THE LIFE HISTORY, USE AND SOCIO–ECONOMICS OF THE EDIBLE STINKBUG *ENCOSTERNUM DELEGORGUEI* (HEMIPTERA: TESSARATOMIDAE), IN SOUTH AFRICA

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DECLARATION

I declare that this thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

(Signature of candidate)

23th day of May 2014, Johannesburg

ABSTRACT

Entomophagy, the consumption of insects, has attracted interest as a low input minilivestock with good nutritional value. The inflated stinkbug, *Encosternum delegorguei*, is an appetizing food, a hangover cure and a trade item in South Africa, Malawi and Zimbabwe yet very little is known about it. This study comprehensively integrates plant aspects (food and shelter) and insect biology (distribution, life cycle and fecundity) with socio-economic and conservation aspects. Firstly, *E. delegorguei* was observed in outdoor insectaries where it exhibited reproductive winter diapause and declining abdominal fat content attributed to non-feeding. In spring (September) *E. delegorguei* fed on *Combretum imberbe, Combretum molle* (Combretaceae), *Peltophorum africanum* (Fabaceae), and to a lesser degree on *Dodonaea viscosa* (Sapindaceae) and the grass *Pennisetum clandestinum* (Poaceae). Copulation occurred during October/November but eclosion was reduced by the egg parasitoid wasp, *Anastatus* sp. Secondly, structured interview schedules with 106 harvesters indicated that an estimated total of 3803 $\pm$ 43.4 kg (mean$\pm$S.E.) dry stinkbugs was harvested with an annual gross per capita income of $\bar{x}$ =US$ 345. In South Africa stinkbugs are consumed by two locally separate ethnic groups the Vhavenda and Mapulana, with a third group, the Bolobedu selling them. Ethnic differences in nomenclature and oral history, methods of collection and preparation, as well as perceptions pertaining to availability were documented between the three groups. Damage to host trees occurred when harvesters poached from pine plantations or private land, whereas, in communal-lands, sustainable methods proliferated. Using a regional maximum entropy modelling method (MAXENT) on winter locations of *E. delegorguei* known to harvesters, current and future distribution scenarios were identified. Winter precipitation and to a lesser degree summer precipitation and winter temperature were key climatic variables limiting the regional distribution of *E. delegorguei*. Moreover, potential new sites unknown to harvesters or areas where minilivestock initiatives could be piloted have been highlighted for further investigation. Opportunities to reduce impediments to collection and trade are discussed in a sustainable framework. For example legitimisation of harvesting and introduction of a collection funnel to reduce conflicts with plantation, orchard and private land managers. Awareness and optimal use of beneficial bio-resources, such as *E. delegorguei*, could encourage community driven habitat stewardship.

This work is dedicated to
Maria, Amalia and Nikolas Slater,
Angela Dzerefos, Vasco de Oliviera,
Matthew Constantinides and Maria Christofides

When an interesting door opened,
I walked through to discover what lay beyond.
I hope I did not leave you behind.
I hope it made our time together more precious and interesting
May you will always be inspired to tackle the impossible,
experience the miracle of nature,
the vitality of the outdoors
and feel God shaping your life.

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My family has had a history of moving to new countries Greece, Russia, Egypt and the Belgium Congo. They have started afresh with very little. My Nona's wooden trunk is testament to her bringing very little to South Africa in the 1950's yet she left me with a love of hard work and doing things with loved ones. An inheritance is normally a life policy, a house or other material goods but sometimes only one descendant's branch may benefit while memories of a person are held lifelong. So here is my humble adventure story and memories. I hope they are worth repeating, writing a novel about or inspire the next generation to do something that no one else would have the audacity to try, like researching the life cycle of an edible stinkbug. Oops sorry! I already did that one.

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DISCLAIMER

The chapters of this thesis have been prepared as papers to be published in various peer-reviewed / DNE accredited journals. Consequently formatting styles vary and overlap may occur so that each chapter can be a stand-alone publication. Co-authors contributions are detailed in Chapter 1.

