$

Linear Relationship between the Base Stations

To intersect the two bearings determined from the base stations and record the subsequent locality of the intersection, first the linear relationship between the two base points D1 and D2 must be known.

The mathematical formula for a straight line is;

$$y = mx + c$$

The slope of the line is defined to be the ratio of rise to run, it is usually denoted by the letter m hence, m = rise / run (Fig. 4.2).

m = (y2-y1)/(x2-x1)

= {(-3311384.89484) - (-3310991.36474)} / {(-82382.22462) – (-82057.84050)}

= 393.53010 / 324.38412

= 1.213161

c = y – mx

= -3311384.89484 - (1.213161 * -82382.22462)

= -3211442.00894

Therefore linear relationship between D1 and D2 is;

y = 1.213161x - 3211442.00894.

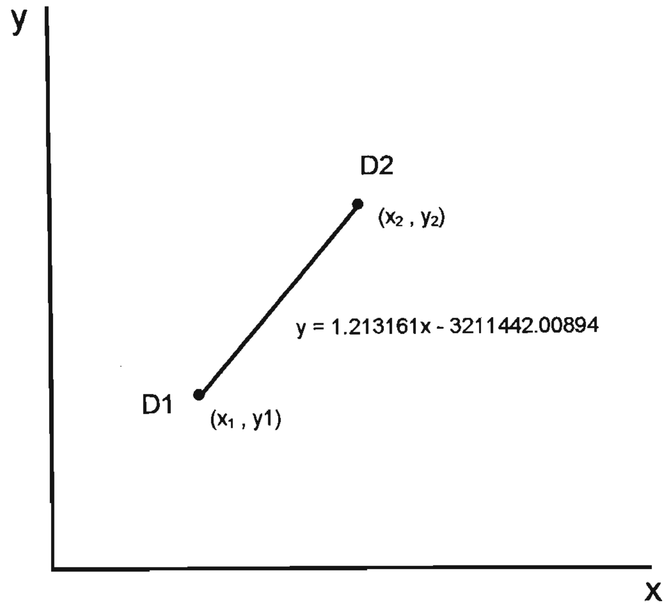


Figure 4.2. Linear relationship between D1 and D2.

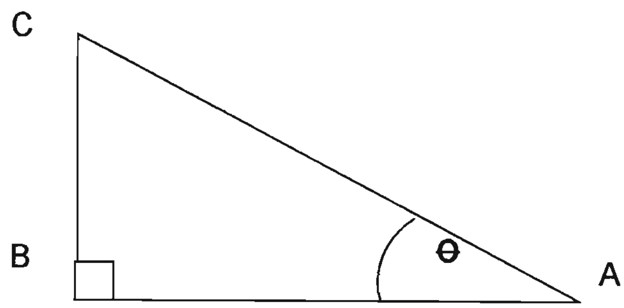
Calculating the Angle of the Slope between the Two Base Stations

As the bearing/direction of a tagged bird was calculated as an angle between the two base stations, the true bearing of the bird from North has to be determined. In order to achieve this, the angle of the slope between the two base stations was calculated. To allow for constant readings, the zero degree for each base station was referenced on each other for each nest site investigated. The true bearing of the bird from both stations can then be calculated from the angle of the slope to determine where these bearings intersect, and thus calculate the position of the bird when directional readings were taken.

sinØ = BC/AC

cosØ = AB/AC

tanØ = sinØ/cosØ = BC/AB



Calculating the angle of the slope.

To calculate the angle in degrees from the ratio of the opposite side to the adjacent side, the Arctangent of the slope has to be calculated as follows.

tanØ = BC/AB = rise / run = m

Ø = 1/tan m or

Ø = tan-1 m

Therefore: if m = 1.213161 for Diptank

then,

tan Ø = 1.213161

Ø = tan-11.213161

= 50.5014°

Calculating the Direction of the Bearings

As the slope of D1D2 is positive, any bearing greater than 180˚, the angle of the slope of D1D2 (50.5014°) must be added to the difference between 360˚ and the bearing. Conversely, if the bearing is smaller than 180˚, then the bearing must be subtracted from the angle of the slope of D1D2 (50.5014°).

If bearing1 > 180° then Ø + (360° – bearing1)

Or if bearing1 < 180° then Ø - bearing1

For example let the bearing for Diptank Base station 1 equal 300, and the bearing for Diptank Base station 2 equal 75 (Fig. 4.4).

Bearing1 = 300°

50.50° + (360° – 300°)

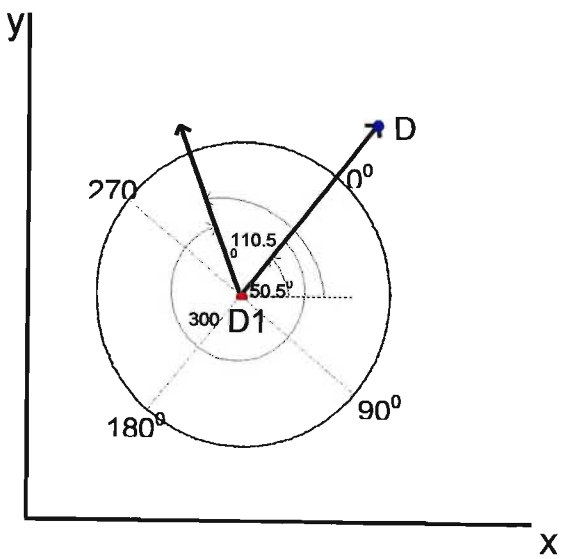
= 50.50° + 60°

= 110.50°

Bearing2 = 75°

50.50° - 75°

= -24.50°



Calculating the direction of the bearings.

Calculating the Linear Equation of the Bearings

In order to compute the intersection between bearing 1 and bearing 2, the linear equation for each bearing must be calculated.

If the straight line equation for Bearing 1 from Base Station 1 is taken to be:

$y1 = m1x1 + c1$

And the equation for Bearing 2 from Base Station 2

$y2 = m2x2 + c2$

The coordinates for Base Station 1 and 2 are known, thus the slope (m) and the y-intercept (c) must be calculated.

Calculating the slope of the bearings from the two base stations

As described above, the tangent of an angle is the sine divided by the cosine of an angle, which is the ratio of the opposite side to the adjacent side, which in turn is the ratio of rise to run, the slope.

$M = BC/AB = \tan Ø$

$M1 = \tan 110.50$

$= -2.674$

$M2 = \tan -24.50$

$= -0.455$

Calculating the y - Intercept (C) of the bearings from the two base stations

$y1 = m1x1 + c1$

$c1 = y1 – (m1x1)$

$c1 = -3311384.89484 – (-2.674 * -82382.22462)$

$= -3531708.773032$

y2 = m2x2 + c2

c2 = y2 – (m2x2)

c2 = -3310991.36474 – (-0.455 * -82057.84050)

= -3348384.711296

Linear equation of the bearings

Bearing 1: y = -2.674x - 3531708.773032

Bearing 2: y = -0.455x - 3348384.711296

Calculating the Intersections of the Bearings

It has been determined that at the point where the two bearing lines intersect the x and y co-ordinates are the same.

Therefore if,

y1 = m1x1 + c1 and

y2 = m2x2 + c2

then,

m1x1 + c1 = m2x2 + c2

c1 – c2 = m2x2 – m1x1

c1 – c2 = x(m2 – m1)

x = (c1 – c2) / (m2 – m1)

x = (-3531708.773032 + 3348384.711296) / (-0.455 + 2.674)

x = -82626.217299

To determine y,

y = m1x1 + c1

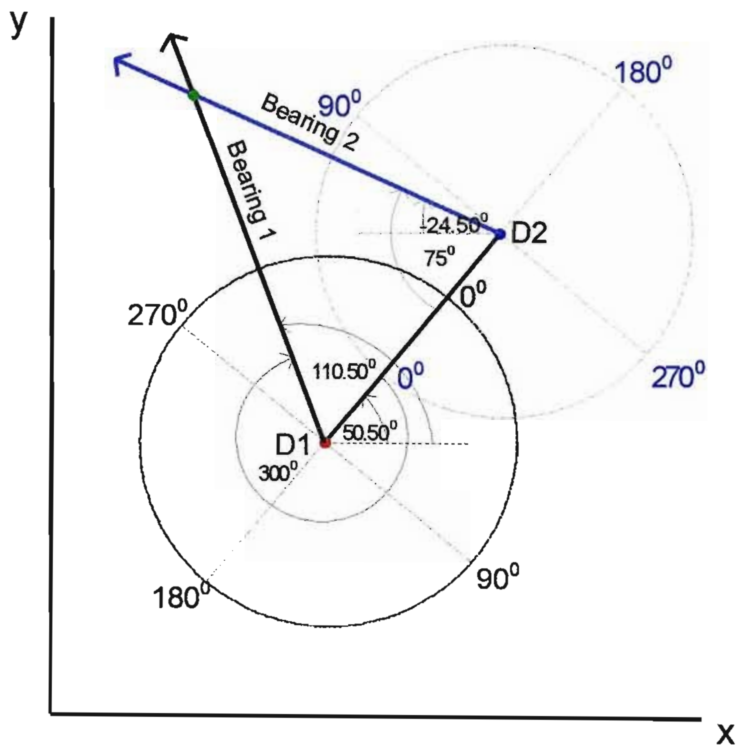
y = (-2.674 * -82626.217299) -3531708.773032

y = -3310732.358282

The point at which the bearing of 3000 from Base Station 1, and 750 from base station 2 at Diptank is:

x = -82626.217299

y = -3310732.358282



Determining the intersections of the bearings.