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LIST OF ABBREVIATIONS

AIC	-	Akaike Information Criterion
AUC	-	Area Under Curve
EIA	-	Environmental Impact Assessment
IPCC	-	Intergovernmental Panel on Climate Change
LEGDP	-	Limpopo Employment, Growth and Development Plan
m amsl	-	Metres above mean sea level
MAXENT	-	Maximum Entropy Modelling Method
MDGs	-	Millennium Development Goals
MEGDP	-	Mpumalanga Employment, Growth and Development Plan
MSOE	-	Malawi State of Environment and Outlook Report
NTFPs	-	Non-Timber Forest Products
PASW	-	Predictive Analytics Software
SA	-	South African

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CHAPTER 1: GENERAL INTRODUCTION**

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1.1 Abstract

Indigenous knowledge systems began as the first humans used plants and animals for food, medicine, fuel and other uses. Particularly for animals, this inter-generational ethnozoological knowledge was transmitted orally and has not been thoroughly documented and checked. Yet indigenous knowledge is crucial to assess sustainability of bio-resources and will inform reachable management goals. One such example from southern Africa is the much favoured edible stinkbug *Encosternum delegorguei*. In this paper we review existing information on this beneficial insect and integrate observations on host plants, insect biology, seasonal distribution and socio-economics from South Africa and to a lesser degree Zimbabwe. Moreover, we show that research originating from Malawi, in the last 37 years, have misnamed the edible stinkbug as *Nezara robusta* Dist. and that the correct identification is *E. delegorguei*. Other studies on edible insects have been done on lepidoptera, where the larval stage is harvested during the summer season. In contrast, *E. delegorguei* has incomplete metamorphosis and the adult is harvested during winter, a time of food scarcity, suggesting that further investigations are warranted on this culturally and economically important insect. Adaptive management and increased exploitation of *E. delegorguei* are potential development options to investigate.

Key words: aggregation; bio-resources; ethnoentomology; food security; southern Africa

1.2 Ethnoentomology

Ethnobiology has developed from listing animals and plants useful to mankind (Quin 1959; Liengme 1981; Hutchings 1989) into a multidisciplinary field dealing with nomenclature and spiritual significance, sustainable use and the empowerment of users to become environmental managers (Nonaka 1996; Hunn 2007). Research undertaken in the humanities and biological sciences has led to an understanding of the green insurance policy that the environment offers vulnerable and poor communities (Paumgarten 2005; Hunter *et al.* 2007; Alves & Souto 2011). Indigenous knowledge of useful animals and plants equates to self-sufficiency in obtaining food, medicine, fuel and other resources depending on the ecosystem and its condition. Unfortunately, many medicinal animals (Arioti 1985; Mander *et al*. 2007; Soewu 2008; Alves & Alves 2011) and plants (Williams *et al*. 2000; Dzerefos & Witkowski 2001) and at least 14 edible insects (Ramos-Elorduy 2006) are known to be over exploited and at risk of becoming extinct.

Ethnozoological and ethnobotanical surveys provide baseline scientific knowledge that allows for adaptive conservation management programmes to be developed for sustainable utilisation. However improved research design, data collection and correct identification are necessary in ethnozoology (Alves & Souto 2011) and ethnobotany (Cunningham 2001). The scarcity of ethnozoological publications relative to ethnobotanical publications has been attributed to illegal use and hunting of animals and lack of research funding and expertise (Alves & Souto 2011).

The sub-discipline, ethnoentomology, which deals with culture specific insect use, is distinct from ethnozoology, which has focused largely on vertebrates. Insects are estimated to comprise about four-fifths of the animal kingdom (Samways 2005), are smaller in size than vertebrates with diverse life histories, larval and adult forms and an outer rather than an endoskeleton (Scholtz & Holm 1985; Scholtz & Mansell 2009). The first published information on southern African insects may be that of Dutch explorer, author and politician, Nicolaes Witsen (1641-1717). In 1692 he published Codex Witsenii with watercolours of medicinal plants and insects from the southern Cape done by German artist Hendrik Claudius (D. McCracken, University of KwaZulu-Natal, pers. comm.). Swedish naturalist Carl Peter Thunberg (1743-1828) who is better known for botanical collections and descriptions may have collected the first insect specimens which were taken to Europe (H. Glen, SANBI, pers. comm.).