Appendix III

Malaise trap sample collection (after Hawkes, 2003).

1. Fill 6 sample jars with 100 ml collecting fluid each (10% EtOH + soap)
2. Fill in date and trap numbers on 6 labels, carry one empty sample jar
3. For each trap:
    - remove sample jar, swirl contents and pour into empty jar, write time on label and add to jar & replace lid
    - add collecting fluid from one jar to sample jar & replace this on trap make sure insulating cover drainage is underneath
    - use jar that had contained the collecting fluid as empty jar for next sample

4. When all traps are emptied, return them to laboratory and for each sample:
    - half fill sample vial with 70% EtOH
    - pour contents of jar into strainer, discard collecting fluid
    - transfer label and any large insects to sample vial using forceps
    - tap strainer out on plastic disc
    - sweep specimens into sample vial using forceps and/or paint brush
    - add 70% EtOH if required to make vial three-quarters full, put on lid and store in large plastic jar (separate jar for each trap)

NOTE:

- Collect samples as close as possible to the same time every day: empty traps in the same order to aid this
- Please make a special note of any days on which samples were collected more than one hour earlier or later than normal
- Date on sample should be the date on which the trap was emptied
- Please keep duplicate records of weather observations
- Sample vial should not be more than three quarters full - if insects plus the half-full tube of EtOH is more than this, transfer half the insects to another vial (WITH A DUPLICATE LABEL and BOTH labels must indicate that there are 2 vials for that sample; also please make a note on the weather data sheet that there are more vials for samples on that day)

- Make sure that there is always at least 2cm depth of EtOH in the large storage jars - top up if needed

MALAISE TRAPS

A. SETTING UP

1. Extend the three sets of poles and insert into the sleeves on the black netting walls, starting at the end of the sleeve with the brass/copper & stainless steel "bottom" assembly. Ensure that the pole end marked with 2 notches and a "T" is inserted first and therefore ends up at the opposite end of the sleeve from the bottom assembly. Leave the netting "bunched up" on the first two pole segments.
2. Pass the ends of the poles marked with a "T" through the reinforced holes in the white netting roof, attach a guy-rope to each by placing the key-ring over the pole and then attach the three poles to the stainless steel centrepiece.
3. Insert the Perspex collecting head assembly through the tube of the centrepiece from above, pulling the tubular portion of the white netting roof through the centrepiece from below. Seat the netting tube around the Perspex tube and fix it in place using the elastic strap.
4. Pull the "bottom" assemblies to extend the black netting down the poles and insert the brass/copper tube into the end tubes of the poles.
5. Attach the hooks on the roof netting to the eyes on the bottom assemblies.
6. Position the trap and fix in place using pegs through the key-rings on the bottom assemblies and at the bottom junction of the three walls. Extend the guy-ropes and peg these out for additional stability.

B. OPERATION

1. Place approximately 100 ml collecting fluid into the collecting jar and screw this into the head assembly. Arrange the insulating cover so that rain can drain away.
2. Every 24 hours remove the collecting jars and strain the contents through the tea strainer , transfer the specimens to a Polytop vial and add 70% ethanol to bring the volume to ¾ full.

Appendix IV

Chi-Square test of observed frequencies of radio telemetry positional data versus the expected frequencies.

Land Cover	Tafeni Pos.	Tafeni Exp		O - E	(O-E)**2
Aliens	6	6.3724511	C: 1	-0.3725	0.0218
Grassland	313	226.7505002	C: 2	86.2495	32.8069
Plantation	0	67.4736879	C: 3	-67.4737	67.4737
Sugarcane	40	73.8576279	C: 4	-33.8576	15.5209
Wetland	20	4.5457329	C: 5	15.4543	52.5403
TOTAL	379	379	Sum	0.0000	168.3636
Land Cover	**Diptank Pos**	**Diptank Exp**		**O - E**	**(O-E)**2**
Aliens	51	36.6439651	C: 1	14.3560	5.6243
Grassland	204	144.4119838	C: 2	59.5880	24.5875
Orchard	0	6.2007940	C: 3	-6.2008	6.2008
Plantation	7	42.0112143	C: 4	-35.0112	29.1776
Sugarcane	4	41.7120288	C: 5	-37.7120	34.0956
Wetland	6	1.0200139	C: 6	4.9800	24.3137
TOTAL	272	272	Sum	0.0000	123.9994
Land Cover	**Florida Pos.**	**Florida Exp**		**O - E**	**(O-E)**2**
Aliens	1	11.5853977	C: 1	-10.5854	9.6717
Grassland	191	86.5736636	C: 2	104.4263	125.9605
Plantation	0	42.3833116	C: 3	-42.3833	42.3833
Sugarcane	17	102.6388527	C: 4	-85.6389	71.4546
Tea	32	19.3376793	C: 5	12.6623	8.2913
Waterbody	0	3.4080834	C: 6	-3.4081	3.4081
Wetland	33	8.0730117	C: 7	24.9270	76.9669
TOTAL	274	274	Sum	0.0000	338.1363
Land Cover	**Total Observed**	**Total Expected**		**O - E**	**(O-E)**2**
Aliens	58	75.3928048	C: 1	-17.393	4.0124
Forest	11	6.7653654	C: 2	4.235	2.6506
Grassland	708	455.9544878	C: 3	252.046	139.3274
Orchard	0	10.3560523	C: 4	-10.356	10.3561
Plantation	7	148.8868450	C: 5	-141.887	135.2160
Settlement	0	2.9887530	C: 6	-2.989	2.9888
Sugarcane	61	205.9659845	C: 7	-144.966	102.0321
Tea	32	17.2352972	C: 8	14.765	12.6483
Waterbody	4	4.7968788	C: 9	-0.797	0.1324
Wetland	59	11.6575311	C: 10	47.342	192.2628
TOTAL	940	940	Sum	0.000	601.6266

Appendix V

Chi-Square for random points - ecotone investigation.

	Observed vs. Expected Frequencies (Spreadsheet1) Chi-Square = 474.6817 df = 40 p < 0.000000			
Case	observed Var3	expected Var2	O - E	(O-E)**2 /E
C: 1	163.0000	88.0000	75.0000	63.9205
C: 2	121.0000	86.0000	35.0000	14.2442
C: 3	184.0000	67.0000	117.0000	204.3134
C: 4	81.0000	52.0000	29.0000	16.1731
C: 5	63.0000	58.0000	5.0000	0.4310
C: 6	37.0000	58.0000	-21.0000	7.6034
C: 7	43.0000	40.0000	3.0000	0.2250
C: 8	38.0000	40.0000	-2.0000	0.1000
C: 9	26.0000	31.0000	-5.0000	0.8065
C: 10	15.0000	31.0000	-16.0000	8.2581
C: 11	22.0000	25.0000	-3.0000	0.3600
C: 12	25.0000	29.0000	-4.0000	0.5517
C: 13	11.0000	25.0000	-14.0000	7.8400
C: 14	17.0000	22.0000	-5.0000	1.1364
C: 15	8.0000	27.0000	-19.0000	13.3704
C: 16	8.0000	15.0000	-7.0000	3.2667
C: 17	3.0000	23.0000	-20.0000	17.3913
C: 18	11.0000	23.0000	-12.0000	6.2609
C: 19	3.0000	19.0000	-16.0000	13.4737
C: 20	3.0000	21.0000	-18.0000	15.4286
C: 21	9.0000	13.0000	-4.0000	1.2308
C: 22	5.0000	16.0000	-11.0000	7.5625
C: 23	3.0000	13.0000	-10.0000	7.6923
C: 24	5.0000	14.0000	-9.0000	5.7857
C: 25	3.0000	11.0000	-8.0000	5.8182
C: 26	3.0000	8.0000	-5.0000	3.1250
C: 27	3.0000	10.0000	-7.0000	4.9000
C: 28	1.0000	16.0000	-15.0000	14.0625
C: 29	2.0000	6.0000	-4.0000	2.6667
C: 30	3.0000	4.0000	-1.0000	0.2500
C: 31	2.0000	5.0000	-3.0000	1.8000
C: 32	1.0000	6.0000	-5.0000	4.1667
C: 33	1.0000	1.0000	0.0000	0.0000
C: 34	0.0000	4.0000	-4.0000	4.0000
C: 35	4.0000	3.0000	1.0000	0.3333
C: 36	2.0000	5.0000	-3.0000	1.8000
C: 37	1.0000	1.0000	0.0000	0.0000
C: 38	5.0000	3.0000	2.0000	1.3333
C: 39	1.0000	1.0000	0.0000	0.0000
C: 40	0.0000	4.0000	-4.0000	4.0000
C: 41	4.0000	16.0000	-12.0000	9.0000
Sum	940.0000	940.0000	0.0000	474.6817

Appendix VI

Insect orders collected. Source: Picker, Griffiths and Weaving, 2002.