The insect-human relationship is an ambivalent one yet seemed to have started positively with Ancient cultures. For instance the bizarre life cycle of the cicada is used metaphorically in Hellenistic literature (Falkner & De Luce 1989) and depicted in jewellery (Higgins 1980). The scarab beetle is a symbol of regeneration in Egyptian mythology and art (Hogue 2003). Moreover the Bible makes reference to entomophagy with the consumption of locusts and manna deemed to be excretions of scale insects (Hogue 2003). Today the general view of insects amongst Caucasians is one of repugnance (DeFoliart 1999; Meyer-Rochow *et al.* 2008) even towards those insects that are harmless and do not threaten agricultural production or spread disease. Consequently scientific investigations and product development have been geared towards blanket extermination (McGeoch 2002; Samways 2005) but beneficial insects provide ecological and economic reasons to question this attitude.

Beneficial insects provide irreplaceable environmental services such as pollination, nutrient recycling and pest control on a wide scale. Insects manufacture an array of chemically complex products such as propolis, royal jelly, honey and wax (Munthali & Mughogho 1992), dye, silk, polish (van Huis *et al.* 2013), poisons (Janaiah *et al.* 1979; Nonaka 1996) and medicines (Mkize *et al.* 2003; Cherniack 2010; Meyer-Rochow 2013). In addition, insects are a food source for other animals (Scudder 2009) and globally, almost 2 000 insect species are eaten by humans alone (Ramos-Elorduy 2009; Jongema 2013). Spiritual and medicinal insect uses have not been as extensively documented as entomophagy (Nonaka 1996; Banjo *et al.*2003; Sileshi *et al.* 2009).

1.3 Entomophagy

Future sustainability of world populations demands that globally more food be produced on less land, using water, energy and agrochemicals more efficiently than before. To reach this goal, humanity has introduced controversial genetically modified foods and, to a lesser extent, the use of insects as a minilivestock (van Huis 2003; Solomon *et al.* 2008; Yen 2009). Insects reared en masse in compact, vertical space reduce production costs. For instance, the entire life cycle of the

Southern green stinkbug *Nezara viridula* L. has been observed in plastic containers with meshed lids of 90 mm diameter and 45 mm depth held on shelves open to the elements on four sides (Musolin *et al*. 2010). Insects are a potential crop for Astroculture a semi-closed system of growing food plants developed on the Russian space station Mir and the International Space Station (McLamb 2008). If Astroculture could provide a renewable, balanced food supply then a mission to Mars and beyond would be possible (McLamb 2008).

Although many cringe at the prospect of eating insects, in reality, insects occur in processed foods as diverse as Vienna sausages, chocolate or breakfast cereals. Indeed, organisations monitoring health and safety such as the US Food and Drug Administration permit a certain level of insect body-parts in factory-made food (FDA 2000). In contrast, in southern and central America, Asia and Africa, entomophagy, improves the diet (Table 1.1), albeit seasonally, of impoverished rural communities (Quin 1959; Dufour 1987; Ashiru 1988; DeFoliart 1995; van der Waal 1999; van Huis 2003; Gondo *et al.* 2010; Chakravorty *et al.* 2011; Rumpold & Schlüter 2013). In the case of the Mopane worm *Imbrasia belina* (Westwood) (Gullan & Cranston 1994) or the African metallic wood boring beetle *Sternocera orissa* Buquet (Nonaka 1996), entomophagy is not restricted to the rural poor but is a sought after cultural delicacy (Bodenheimer 1951; Gullan & Cranston 1994; DeFoliart 1999; Allotey & Mpuchane 2003; van Huis *et al.* 2013). Even the inflated stinkbug *Encosternum* (=*Haplosterna*) *delegorguei* Spinola, known in South Africa as Thongolifha, is a gourmet food. This is evident in the writings of Faure (1944): ‘’With my own eyes I saw five natives eating several of the bugs in quick succession, with evident relish, immediately after removing the head and giving a perfunctory squeeze or two. Had I not seen this performance, I would have found it very difficult to believe that any human being could possibly eat these insects, since their odour is particularly strong and nauseating. Since seeing is believing, I now have no doubts about the high esteem in which this delicacy is held by the natives.’’

Table 1.1: Research showing nutritional value of insects and comparison to known sources of proteins in the human diet

Taxon	Macronutrients	Vitamins	Micronutrients	Source
Encosternum delegorguei (Hemiptera)	High protein* and the essential amino acids isoleucine, leucine, lysine, methionine, phenyl-alanine#, threonine#, tryptophan# and valine	Vitamins A, B_1, B_2 and E. No vitamin C	Calcium. iron, magnesium, phosphorus, potassium, selenium, sodium and zinc	Teffo *et al*. 2007
Aspongopus nepalensis (Hemiptera)	High protein, monounsaturated fatty acids, oleic and palmitic acids. Moderate amounts of eicosenoic, linoleic, linolenic stearic, myristic acids palmitoleic. No omega 3 fatty acids	Vitamins A+, B_1, B_2 , C, D and E	Calcium, copper, iron#, sodium, magnesium, manganese, potassium and zinc*	Chakravorty *et al.* 2011
Five pentatomids	High in protein, fat and eight essential amino acids	-	Calcium, potassium and sodium	Feng *et al*. 2000
Sternocera orissa (Coleoptera)	High protein*	-	-	Shadung *et al.* 2012
Various Orthoptera	High protein#	Vitamins B_1*, B_2* and B_3+	Zinc	Blásquez *et al.* 2012; Rumpold & Schlüter 2013
Anaphe venata (Lepidoptera)	High protein* and the essential amino acids isoleucine, leucine, lysine, phenylalanine, threonine and valine	-	Iron* and phosphorus*	Ashiru 1988
Hemijana variegata (Lepidoptera)	High protein# and fat*	Vitamin C*	-	Egan *et al.* 2014

* Higher content than beef, chicken or pork

Comparable to conventional meats

+ Higher than milk

To this day entomophagy is common in rural areas of Limpopo (Makhado *et al*. 2009; Egan 2013) and Mpumalanga Provinces (Twine *et al.* 2003), South Africa and Zimbabwe (Dube *et al.* 2013) where between 71 and 93% of households reported eating insects. Relative to its neighbours South Africa is a developed nation yet protein deficiency and death in children still occurs (LEGDP 2004) hence better nutrition including entomophagy should be promoted (DeFoliart 1999).

Ethnoentomology studies in sub-Saharan Africa have mostly focused on edible insects. The caterpillars *I. belina* (Ditlhogo 1996; Rebe 1999; Illgner & Nel 2000; Greyling & Potgieter 2004; Gondo *et al.* 2010) and *Hemijana variegata* Rothschild (Egan 2013) have been the most comprehensively studied of the edible insects. Some research has focused on utilisation or nutritional value of locusts (van der Waal 1999; Solomon *et al*. 2008; Kinyuru *et al.* 2010), termites (Sileshi *et al.* 2009; Kinyuru *et al*. 2010) and stinkbugs (Cuthbertson 1937; Faure 1944; Makuku 1993; Dudley 2004; Mapendembe 2004; Teffo *et al*. 2007; Morris 2010; van Huis 2013). Other studies have described insect use at a local scale by a specific ethnic group (Jensen Krige & Krige 1943; Nonaka 1996; Gardiner & Gardiner 2003). With noted exceptions (Ditlhogo 1996; Rebe 1999; Akpalu *et al.* 2009; Gondo *et al*. 2010; Egan 2013), ethnoentomology research in sub-Saharan Africa falls short on linking human use with insect population dynamics, distribution, sustainable use and, to a lesser extent, economics. Notably similar concerns over Australian (Yen 2012), Asian (Johnson 2010) and Latin American (Ramos-Elorduy 2006) edible insects have also been raised. In the context of climate change, entomology research should be increased as insects appear to be more susceptible to human induced changes and more likely than birds and plants to become extinct (Scudder 2009).

1.4 Preparation of insects for food

Insects can have potent defence chemicals (Nonaka 1996; Schabel 2006) or armed bodies to render them unattractive to predators and palatability may depend on removal of these defences. For instance the African silkworm *Anaphe venata* Butler is roasted in sand to burn off the setae or stiff hairs covering the body (Iwalewa *et al.* 2005), the spikey legs of grasshoppers are removed (Nonaka 1996) and the bitter-tasting guts of *I. belina* are squeezed out (M.