Apterygota	
Collembola	Springtails
Diplura	Two Pronged Bristle-tails
Exopterygota	
Ephemeroptera	Mayflies
Odonata	Dragonflies
Plecoptera	Stoneflies
Orthoptera	Grasshoppers and crickets
Embioptera	Web Spinners
Dictyoptera	Cockroaches and Mantids
Isoptera	Termites
Hemiptera	True Bugs
Endopterygota	
Coleoptera	Beetles
Mecoptera	Scorpionflies
Diptera	True Flies
Lepidoptera	Butterflies and Moths
Trichoptera	Caddis Flies
Hymenoptera	Ants, Bees and Wasps

Appendix VII

Statistical data tables for the Chi-Square test and the Kruskal-Wallis ANOVA for average insect mass (per orders), by habitat type.

Edible Coleoptera Average Mass (gm) and Habitat

Dependent: ColeAvg	Median Test, Overall Median = .002000; ColeAvg (Stat data 13 Nov05) Independent (grouping) variable: Habitat Chi-Square = 16.58803, df = 4, p = .0023 Grassland	Plantation	Sugarcane	Tea	Wetland	Total
<= Median: observed	24.00000	11.00000	24.00000	19.00000	15.00000	93.0000
expected	18.60000	18.60000	18.60000	18.60000	18.60000	
obs.-exp.	5.40000	-7.60000	5.40000	0.40000	-3.60000	
> Median: observed	8.00000	21.00000	8.00000	13.00000	17.00000	67.0000
expected	13.40000	13.40000	13.40000	13.40000	13.40000	
obs.-exp.	-5.40000	7.60000	-5.40000	-0.40000	3.60000	
Total: observed	32.00000	32.00000	32.00000	32.00000	32.00000	160.0000

Depend.: ColeAvg	Kruskal-Wallis ANOVA by Ranks; ColeAvg (Stat data 13 Nov05) Independent (grouping) variable: Habitat Kruskal-Wallis test: H (4, N= 160) =21.38306 p =.0003 Code	Valid N	Sum of Ranks	
Grassland	101	32	2084.00	[redacted]
Plantation	102	32	3344.00	
Sugarcane	103	32	1999.50	
Tea	104	32	2381.50	
Wetland	105	32	3071.00	

Edible Diptera Average Mass (gm) and Habitat

Dependent: DipAvg	Median Test, Overall Median = .001139; DipAvg (Stat data 13 Nov05) Independent (grouping) variable: Habitat Chi-Square = 36.25000, df = 4, p = .0000 Grassland	Plantation	Sugarcane	Tea	Wetland	Tota
<= Median: observed	7.00000	28.0000	21.00000	14.00000	10.00000	80.00
expected	16.00000	16.0000	16.00000	16.00000	16.00000	
obs.-exp.	-9.00000	12.0000	5.00000	-2.00000	-6.00000	
> Median: observed	25.00000	4.0000	11.00000	18.00000	22.00000	80.00
expected	16.00000	16.0000	16.00000	16.00000	16.00000	
obs.-exp.	9.00000	-12.0000	-5.00000	2.00000	6.00000	
Total: observed	32.00000	32.0000	32.00000	32.00000	32.00000	160.00

Depend.: DipAvg	Kruskal-Wallis ANOVA by Ranks; DipAvg (Stat data 13 Nov05) Independent (grouping) variable: Habitat Kruskal-Wallis test: H (4, N= 160) =42.48798 p =.0000 Code	Valid N	Sum of Ranks	
Grassland	101	32	3529.000	[redacted]
Plantation	102	32	1321.500	
Sugarcane	103	32	2165.000	
Tea	104	32	2849.000	
Wetland	105	32	3015.500	

Edible Hemiptera Average Mass (gm) and Habitat

Dependent: HemiAvg	Median Test, Overall Median = .7386E-; HemiAvg (Stat data 13 Nov05) Independent (grouping) variable: Habitat Chi-Square = 30.00000, df = 4, p = .0000					
	Grassland	Plantation	Sugarcane	Tea	Wetland	Tota
<= Median: observed	17.00000	26.0000	19.00000	13.00000	5.0000	80.00
expected	16.00000	16.0000	16.00000	16.00000	16.0000	
obs.-exp.	1.00000	10.0000	3.00000	-3.00000	-11.0000	
> Median: observed	15.00000	6.0000	13.00000	19.00000	27.0000	80.00
expected	16.00000	16.0000	16.00000	16.00000	16.0000	
obs.-exp.	-1.00000	-10.0000	-3.00000	3.00000	11.0000	
Total: observed	32.00000	32.0000	32.00000	32.00000	32.0000	160.00

Depend.: HemiAvg	Kruskal-Wallis ANOVA by Ranks; HemiAvg (Stat data 13 Nov05) Independent (grouping) variable: Habitat Kruskal-Wallis test: H (4, N= 160) =37.59138 p =.0000		
	Code	Valid N	Sum of Ranks
Grassland	101	32	2387.000
Plantation	102	32	1705.500
Sugarcane	103	32	2234.000
Tea	104	32	2692.000
Wetland	105	32	3861.500

Edible Hymenoptera Average Mass (gm) and Habitat

Dependent: HymAvg	Median Test, Overall Median = .001500; HymAvg (Stat data 13 Nov05) Independent (grouping) variable: Habitat Chi-Square = 2.651657, df = 4, p = .6177					
	Grassland	Plantation	Sugarcane	Tea	Wetland	Total
<= Median: observed	18.00000	14.00000	19.00000	17.00000	14.00000	82.0000
expected	16.40000	16.40000	16.40000	16.40000	16.40000	
obs.-exp.	1.60000	-2.40000	2.60000	0.60000	-2.40000	
> Median: observed	14.00000	18.00000	13.00000	15.00000	18.00000	78.0000
expected	15.60000	15.60000	15.60000	15.60000	15.60000	
obs.-exp.	-1.60000	2.40000	-2.60000	-0.60000	2.40000	
Total: observed	32.00000	32.00000	32.00000	32.00000	32.00000	160.0000

Depend.: HymAvg	Kruskal-Wallis ANOVA by Ranks; HymAvg (Stat data 13 Nov05) Independent (grouping) variable: Habitat Kruskal-Wallis test: H (4, N= 160) =7.417836 p =.1154		
	Code	Valid N	Sum of Ranks
Grassland	101	32	2299.000
Plantation	102	32	3046.500
Sugarcane	103	32	2220.000
Tea	104	32	2483.000
Wetland	105	32	2831.500

Edible Isoptera Average Mass (gm) and Habitat

Dependent: IsoAvg	Median Test, Overall Median = 0.00000; IsoAvg (Stat data 13 Nov05) Independent (grouping) variable: Habitat Chi-Square = 23.01370, df = 4, p = .0001					
	Grassland	Plantation	Sugarcane	Tea	Wetland	Tota
<= Median: observed	23.00000	32.00000	32.00000	31.00000	28.00000	146.000
expected	29.20000	29.20000	29.20000	29.20000	29.20000	
obs.-exp.	-6.20000	2.80000	2.80000	1.80000	-1.20000	
> Median: observed	9.00000	0.00000	0.00000	1.00000	4.00000	14.00
expected	2.80000	2.80000	2.80000	2.80000	2.80000	
obs.-exp.	6.20000	-2.80000	-2.80000	-1.80000	1.20000	
Total: observed	32.00000	32.00000	32.00000	32.00000	32.00000	160.000

Depend.: IsoAvg	Kruskal-Wallis ANOVA by Ranks; IsoAvg (Stat data 13 Nov05) Independent (grouping) variable: Habitat Kruskal-Wallis test: H (4, N= 160) =22.81304 p =.0001		
	Code	Valid N	Sum of Ranks
Grassland	101	32	3075.000
Plantation	102	32	2352.000
Sugarcane	103	32	2352.000
Tea	104	32	2437.000
Wetland	105	32	2664.000

Appendix VIII

Summary of averaged environmental and insect sample data.

Date	Time	AM/PM	Min temp (°C)	Max temp (°C)	Ave temp (°C)	Min RH (%)	Max RH (%)	Ave RH (%)
25 November 2004	12:00:00	PM	20.95	35.70	30.05	24.80	78.30	46.89
26 November 2004	06:00:00	AM	15.62	29.50	23.78	40.50	100.00	62.30
26 November 2004	12:00:00	PM	16.76	29.90	23.61	44.90	98.80	68.70
27 November 2004	06:00:00	AM	17.14	19.81	18.43	100.00	100.00	100.00
27 November 2004	12:00:00	PM	17.14	19.81	18.67	100.00	100.00	100.00
28 November 2004	06:00:00	AM	17.90	30.31	26.55	51.70	95.10	65.15
28 November 2004	12:00:00	PM	18.28	31.12	22.22	55.60	99.60	85.01
29 November 2004	06:00:00	AM	16.00	34.01	27.93	38.50	89.20	56.66
29 November 2004	12:00:00	PM	20.19	33.59	27.36	41.50	95.60	65.15
30 November 2004	06:00:00	AM	16.38	18.66	17.45	100.00	100.00	100.00
30 November 2004	12:00:00	PM	14.47	16.38	15.51	100.00	100.00	100.00
01 December 2004	06:00:00	AM	16.00	31.12	26.10	55.90	100.00	69.16
01 December 2004	12:00:00	PM	20.19	33.17	27.60	46.00	82.00	62.17
02 December 2004	06:00:00	AM	16.00	22.86	19.53	72.10	100.00	85.50
02 December 2004	12:00:00	PM	17.90	25.17	21.91	61.80	91.80	74.47
03 December 2004	06:00:00	AM	16.76	30.31	21.58	61.30	100.00	90.86
03 December 2004	12:00:00	PM	24.40	32.34	30.40	54.40	78.00	59.82
04 December 2004	06:00:00	AM	19.81	37.88	33.71	25.80	99.50	43.73
04 December 2004	12:00:00	PM	24.01	38.32	33.78	26.40	69.20	41.53
05 December 2004	06:00:00	AM	19.04	36.57	32.07	40.30	100.00	54.23
05 December 2004	12:00:00	PM	17.90	36.57	28.74	31.40	91.80	59.00
06 December 2004	06:00:00	AM	18.28	34.85	28.77	40.50	99.20	62.48
06 December 2004	12:00:00	PM	19.81	35.70	23.93	38.60	95.30	79.02
07 December 2004	06:00:00	AM	18.28	25.95	21.05	80.50	100.00	97.44
07 December 2004	12:00:00	PM	16.00	29.90	25.50	64.40	94.80	76.22
08 December 2004	06:00:00	AM	12.93	22.48	17.96	62.40	98.40	77.89
08 December 2004	12:00:00	PM	14.09	19.81	16.92	66.80	94.70	81.27
09 December 2004	06:00:00	AM	14.09	17.52	15.85	91.70	98.80	96.80
09 December 2004	12:00:00	PM	14.09	17.52	15.67	89.20	98.60	94.12
10 December 2004	06:00:00	AM	14.47	29.10	21.97	53.90	99.20	79.51
10 December 2004	12:00:00	PM	17.90	28.70	25.50	49.90	80.80	59.98
11 December 2004	06:00:00	AM	11.38	28.70	23.49	41.80	99.00	63.75

Min abs (gm/m3)	Max abs (gm/m3)	Ave abs (gm/m3)	TEA E (gm)	TEA E no	SUGAR E (gm)	SUGAR E no	WET E (gm)	WET E no
9.70	15.50	13.62	0.146	73	0.106	50	0.309	90
10.30	14.10	12.69	0.267	40	0.047	42	0.25	74
12.80	14.80	13.91	0.152	75	0.0459	41	0.352	91
14.60	17.10	15.77	0.096	36	0.01	7	0.063	49
14.60	17.10	16.00	0.108	68	0.181	23	0.144	75
13.90	18.80	16.13	0.093	98	0.05	61	0.196	140
14.80	19.90	16.36	0.17	97	0.023	32	0.141	58
11.60	18.40	14.90	0.039	64	0.109	89	0.176	113
14.10	22.40	16.41	0.371	168	0.107	33	0.205	136
13.90	16.00	14.87	0.009	14	0.006	20	0.065	24
12.40	13.90	13.22	0.08	40	0.006	14	0.017	30
13.60	19.90	16.67	0.08	69	0.171	143	0.246	73
12.00	19.70	16.24	0.074	61	0.1	127	0.188	101
12.80	15.80	14.26	0.134	29	0.029	45	0.061	44
13.50	15.40	14.22	0.047	58	0.036	65	0.08	84
14.30	20.00	16.99	0.039	20	0.081	67	0.249	121
17.40	20.30	18.46	0.045	30	0.069	86	0.152	86
11.50	19.40	15.06	0.031	35	0.024	39	0.068	36
11.30	19.30	14.71	0.013	27	0.01	31	0.17	86
15.40	20.80	17.58	0.046	26	0.11	74	0.232	80
12.80	19.80	15.62	0.045	28	0.045	64	0.329	128
14.30	18.80	16.69	0.046	42	0.149	92	0.346	100
13.60	18.00	16.29	0.067	59	0.016	53	0.147	74
15.40	24.30	17.97	0.077	21	0.032	49	0.203	117
12.10	23.00	18.06	0.063	32	0.086	53	0.244	117
11.10	12.80	11.77	0.012	15	0.071	48	0.072	51
11.10	13.00	11.63	0.038	31	0.034	29	0.068	79
11.90	14.70	13.06	0.066	5	0.011	13	0.031	26
11.50	13.80	12.56	0.041	36	0.019	16	0.05	90
12.20	18.00	15.25	0.053	54	0.148	43	0.073	87
12.10	16.60	14.09	0.046	41	0.094	76	0.15	98
10.10	16.60	12.96	0.026	18	0.04	28	0.118	50

GRASS E (gm)	GRASS E no	PLANT E (gm)	PLANT E no	TEA I (gm)	TEA I no	SUGAR I (gm)	SUGAR I no	WET I (gm)	WET I no
0.599	121	0.253	258	0	0	0.552	1	0.214	3
0.083	97	0.22	88	0.002	1	0.002	3	0.01	3
0.078	65	0.178	113	0.951	1	0	0	0.001	2
0.015	17	0.113	133	0	0	0.002	1	0	0
0.046	12	0.096	129	0.002	6	0	0	0.002	2
0.223	123	0.219	140	0	0	0	0	0.016	1
0.237	85	0.068	85	0	0	0	0	0.011	3
0.334	113	0.201	154	0.524	2	0.331	3	0.007	1
0.719	155	0.189	114	0	0	0.108	2	0.106	3
0.055	17	0.083	45	0.001	1	0	0	0.001	2
0.033	31	0.127	52	0.001	13	0.002	4	0.03	4
0.103	116	0.169	215	0	0	0.001	3	0.156	22
0.209	146	0.2032	264	0.008	2	0.002	4	0.004	8
0.174	94	0.095	103	0.028	2	0.011	22	0.006	3
0.179	52	0.128	147	0.003	1	0.006	9	0.012	2
0.094	158	0.121	229	0.004	2	0.307	9	0.012	8
0.107	67	0.214	205	0.128	1	0.003	4	0.031	3
0.076	75	0.1	128	0.26	2	0.201	1	0.037	1
0.04	41	0.018	39	0.763	4	0.489	2	0.008	2
0.074	49	0.156	153	0.842	2	0	0	0.07	2
0.117	48	0.296	195	0	0	0.001	1	0.019	3
0.098	53	0.088	149	0.003	1	0.001	2	0.001	1
0.225	31	0.0505	402	0	0	0.003	4	0	0
0.17	44	0.18	167	0.001	6	0.005	9	0.019	1
0.147	47	0.049	217	0.001	4	0.002	4	0.001	1
0.047	21	0.115	216	0.043	4	0.016	16	0.006	3
0.071	27	0.083	193	0	0	0.001	1	0.002	2
0.003	3	0.029	43	0.001	1	0.033	5	0	0
0.067	24	0.036	182	0	0	0.002	3	0	0
0.141	81	0.065	140	0.172	1	0.002	3	0.007	1
0.163	54	0.169	140	0	0	0	0	0.075	4
0.111	59	0.095	86	0.183	2	0.001	1	0.004	2

GRASS I (gm)	GRASS I no	PLANT I (gm)	PLANT I no	TOTAL EDIBLE NO.	TOTAL EDIBLE MASS	TOTAL INEDIBLE NO.	TOTAL INEDIBLE MASS
0.003	2	0.004	3	592	1.413	9	0.773
0	0	0.004	7	341	0.867	14	0.018
0.003	4	0.516	4	385	0.8059	11	1.471
0	0	0.001	7	242	0.297	8	0.003
0	0	0.004	3	307	0.575	11	0.008
0.184	3	1.129	8	562	0.781	12	1.329
0.003	5	0.561	7	357	0.639	15	0.575
0.01	3	0.012	4	533	0.859	13	0.884
0.006	6	0.299	5	606	1.591	16	0.519
0.004	9	0.003	15	120	0.218	27	0.009
0.004	3	0.002	112	167	0.263	136	0.039
0.007	3	0.005	13	616	0.769	41	0.169
0.002	1	0.607	7	699	0.7742	22	0.623
0.017	36	0.004	5	315	0.493	68	0.066
0.004	5	0.002	3	406	0.47	20	0.027
0.031	20	0.003	4	595	0.584	43	0.357
0.003	2	0.464	6	474	0.587	16	0.629
0.001	1	0.036	2	313	0.299	7	0.535
0.201	2	0.164	2	224	0.251	12	1.625
0.098	1	0.002	2	382	0.618	7	1.012
0.024	9	0.003	3	463	0.832	16	0.047
0.01	5	0.002	2	436	0.727	11	0.017
0.003	4	0.003	3	619	0.5055	11	0.009
0.004	3	0.622	429	398	0.662	448	0.651
0.03	35	0.453	5	466	0.589	49	0.487
0.008	1	0.002	2	351	0.317	26	0.075
0.001	1	0.002	1	359	0.294	5	0.006
0	0	0.02	548	90	0.14	554	0.054
0	0	0.021	362	348	0.213	365	0.023
0.005	5	0.001	1	405	0.48	11	0.187
0.006	3	0.008	2	409	0.622	9	0.089
0.005	1	0.078	5	241	0.39	11	0.271

Appendix IX

FIRM – Formal Inference based Recursive Modelling.