Thagwana, Department of Environmental Affairs and Tourism, pers. comm.). Defence chemicals of *E. delegorguei* stains human skin orange, stings eyes (Makuku 1993) and may cause temporary blindness (Faure 1944) while those of the Jiuxiang bug *Coridius chinensis* Dallas, can cause paralysis in humans if not removed (Chakravorty *et al*. 2011). Stinkbugs are considered edible once the noxious defence chemical is neutralised by heat (Nonaka 2009) or the stink gland is manually removed (Toms & Thagwana 2003). However there are records of people eating the pentatomid *Lyramorpha edulis* Blöte (Blöte 1952) and the tessaratomid *Tessaratoma quadrata* Distant (Chakravorty *et al.* 2011) raw with the stink chemical unaltered. In Laotian cuisine *T. quadrata* is made into a spicy paste or skewered on sticks and roasted (K. Nonaka, Rikkyo University, pers. comm.) while Indians use it as a chutney (Chakravorty *et al.* 2011).

1.5 Harvesting

Large-bodied aggregating insects, such as *E. delegorguei* are a high yield winter crop for Vhavenda communities in South Africa (Toms & Thagwana 2003; Teffo *et al*. 2007). In Zimbabwe it is known as Harurwa (Mjele 1934; Quin 1959; Gardiner & Gardiner 2003; Picker *et al*. 2004) and harvesting is controlled by the traditional authority (Mapendembe 2004). From April to September each year *E. delegorguei* occur at known sites (Mjele 1934). Harvesting is done by hand-brushing the stinkbugs off branches into bags. In Malawi, a stinkbug collection funnel is used to shake branches and capture dislodged stinkbugs (Dudley 2004). Funnels are made out of plastic sheets sown together with a bamboo ring supporting the mouth of the funnel and suspended on poles up to five meters long (Dudley 2004). In Laos, stinkbugs are collected using a fishing net on a three meter tall pole (K. Nonaka, Rikkyo University, pers. comm.). In Africa more lucrative natural resources such as medicinal plants may be monopolised by males or family corporates (Botha *et al.* 2004) but insect collection is mainly female driven (van Huis 2003; Gondo *et al.* 2010).

1.6 Study species

1.6.1 Taxonomy of stinkbugs

Hemiptera have a piercing and sucking mouthpart called a stylet or rostrum, two paired wings, membranous hind wings and immature stages resembling small, wingless, non-reproductive adults (McGavin 2001; Picker *et al.* 2004). The four Hemipteran suborders are the Heteroptera (true bugs), Coleorrhyncha (moss bugs), Auchenorrhyncha (hoppers, lantern bugs and cicadas) and Sternorrhyncha (whiteflies, aphids, scale insects and mealie bugs) (McGavin 2001). Many heteropteran families produce a foul defence chemical to discourage predators.

Tessaratomidae (inflated stinkbugs) and the much larger family Pentatomidae (stinkbugs and shield bugs) are easily confused, as both groups are phytophagous, produce a defence chemical, have oval-shaped bodies, a small, triangular head bearing four to five segmented antennae and two or three segmented tarsi (Scholtz & Holm 1986; Picker *et al*. 2004; Henry 2009). Differentiating attributes are subtle and compounded by the diversity of species. Many tessaratomids (Cant *et al.* 1996a) and pentatomids (Cherry *et al.* 1998; Panizzi *et al*. 2000.) are regarded as agricultural pests since their feeding results in plant wilting, loss of host fecundity and increased vulnerability to pathogens. In Africa, only two percent of herbivorous insects are pests, yet 50% of failed crops are attributed to them (Scholtz & Mansell 2009).