Version 3.0: 2005/02/18

University of Minnesota

FIRM Formal Inference - based Recursive Modelling
Version 3.0: 2005/02/18
Copyright 2002 Douglas M Hawkins
University of Minnesota

Dependent variable no. 3 is named HabitatType
Predictor variables

no	posn	name		no of cats	split	merge	may?	type
1	14	EdWt	(Edible Mass)	0	5.000	5.100	yes	real
2	15	EdNum	(Edible Number)	0	5.000	5.100	yes	real
3	16	EdAvgWt	(Edible Average Mass)	0	5.000	5.100	yes	real
4	17	DipWt	(Diptera Mass)	0	5.000	5.100	yes	real
5	18	DipNum	(Diptera Number)	0	5.000	5.100	yes	real
6	19	DipAvgWt	(Diptera Average Mass)	0	5.000	5.100	yes	real
7	20	HemWt	(Hemiptera Mass)	0	5.000	5.100	yes	real
8	21	HemNum	(Heniptera Number)	0	5.000	5.100	yes	real
9	22	HemAvgWt	(Hemiptera Average Mass)	0	5.000	5.100	yes	real
10	23	IsoWt	(Isoptera Mass)	0	5.000	5.100	yes	real
11	24	IsoNum	(Isoptera Number)	0	5.000	5.100	yes	real
12	25	IsoAvgWt	(Isopter Average Mass)	0	5.000	5.100	yes	real
13	26	ColWt	(Coleoptera Mass)	0	5.000	5.100	yes	real
14	27	ColNum	(Coleoptera Number)	0	5.000	5.100	yes	real
15	28	ColAvgWt	(Coleoptera Average Mass)	0	5.000	5.100	yes	real
16	29	HymWt	(Hymenoptera Mass)	0	5.000	5.100	yes	real
17	30	HymNum	(Hymenoptera Number)	0	5.000	5.100	yes	real
18	31	HymAvgWt	(Hymenoptera Average Mass)	0	5.000	5.100	yes	real

```
Run options in effect
 Full split/merge details of predictors
 Minimum size of a group may have 5
 For a group to be analyzed, it must: - contain at least 10 cases;
 Analysis will stop after   50 groups have been formed
 Minimum % raw significance to split 1.000
 Minimum % conservative significance to split 1.000
 Maximum # of ways a node may be split 5
 Dependent has    5 categories named

            1   G    (grassland)
            2   P    (Plantation)
            3   S    (Sugarcane)
            4   T    (Tea)
            5   W    (Wetland)

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Analysis of group 1

```
Predictor                    P values

        Bonferroni  mult. com  breakdown into classes
EdWt     0.0135%  16.4516%  <=3.60E-02 ;; <=4.70E-02 ;; <=8.00E-02 ;; <=0.128 ;; >0.128
EdNum    5.24E-10%  4.97E-03%  <=42. ;; <=53. ;; <=73. ;; <=143. ;; >143.
EdAvgWt  6.10E-05%  2.4068%  <=8.46E-04 ;; <=1.11E-03 ;; <=1.50E-03 ;; >1.50E-03
DipWt    3.91E-04%  4.8612%  <=4.00E-02 ;; <=0.101 ;; >0.101
DipNum   8.41E-22%  3.25E-12%  <=63. ;; <=110. ;; >110.
DipAvgWt 1.37E-06%  0.2736%  <=4.60E-04 ;; <=1.03E-03 ;; >1.03E-03
HemWt    0.2513%  47.6030%  <=1.80E-02 ;; <=3.20E-02 ;; >3.20E-02
HemNum   0.1172%  34.6620%  <=7. ;; >7.
HemAvgWt 2.00E-08%  0.0224%  <=8.18E-04 ;; <=1.33E-03 ;; >1.33E-03
```

```
IsoWt     6.43E-04%  0.0126%   <=0.0 ;; >0.0
IsoNum    6.43E-04%  0.0126%   <=0.0 ;; >0.0
IsoAvgWt 6.43E-04%  0.0126%   <=0.0 ;; >0.0
ColWt     5.32E-04%  6.0260%   <=1.00E-03 ;; <=8.00E-03 ;; <=3.40E-02 ;; >3.40E-02
ColNum    1.52E-07%  2.24E-03%  <=3. ;; >3.
ColAvgWt 1.7762%  56.4341% <=0.0 ;; <=6.67E-04 ;; <=8.00E-03 ;; <=1.58E-02 ;; >1.58E-02
HymWt     0.0724%  2 9.0536%  <=7.00E-03 ;; >7.00E-03
HymNum    1.8118%  38.9205%  <=5. ;; >5.
HymAvgWt 10.4318%  87.5270%  <=2.00E-03 ;; <=2.50E-03 ;; >2.50E-03

Best predictor    5   DipNum   Bonferroni and MC P values 8.41E-22% 3.25E-12%
Chisquared 124.974 nominal P   4.62E-24%

Group   size      G        P        S        T        W     splittable?  makeup
  2     103      27        5       29       30       12        T          <=63.
  3      34       3        7        3        1       20        T          <=110.
  4      23       2       20        0        1        0        T          >110.


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Analysis of group    2
Predictor                    P values

               Bonferroni  mult. com  breakdown into classes
EdWt             34.9582%  89.9141%  <=5.30E-02 ;; <=8.00E-02 ;; <=0.11 ;; >0.11
EdNum            35.9332%  94.9519%  <=42. ;; <=53. ;; >53.
EdAvgWt          0.1004%   34.7115%  <=8.46E-04 ;; <=1.06E-03 ;; <=1.50E-03 ;; >1.50E-03
DipWt            0.4054%   53.1589%  <=3.20E-02 ;; <=5.60E-02 ;; >5.60E-02
DipNum           0.2540%   47.7254%  <=39. ;; <=43. ;; >43.
DipAvgWt         4.0026%   72.3020%  <=6.67E-04 ;; <=1.81E-03 ;; <=3.00E-03 ;; >3.00E-03
HemNum           6.3167%   83.3624%  <=7. ;; <=29. ;; >29.
HemAvgWt         8.73E-03% 11.7597%  <=1.33E-03 ;; >1.33E-03
IsoWt            1.28E-03% 9.84E-03%  <=8.00E-03 ;; >8.00E-03
IsoNum           1.28E-03% 9.84E-03% <=1. ;; >1.
IsoAvgWt         2.01E-03% 0.0148%   <=0.0 ;; >0.0
ColWt            28.3922%  74.6731%  <=1.00E-03 ;; <=2.00E-03 ;; <=2.40E-02 ;; >2.40E-02
ColNum           4.42E-03% 0.8151%   <=3. ;; >3.
ColAvgWt         95.2896%  98.0899%  <=0.0 ;; <=6.67E-04 ;; >6.67E-04
HymNum           1.4190%   28.1532%  <=5. ;; >5.

Best predictor   10   IsoWt   Bonferroni and MC P values 1.28E-03% 9.84E-03%
Chisquared  21.140 nominal P   4.27E-04%

Group    size      G        P        S        T        W     splittable?  makeup
  5       96      20        5       29       30       12        T          <=8.00E-03
  6        7       7        0        0        0        0        F          >8.00E-03


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Analysis of group    3
Predictor                    P values

               Bonferroni  mult. com  breakdown into classes
EdAvgWt          1.1465%   19.3345%  <=1.85E-03 ;; >1.85E-03
DipWt            0.8893%   16.7788%  <=9.70E-02 ;; >9.70E-02
DipAvgWt         0.8893%   16.7788%  <=1.12E-03 ;; >1.12E-03
HemWt            1.0939%   24.7966%  <=7.00E-03 ;; >7.00E-03
HemAvgWt         0.0117%    0.9782%  <=1.06E-03 ;; >1.06E-03
ColWt            0.9308%   13.0498%  <=1.80E-02 ;; <=3.40E-02 ;; >3.40E-02
ColAvgWt         0.4285%    5.3047%  <=4.00E-03 ;; <=5.43E-03 ;; >5.43E-03

Best predictor    9   HemAvgWt   Bonferroni and MC P values   0.0117%   0.9782%
Chisquared  18.533 nominal P   1.67E-03%

Group    size      G        P        S        T        W     splittable?  makeup
  7       17       2        7        3        1        4        T          <=1.06E-03
  8       17       1        0        0        0       16        T          >1.06E-03


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Analysis of group     4
 Predictor                        P values

                              Bonferroni  mult. com  breakdown into classes
 No prediction possible


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Analysis of group     5
Predictor                        P values

              Bonferroni  mult. com  breakdown into classes
EdWt             2.2411%    76.5188%  <=5.30E-02 ;; >5.30E-02
EdNum           72.1356%     97.4063%  <=42. ;; <=53. ;; >53.
EdAvgWt          0.9221%    57.0329%  <=8.46E-04 ;; <=1.06E-03 ;; <=1.62E-03 ;; >1.62E-03
DipWt            0.3951%    51.2013%  <=5.60E-02 ;; >5.60E-02
DipNum           0.5047%    55.7429%  <=39. ;; <=45. ;; >45.
DipAvgWt         1.6346%    63.1160%  <=6.67E-04 ;; <=1.81E-03 ;; <=3.44E-03 ;; >3.44E-03
HemNum          25.5102%     93.3058%  <=7. ;; <=29. ;; >29.
HemAvgWt         0.0297%    20.3410%  <=1.33E-03 ;; >1.33E-03
ColWt            7.6593%    48.5314%  <=1.00E-03 ;; <=2.00E-03 ;; <=2.40E-02 ;; >2.40E-02
ColNum           1.95E-03%     0.1396%  <=3. ;; >3.

Best predictor    14    ColNum    Bonferroni and MC P values 1.95E-03%    0.1396%
Chisquared  21.659 nominal P    3.26E-04%

Group     size      G         P         S         T         W     splittable?  makeup
  9        79       17        3         29        25        5        T          <=3.
 10        17        3        2          0         5        7        T          >3.


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Analysis of group     7
Predictor                        P values

              Bonferroni  mult. com  breakdown into classes
ColWt            0.4402%     1.7581%  <=3.40E-02 ;; >3.40E-02
ColNum           0.2519%     1.0936%  <=2. ;; >2.

Best predictor    14    ColNum    Bonferroni and MC P values    0.2519%    1.0936%
Chisquared   11.151 nominal P      0.0840%

Group     size      G         P         S         T         W     splittable?  makeup
 11         7        2        0          2         0        3        F          <=2.
 12        10        0        7          1         1        1        T          >2.


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Analysis of group     8
Predictor                        P values

                              Bonferroni  mult. com  breakdown into classes
No prediction possible


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Analysis of group     9
Predictor                        P values

              Bonferroni  mult. com  breakdown into classes
EdWt             1.1937%    67.6344%  <=0.11 ;; >0.11
EdAvgWt          0.2256%    43.2158%  <=8.46E-04 ;; >8.46E-04
DipWt           18.1965%    91.3766%  <=3.20E-02 ;; <=7.50E-02 ;; >7.50E-02
DipAvgWt         0.0855%    30.9144%  <=9.67E-04 ;; >9.67E-04
HemWt            1.5153%    64.8951%  <=3.00E-03 ;; >3.00E-03
HemNum           0.6318%    58.1677%  <=7. ;; >7.
ColWt            4.6887%    27.5984%  <=1.00E-03 ;; <=2.00E-03 ;; >2.00E-03

Best predictor     6   DipAvgWt   Bonferroni and MC P values    0.0855%   30.9144%
Chisquared  16.070 nominal P    6.11E-03%
```

```
Group     size      G        P        S        T        W     splittable?  makeup
 13        28       0        2       16        9        1        T         <=9.67E-04
 14        51      17        1       13       16        4        T         >9.67E-04


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Analysis of group    10
Predictor                     P values

                          Bonferroni  mult. com  breakdown into classes
DipNum                       0.2911%    1.2372%  <=24. ;; >24.

Best predictor     5   DipNum   Bonferroni and MC P values   0.2911%   1.2372%
Chisquared  10.884 nominal P      0.0970%

Group     size      G        P        S        T        W     splittable?  makeup
 15        8        2        0        0        5        1        F         <=24.
 16        9        1        2        0        0        6        F         >24.


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Analysis of group    12
Predictor                     P values
                          Bonferroni  mult. com  breakdown into classes
No prediction possible


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Analysis of group    13
Predictor                     P values
                          Bonferroni  mult. com  breakdown into classes
No prediction possible


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Analysis of group    14
Predictor                     P values

          Bonferroni  mult. com  breakdown into classes
EdAvgWt       24.5006%   78.0616%  <=1.06E-03 ;; <=1.62E-03 ;; >1.62E-03
HemWt          0.5922%   50.4063%  <=1.00E-03 ;; >1.00E-03

Best predictor     7   HemWt   Bonferroni and MC P values   0.5922%  50.4063%
Chisquared  12.289 nominal P     0.0456%

Group     size      G        P        S        T        W     splittable?  makeup
 17        5        0        1        1        2        1        F         <=1.00E-03
 18        46      17        0       12       14        3        T         >1.00E-03


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Analysis of group    18
Predictor                     P values