1.6.2 Edible stinkbugs

There are at least 102 edible species in the order Hemiptera (Ramos-Elorduy 2006) which include waterstriders, waterbugs and stinkbugs (Quin 1959; DeFoliart 1999). The Giant waterbug *Lethocerus indicus* Lep. & Serv. from Thailand (DeFoliart 1999) and the Giant mesquite bug *Thasus gigas* Burm from Mexico (Ramos-Elorduy 2006), are exported to other countries for consumption. Tessaratomids with large fatty bodies are tasty dishes in some parts of the world, for example *E. delegorguei* from sub-Saharan Africa (Quin 1959; Illgner & Nel 2000; Gardiner & Gardiner 2003; van der Waal 2004), *T. quadrata* from Laos (Aukema & Rieger 2006; Nonaka 2009; Boulidam 2010), *Eusthenes saevus* Stål from China (Feng *et al*. 2000) and *Pygoplatys* spp., *Tessaratoma papillosa* (Drury) and *Tessaratoma javanica* Thunberg from Thailand (Hanboonsong 2010). Pentatomids such as *Euschistus strenuus* Stål and *Atizies taxcoensis* Ancona from Mexico (DeFoliart 1999), *Aspongopus nepalensis* Westwood (Chakravorty *et al*. 2011), *Bagrada picta* Fabr. and *Erthesina fullo* Thunb. from Asia (DeFoliart

1999) and *Lyramorpha edulis* Blöte from Papua New Guinea (Blöte 1952) are also edible.

1.6.3 *Encosternum delegorguei*

From 1842 to 1848, German biologist Wilhelm Karl Hartwich Peters (1815-1883), collected thousands of animal and plant specimens from sub-Saharan Africa (Bauer 2004). The collections were shipped to Europe and some were auctioned (Bauer 2004). Although his primary interest was herpetology, he also collected the earliest known specimen of *E. delegorguei* housed at the Museum of Natural History in Berlin. The species was described in 1852 by the entomologist Massimiliano Spinola (1780-1857). Spinola was a wealthy Italian known for purchasing exotic collections of Coleoptera, Hymenoptera and Hemiptera.

Encosternum delegorguei is widely distributed in subtropical open woodland and bushveld in Botswana, South Africa, Swaziland, Malawi, Mozambique, Namibia and Zimbabwe (Picker *et al*. 2004). It is a large, green dorsally flat and shield-shaped stinkbug having a body length of 25 mm (Picker *et al.* 2004). It has a small rostrum of length 3.0 mm whereas rostrums of 3.5 to 5.9 mm have been measured for pentatomid agricultural pests (Depieri & Panizzi 2010*).* *Encosternum delegorguei* is a strong, noisy flier which aggregates in tree tops during winter.

1.6.4 Misidentification of Malawian edible stinkbugs

Stinkbugs that are eaten in Malawi and locally known as Nkhunguni, have been named in publications as the Green stinkbug *Nezara robusta* Dist. (Family Pentatomidae) (Esbjerg 1976; Dudley 2004; Schabel 2006; Morris 2010; van Huis 2013). However, photographs taken in 2013 of Nkhunguni specimens housed at the Forestry Research Institute of Malawi (FRIM) had been labelled as *E. delegorguei*. Upon viewing these photographs, the entomologist Dr Dawid Jacobs, an expert on southern African stinkbugs (University of Pretoria), agreed that they were not *N. robusta*. However, he also cautioned that they could be another tessaratomid *Selenymenum piriforme* Montandon. The number of antennal segments was relevant as *E. delegorguei* has five segments with the second segment being very small whereas *S. piriforme* has four segments. The museum curator Herbert Jenga, revisited the specimens at FRIM and on 16 July

2013 confirmed that they were *E. delegorguei* based on the number and length of antenna segments. Furthermore, descriptions of locality, aggregation behaviour, preparation for human consumption and taste support the identification as *E. delegorguei.*

1.6.5 Plants used for perching, food and oviposition

Insects require plants for food and to provide shelter and often camouflage from predators from the sedentary egg stage through to the mature adult. Once-off observations may provide information on a host plant but may not indicate accurately the plant-insect relationship, seasonality and whether it alters as the insect metamorphoses or remains constant throughout the life cycle. Recurrent observations throughout the life cycle are essential to understand the dynamics at work in an insect like *E. delegorguei* which occurs in the seasonally-arid tropical areas of Africa and exhibits winter aggregation. In Zimbabwe, winter host plants were *Uapaca kirkiana* Müll. Arg. and *Oxyanthus speciosus* DC (Picker *et al*. 2004) but in summer eggs were laid on grass stems and twigs of *Combretum imberbe* Wawra and *Combretum apiculatum* Sond. (Mawanza 1999). *Encosternum delegorguei* has been recorded *on Acacia ataxacantha* DC. in Mpumalanga Province, South Africa (Faure 1944; Quin 1959). Food plants are reported to be *Dodonaea viscosa* Jacq. var. *angustifolia* (L.f.) Benth. and *Diospyros mespiliformis* Hochst. ex A.DC. in Limpopo Province, South Africa (Toms & Thagwana 2003; Teffo *et al*. 2007) and *Brachystegia* spp. in Malawi (Morris 2010). Earlier studies suggest that *E. delegorguei* adults do not feed in winter but subsist on condensed water vapour (Faure 1944; Makuku 1993) which indicates that diapause, a suspended state of development (Gullan & Cranston 1994) where a plant might be used as a perch but not as food might be occurring. Increased body fat is a good indicator of diapause (Musolin *et al*. 2001; Musolin *et al*. 2007).

1.7 Rationale

1.7.1 Limited knowledge on edible insects

In a review paper of sub-Saharan edible insects, Illigner & Nel (2000) commented that “information on entomophagy is difficult to acquire and where it does exist, sources are disparate and obscure.” Vantomme *et al*. (2004), referring to central

Africa, agreed that nomenclature, life cycles and distribution data on edible insects is sparse and called for biological research incorporating indigenous knowledge systems. Entomophagy studies are predominantly on holometabolous lepidopterans, where larval, pupal and adult stages are distinguishable (Rebe 1999; Greyling & Potgieter 2004; Illgner & Nel 2000; Gondo *et al.* 2010; Egan 2013) and the larvae are harvested from the population. In contrast, in hemimetabolous hemipterans, for example stinkbugs, and orthopterans, for example grasshoppers and crickets, there is incomplete metamorphosis and the adult, reproductive stage, is harvested for food. Moreover, *E. delegorguei* is the only reliable winter insect crop available during "the hunger gap'' the dry winter period when edible bio-resources and subsistence crops are in short supply.

1.7.2 Gaps in our knowledge of the life cycle of *E. delegorguei*

The substantial literature on edible stinkbugs in South Africa (Faure 1944; Toms & Thagwana 2003; Teffo *et al.* 2007; Makhado *et al.* 2009), Zimbabwe (Cuthbertson 1937; Makuku 1993; Mawanza 1999; Gardiner & Gardiner 2003; Mapendembe 2004) and Malawi (Dudley 2004; Morris 2010) mainly describes harvesting and preparation. Only one publication has reported on nutritional value (Teffo *et al*. 2007). Apart from observations of adults congregating in specific areas in winter, no information exists on the number of nymphal stages, annual generations, time of egg laying or fat deposition. Studies done on another tessaratomid, *Musgraveia sulciventris* Stål offer some insights on what could be expected (McDonald 1969; Cant *et al*. 1996a, b; Panizzi *et al.* 2000). This research is unique as previous work on stinkbugs has only considered them pests to be annihilated (McDonald 1969; Cherry *et al*. 1998; Panizzi *et al*. 2000, 2002), whereas in this study optimising or sustaining populations is the focus.

1.7.3 Temporal food requirements

Although mention is made of various woody plant species supporting *E. delegorguei* (Faure 1944; Quin 1959; Makuku 1993; Mawanza 1999; Illigner & Nel 2000; Picker *et al.* 2004; Toms & Thagwana 2003; Teffo *et al*. 2007), it is not known if different stages in the life cycle have different food requirements as is noted for the Small green stinkbug *Piezodorus guildinii* Westwood (Panizzi *et al*. 2002). Pentatomids may switch food sources due to a preference for growing shoots or fruits (McPherson & McPherson 2000; Panizzi *et al*. 2002) but these distinctions have not been made in *E. delegorguei*. Nor is it known if *E.*

delegorguei enters diapause, which many insects employ in order to survive unfavourable environmental conditions such as when the quality of food plants is poor (Fielding 1990; Gullan & Cranston 1994; Musolin *et al*. 2001). Clearly an understanding of the life cycle of *E. delegorguei*, its food requirements at different stages of development and discerning between plants used for food, perches or egg laying is required.