          Bonferroni  mult. com  breakdown into classes
EdAvgWt       51.4930%   80.1332%  <=1.06E-03 ;; <=1.62E-03 ;; >1.62E-03
No prediction possible
```

Appendix X

Statistical data tables for the Pearson Product-Moment correlations (Temperature, minimum, maximum and average).

Correlations (Stat data 13 Nov05)
Marked correlations are significant at p < .05000
(Casewise deletion of missing data)

Var. X & Var. Y	Mean	Std.Dv.	r(X,Y)	r^2	t	p	N	Constant dep: Y	Slope dep: Y	Constant dep: X	Slope dep: X
MinTemp	17.31750	2.84581									
EdGm	0.11829	0.10194	0.222745	0.049615	2.872013	0.004639	160	-0.01990	0.007979	16.58200	6.2180
MinTemp	17.31750	2.84581									
EdNum	80.13125	59.92838	0.180866	0.032712	2.311568	0.022093	160	14.17322	3.808750	16.62927	0.0086
MinTemp	17.31750	2.84581									
DipGm	0.06738	0.05260	0.052016	0.002706	0.654713	0.513605	160	0.05073	0.000961	17.12787	2.8144
MinTemp	17.31750	2.84581									
DipNum	59.50625	53.94348	0.122404	0.014983	1.550256	0.123081	160	19.32578	2.320224	16.93324	0.0065
MinTemp	17.31750	2.84581									
HemiGm	0.01107	0.01134	0.152031	0.023113	1.933473	0.054966	160	0.00058	0.000606	16.89511	38.1392
MinTemp	17.31750	2.84581									
HemiNum	12.80000	13.63255	0.120382	0.014492	1.524268	0.129441	160	2.81336	0.576679	16.99584	0.0251
MinTemp	17.31750	2.84581									
IsoGm	0.00962	0.06571	0.129328	0.016726	1.639395	0.103121	160	-0.04209	0.002986	17.26362	5.6014
MinTemp	17.31750	2.84581									
IsoNum	1.27500	8.51853	0.127589	0.016279	1.616979	0.107878	160	-5.33887	0.381919	17.26315	0.0426
MinTemp	17.31750	2.84581									
ColeGm	0.01521	0.02973	0.183631	0.033720	2.348133	0.020106	160	-0.01801	0.001919	17.05013	17.5754
MinTemp	17.31750	2.84581									
ColeNum	2.92500	3.06030	0.224924	0.050591	2.901601	0.004243	160	-1.26369	0.241876	16.70571	0.2092
MinTemp	17.31750	2.84581									
HymGm	0.01099	0.02603	0.154627	0.023910	1.967297	0.050900	160	-0.01351	0.001414	17.13177	16.9042
MinTemp	17.31750	2.84581									
HymNum	2.45625	2.67964	0.225348	0.050782	2.907358	0.004170	160	-1.21834	0.212189	16.72967	0.2393
MaxTemp	28.54156	6.57350									
EdGm	0.11829	0.10194	0.333188	0.111015	4.441923	0.000017	160	-0.02920	0.005167	26.00028	21.4844
MaxTemp	28.54156	6.57350									
EdNum	80.13125	59.92838	0.293812	0.086325	3.863684	0.000163	160	3.68041	2.678579	25.95909	0.0322
MaxTemp	28.54156	6.57350									
DipGm	0.06738	0.05260	0.166981	0.027883	2.128805	0.034821	160	0.02925	0.001336	27.13539	20.8697
MaxTemp	28.54156	6.57350									
DipNum	59.50625	53.94348	0.183539	0.033687	2.346922	0.020170	160	16.51809	1.506160	27.21065	0.0224
MaxTemp	28.54156	6.57350									
HemiGm	0.01107	0.01134	0.329871	0.108815	4.392260	0.000020	160	-0.00517	0.000569	26.42458	191.1501
MaxTemp	28.54156	6.57350									
HemiNum	12.80000	13.63255	0.309324	0.095682	4.088670	0.000069	160	-5.50932	0.641497	26.63240	0.1492
MaxTemp	28.54156	6.57350									
IsoGm	0.00962	0.06571	0.123172	0.015171	1.560122	0.120732	160	-0.02552	0.001231	28.42303	12.3226
MaxTemp	28.54156	6.57350									
IsoNum	1.27500	8.51853	0.123241	0.015188	1.561015	0.120521	160	-3.28328	0.159707	28.42031	0.0951
MaxTemp	28.54156	6.57350									
ColeGm	0.01521	0.02973	0.224350	0.050333	2.893798	0.004344	160	-0.01375	0.001015	27.78703	49.5994
MaxTemp	28.54156	6.57350									
ColeNum	2.92500	3.06030	0.317816	0.101007	4.213330	0.000042	160	-1.29798	0.147959	26.54476	0.6827
MaxTemp	28.54156	6.57350									
HymGm	0.01099	0.02603	0.210237	0.044200	2.703053	0.007622	160	-0.01277	0.000833	27.95824	53.0895
MaxTemp	28.54156	6.57350									
HymNum	2.45625	2.67964	0.428002	0.183186	5.952686	0.000000	160	-2.52345	0.174472	25.96263	1.0499
AvgTemp	23.86278	5.24796									
EdGm	0.11829	0.10194	0.292893	0.085786	3.850471	0.000171	160	-0.01748	0.005690	22.07931	15.0778
AvgTemp	23.86278	5.24796									
EdNum	80.13125	59.92838	0.229104	0.052488	2.958477	0.003567	160	17.70105	2.616217	22.25513	0.0201
AvgTemp	23.86278	5.24796									
DipGm	0.06738	0.05260	0.114313	0.013067	1.446370	0.150054	160	0.04004	0.001146	23.09425	11.4061
AvgTemp	23.86278	5.24796									
DipNum	59.50625	53.94348	0.115148	0.013259	1.457080	0.147079	160	31.26228	1.183599	23.19617	0.0112
AvgTemp	23.86278	5.24796									
HemiGm	0.01107	0.01134	0.306934	0.094208	4.053769	0.000079	160	-0.00476	0.000663	22.29020	141.9938
AvgTemp	23.86278	5.24796									
HemiNum	12.80000	13.63255	0.302482	0.091495	3.989007	0.000101	160	-5.95026	0.785753	22.37231	0.1164
AvgTemp	23.86278	5.24796									
IsoGm	0.00962	0.06571	0.116219	0.013507	1.470811	0.143331	160	-0.02510	0.001455	23.77349	9.2824
AvgTemp	23.86278	5.24796									
IsoNum	1.27500	8.51853	0.115722	0.013392	1.464442	0.145060	160	-3.20740	0.187841	23.77188	0.0713
AvgTemp	23.86278	5.24796									
ColeGm	0.01521	0.02973	0.198334	0.039336	2.543547	0.011934	160	-0.01160	0.001124	23.33025	35.0059
AvgTemp	23.86278	5.24796									
ColeNum	2.92500	3.06030	0.326643	0.106696	4.344121	0.000025	160	-1.62034	0.190478	22.22435	0.5601
AvgTemp	23.86278	5.24796									
HymGm	0.01099	0.02603	0.237476	0.056395	3.072933	0.002497	160	-0.01712	0.001178	23.33675	47.8754
AvgTemp	23.86278	5.24796									
HymNum	2.45625	2.67964	0.459279	0.210937	6.499048	0.000000	160	-3.13982	0.234511	21.65343	0.8995

Statistical data tables for the Pearson Product-Moment correlation (Relative humidity, minimum, maximum and average).

Correlations (Stat data 13 Nov05)
Marked correlations are significant at p < .05000
(Casewise deletion of missing data)

Var. X & Var. Y	Mean	Std.Dv.	r(X,Y)	r²	t	p	N	Constant dep: Y	Slope dep: Y	Constant dep: X	Slope dep: X
MinRH	57.89375	22.81734									
EdGm	0.11829	0.10194	-0.319283	0.101942	-4.23499	0.000039	160	0.2009	-0.001427	66.34669	-71.463
MinRH	57.89375	22.81734									
EdNum	80.13125	59.92838	-0.260513	0.067867	-3.39171	0.000878	160	119.7434	-0.684222	65.84185	-0.099
MinRH	57.89375	22.81734									
DipGm	0.06738	0.05260	-0.130785	0.017105	-1.65818	0.099264	160	0.0848	-0.000301	61.71670	-56.738
MinRH	57.89375	22.81734									
DipNum	59.50625	53.94348	-0.149561	0.022368	-1.90133	0.059079	160	79.9765	-0.353583	61.65824	-0.063
MinRH	57.89375	22.81734									
HemiGm	0.01107	0.01134	-0.326652	0.106701	-4.34426	0.000025	160	0.0205	-0.000162	65.17034	-657.028
MinRH	57.89375	22.81734									
HemiNum	12.80000	13.63255	-0.288071	0.082985	-3.78129	0.000221	160	22.7642	-0.172112	64.06534	-0.482
MinRH	57.89375	22.81734									
IsoGm	0.00962	0.06571	-0.131864	0.017388	-1.67210	0.096483	160	0.0316	-0.000380	58.33421	-45.792
MinRH	57.89375	22.81734									
IsoNum	1.27500	8.51853	-0.129019	0.016646	-1.63542	0.103952	160	4.0636	-0.048168	58.33437	-0.346
MinRH	57.89375	22.81734									
ColeGm	0.01521	0.02973	-0.239005	0.057123	-3.09391	0.002337	160	0.0332	-0.000311	60.68389	-183.411
MinRH	57.89375	22.81734									
ColeNum	2.92500	3.06030	-0.326831	0.106818	-4.34692	0.000025	160	5.4628	-0.043835	65.02146	-2.437
MinRH	57.89375	22.81734									
HymGm	0.01099	0.02603	-0.184615	0.034083	-2.36116	0.019437	160	0.0232	-0.000211	59.67176	-161.821
MinRH	57.89375	22.81734									
HymNum	2.45625	2.67964	-0.432690	0.187221	-6.03280	0.000000	160	5.3981	-0.050815	66.94353	-3.684
MaxRH	94.61563	8.02951									
EdGm	0.11829	0.10194	-0.128783	0.016585	-1.63237	0.104593	160	0.2730	-0.001635	95.81544	-10.143
MaxRH	94.61563	8.02951									
EdNum	80.13125	59.92838	-0.129981	0.016895	-1.64781	0.101379	160	171.9191	-0.970113	96.01115	-0.017
MaxRH	94.61563	8.02951									
DipGm	0.06738	0.05260	0.022664	0.000514	0.28496	0.776049	160	0.0533	0.000148	94.38249	3.460
MaxRH	94.61563	8.02951									
DipNum	59.50625	53.94348	-0.082537	0.006812	-1.04103	0.299453	160	111.9703	-0.554497	95.34670	-0.012
MaxRH	94.61563	8.02951									
HemiGm	0.01107	0.01134	-0.101140	0.010229	-1.27786	0.203172	160	0.0246	-0.000143	95.40847	-71.589
MaxRH	94.61563	8.02951									
HemiNum	12.80000	13.63255	-0.105444	0.011118	-1.33284	0.184505	160	29.7383	-0.179023	95.41058	-0.062
MaxRH	94.61563	8.02951									
IsoGm	0.00962	0.06571	-0.105306	0.011089	-1.33108	0.185081	160	0.0912	-0.000862	94.73941	-12.869
MaxRH	94.61563	8.02951									
IsoNum	1.27500	8.51853	-0.091820	0.008431	-1.15905	0.248185	160	10.4917	-0.097412	94.72597	-0.087
MaxRH	94.61563	8.02951									
ColeGm	0.01521	0.02973	-0.133758	0.017891	-1.69656	0.091749	160	0.0621	-0.000495	95.16512	-36.121
MaxRH	94.61563	8.02951									
ColeNum	2.92500	3.06030	-0.137319	0.018856	-1.74258	0.083353	160	7.8769	-0.052336	95.66948	-0.360
MaxRH	94.61563	8.02951									
HymGm	0.01099	0.02603	-0.098148	0.009633	-1.23969	0.216928	160	0.0411	-0.000318	94.94826	-30.274
MaxRH	94.61563	8.02951									
HymNum	2.45625	2.67964	-0.231401	0.053547	-2.98982	0.003239	160	9.7629	-0.077224	96.31877	-0.693
AvgRH	73.71224	17.36151									
EdGm	0.11829	0.10194	-0.272100	0.074039	-3.55436	0.000500	160	0.2361	-0.001598	79.19353	-46.340
AvgRH	73.71224	17.36151									
EdNum	80.13125	59.92838	-0.194516	0.037836	-2.49263	0.013711	160	129.6237	-0.671428	78.22780	-0.056
AvgRH	73.71224	17.36151									
DipGm	0.06738	0.05260	-0.072469	0.005252	-0.91332	0.362464	160	0.0836	-0.000220	75.32406	-23.922
AvgRH	73.71224	17.36151									
DipNum	59.50625	53.94348	-0.077620	0.006025	-0.97862	0.329263	160	77.2835	-0.241171	75.19881	-0.025
AvgRH	73.71224	17.36151									
HemiGm	0.01107	0.01134	-0.307606	0.094622	-4.06358	0.000076	160	0.0259	-0.000201	78.92611	-470.779
AvgRH	73.71224	17.36151									
HemiNum	12.80000	13.63255	-0.294500	0.086730	-3.87359	0.000157	160	29.8457	-0.231246	78.51294	-0.375
AvgRH	73.71224	17.36151									
IsoGm	0.00962	0.06571	-0.119885	0.014373	-1.51788	0.131042	160	0.0431	-0.000454	74.01694	-31.677
AvgRH	73.71224	17.36151									
IsoNum	1.27500	8.51853	-0.115793	0.013408	-1.46535	0.144811	160	5.4629	-0.056815	74.01314	-0.236
AvgRH	73.71224	17.36151									
ColeGm	0.01521	0.02973	-0.210954	0.044502	-2.71270	0.007414	160	0.0418	-0.000361	75.58607	-123.177
AvgRH	73.71224	17.36151									
ColeNum	2.92500	3.06030	-0.324190	0.105099	-4.30766	0.000029	160	7.1373	-0.057145	79.09184	-1.839
AvgRH	73.71224	17.36151									
HymGm	0.01099	0.02603	-0.213073	0.045400	-2.74123	0.006827	160	0.0345	-0.000319	75.27365	-142.108
AvgRH	73.71224	17.36151									
HymNum	2.45625	2.67964	-0.476775	0.227314	-6.81774	0.000000	160	7.8805	-0.073587	81.29971	-3.089

Statistical data tables for the Pearson Product-Moment correlation (Absolute humidity, minimum, maximum and average).

Correlations (Stat data 13 Nov05)
Marked correlations are significant at $p < .05000$
(Casewise deletion of missing data)

Var. X & Var. Y	Mean	Std.Dv.	r(X,Y)	r²	t	p	N	Constant dep: Y	Slope dep: Y	Constant dep: X	Slope dep: X
MinAH	12.89688	1.72103									
EdGm	0.11829	0.10194	0.029610	0.000877	0.372360	0.710124	160	0.0957	0.001754	12.83775	0.49988
MinAH	12.89688	1.72103									
EdNum	80.13125	59.92838	0.066008	0.004357	0.831521	0.406934	160	50.4880	2.298480	12.74498	0.00190
MinAH	12.89688	1.72103									
DipGm	0.06738	0.05260	0.064470	0.004156	0.812059	0.417980	160	0.0420	0.001970	12.75473	2.10958
MinAH	12.89688	1.72103									
DipNum	59.50625	53.94348	0.088322	0.007801	1.114552	0.266735	160	23.8031	2.768356	12.72919	0.00282
MinAH	12.89688	1.72103									
HemiGm	0.01107	0.01134	0.007389	0.000055	0.092883	0.926114	160	0.0104	0.000049	12.88446	1.12103
MinAH	12.89688	1.72103									
HemiNum	12.80000	13.63255	-0.027718	0.000768	-0.348541	0.727898	160	15.6316	-0.219557	12.94166	-0.00350
MinAH	12.89688	1.72103									
IsoGm	0.00962	0.06571	-0.047007	0.002210	-0.591525	0.555014	160	0.0328	-0.001795	12.90872	-1.23125
MinAH	12.89688	1.72103									
IsoNum	1.27500	8.51853	-0.033445	0.001119	-0.420637	0.674592	160	3.4100	-0.165544	12.90549	-0.00676
MinAH	12.89688	1.72103									
ColeGm	0.01521	0.02973	-0.009647	0.000093	-0.121270	0.903631	160	0.0174	-0.000167	12.90537	-0.55840
MinAH	12.89688	1.72103									
ColeNum	2.92500	3.06030	0.002224	0.000005	0.027956	0.977732	160	2.8740	0.003955	12.89322	0.00125
MinAH	12.89688	1.72103									
HymGm	0.01099	0.02603	0.128689	0.016561	1.631157	0.104849	160	-0.0141	0.001946	12.80339	8.50807
MinAH	12.89688	1.72103									
HymNum	2.45625	2.67964	-0.070605	0.004985	-0.889705	0.374977	160	3.8740	-0.109931	13.00826	-0.04535
MaxAH	17.75000	2.90218									
EdGm	0.11829	0.10194	0.231487	0.053586	2.990983	0.003227	160	-0.0260	0.008131	16.97050	6.59003
MaxAH	17.75000	2.90218									
EdNum	80.13125	59.92838	0.223194	0.049816	2.878109	0.004555	160	-1.6755	4.608834	16.88388	0.01081
MaxAH	17.75000	2.90218									
DipGm	0.06738	0.05260	0.177092	0.031362	2.261761	0.025076	160	0.0104	0.003209	17.09159	9.77183
MaxAH	17.75000	2.90218									
DipNum	59.50625	53.94348	0.164127	0.026938	2.091404	0.038092	160	5.3570	3.050665	17.22455	0.00883
MaxAH	17.75000	2.90218									
HemiGm	0.01107	0.01134	0.193614	0.037486	2.480628	0.014163	160	-0.0024	0.000757	17.20142	49.53302
MaxAH	17.75000	2.90218									
HemiNum	12.80000	13.63255	0.190281	0.036207	2.436308	0.015949	160	-3.0653	0.893817	17.23150	0.04051
MaxAH	17.75000	2.90218									
IsoGm	0.00962	0.06571	0.082087	0.006738	1.035307	0.302108	160	-0.0234	0.001858	17.71513	3.62569
MaxAH	17.75000	2.90218									
IsoNum	1.27500	8.51853	0.096748	0.009360	1.221830	0.223592	160	-3.7656	0.283976	17.70797	0.03296
MaxAH	17.75000	2.90218									
ColeGm	0.01521	0.02973	0.122700	0.015055	1.554063	0.122170	160	-0.0071	0.001257	17.56781	11.97634
MaxAH	17.75000	2.90218									
ColeNum	2.92500	3.06030	0.180574	0.032607	2.307717	0.022312	160	-0.4548	0.190412	17.24911	0.17124
MaxAH	17.75000	2.90218									
HymGm	0.01099	0.02603	0.104003	0.010817	1.314431	0.190606	160	-0.0056	0.000933	17.62260	11.59508
MaxAH	17.75000	2.90218									
HymNum	2.45625	2.67964	0.142296	0.020248	1.807017	0.072662	160	0.1242	0.131384	17.37146	0.15411
AvgAH	15.12517	1.82280									
EdGm	0.11829	0.10194	0.181928	0.033098	2.325616	0.021310	160	-0.0356	0.010175	14.74040	3.25294
AvgAH	15.12517	1.82280									
EdNum	80.13125	59.92838	0.223259	0.049845	2.878988	0.004543	160	-30.8891	7.340104	14.58103	0.00679
AvgAH	15.12517	1.82280									
DipGm	0.06738	0.05260	0.163743	0.026812	2.086383	0.038550	160	-0.0041	0.004725	14.74281	5.67487
AvgAH	15.12517	1.82280									
DipNum	59.50625	53.94348	0.186323	0.034716	2.383793	0.018322	160	-23.8941	5.514009	14.75052	0.00630
AvgAH	15.12517	1.82280									
HemiGm	0.01107	0.01134	0.170572	0.029095	2.175939	0.031045	160	-0.0050	0.001062	14.82163	27.40814
AvgAH	15.12517	1.82280									
HemiNum	12.80000	13.63255	0.165238	0.027304	2.105956	0.036789	160	-5.8917	1.235798	14.84237	0.02209
AvgAH	15.12517	1.82280									
IsoGm	0.00962	0.06571	0.020335	0.000414	0.255665	0.798542	160	-0.0015	0.000733	15.11975	0.56414
AvgAH	15.12517	1.82280									
IsoNum	1.27500	8.51853	0.029906	0.000894	0.376078	0.707363	160	-0.8389	0.139760	15.11701	0.00640
AvgAH	15.12517	1.82280									
ColeGm	0.01521	0.02973	0.072220	0.005216	0.910170	0.364119	160	-0.0026	0.001178	15.05782	4.42743
AvgAH	15.12517	1.82280									
ColeNum	2.92500	3.06030	0.144862	0.020985	1.840298	0.067600	160	-0.7536	0.243209	14.87279	0.08628
AvgAH	15.12517	1.82280									
HymGm	0.01099	0.02603	0.174631	0.030496	2.229329	0.027202	160	-0.0267	0.002494	14.99082	12.22817
AvgAH	15.12517	1.82280									
HymNum	2.45625	2.67964	0.119689	0.014326	1.515366	0.131678	160	-0.2050	0.175952	14.92519	0.08142