1.7.4 Economics

Imbrasia belina (Mopane worm), *Gonometa postica* Walker (African wild silkmoth) and *Gonometa rufobrunnea* Aurivillius (Wild silkmoth) are known commercial insects in southern Africa (McGeoch 2002) but many others are also traded in informal markets as food (Twine *et al.* 2003; Makhado *et al.* 2009) or are available online to international consumers (van Huis 2013). During the 2004/5 season in Limpopo Province, South Africa, it was calculated that 0.1 kg dried *I. belina* fetched between US$ 0.65 to 1.30 while a cup of stinkbugs or termites fetched US$ 0.65 (Makhado *et al.* 2009). Out of season prices for dried *I. belina* can be higher than other sources of protein such as eggs, chicken or beef (Rebe 1999) and contributed a quarter of rural household income (Gondo *et al.* 2010). Similarly, the edible caterpillar *H. variegata* was more expensive than beef mince and people preferred to eat rather than sell it (Egan 2013). In Zimbabwe, a study of 30 villages harvesting *E. delegorguei* showed that a household can earn US$ 190 year^{-1}, which is described as a ‘’considerable income’’ for a rural area (Mapendembe 2004). No empirical field information is available on actual or potential quantities of *E. delegorguei* harvested in South Africa and Malawi, although it is a sought after natural resource.

1.7.5 Conservation and management of insects

Threats to insect conservation include habitat loss or fragmentation, spread of invasive alien organisms, environmental pollution and pesticides (McGeoch 2002; Samways 2005). A greater awareness and optimal use of beneficial insects in rural economies could lead to a re-assessment of local natural resource management strategies, including clearing of indigenous vegetation, timing and frequency of burning, release of pollutants and pesticide use. In Asia, insect use has coincided with decreased pesticide use (DeFoliart 1999). Korean edible grasshoppers, such as *Oxya velox* Fab., declined from 1960 to 1970, due to the application of rice pesticides. Organic farming in the 1980's allowed recovery of populations and harvesting for the dinner table recommenced (Pemberton 1994).

In Africa, habitat degradation is probably a greater threat than pesticide use. The felling of food trees has been suggested as a reason for reduced harvests of edible caterpillars in Nigeria (Ashiru 1988) and southern Africa (Munthali & Mughogho 1992; Akpalu *et al.* 2009). Similarly, in Malawi remote sensing showed large-scale felling of trees, which communities confirmed was to collect edible stinkbugs (Mlotha 2001). Best practice management of *E. delegorguei* during the harvesting season has been reported from the Jiri Forest, Zimbabwe. A co-operative of 30 villages prevent tree felling, land cultivation and overexploitation through the nomination of forest monitors (Makuku 1993; Mapendembe 2004). Fines are levied for noncompliance by a community court (Mawere 2013). Conversion of historical harvesting areas to agriculture has led to local extinctions of *E. delegorguei* in Limpopo Province, South Africa (Toms & Thagwana 2003). Further changes due to loss of food plants in rural areas where natural resources are harvested and where an increased rate of wood harvesting since 1994 has altered ecological processes (Dovie *et al.* 2004; Twine 2005). In the interests of sustainable livelihoods the factors governing the population dynamics of *E. delegorguei* need to be researched.

1.8 Aims and objectives

This study aims to integrate host plant requirements, insect biology, seasonal distribution, socio-economic significance and conservation concerns arising from the utilisation of *E. delegorguei* as a source of food and income and to make recommendations for sustainable use. The specific research objectives of the biological component of the study were to:

- maintain *E. delegorguei* in captivity and record daily behaviour during the course of a year;
- identify plants used as perches, food or oviposition sites;
- determine when mating, oviposition and eclosion (hatching) occur;
- determine whether there is diapause by assessing seasonal change in fat reserves;
- record number of eggs laid per female;
- monitor survival and development of nymphs of different instars;

- determine the seasonal distribution of *E. delegorguei*;
- determine the bioclimatic envelope of variable of *E. delegorguei*;
- make predictions with regards to sustainable use within the context of a changing climate.

The socio-economic objectives were to:

- compare local knowledge, nomenclature and origin of use of *E. delegorguei* in three distinct South African ethnic groups, the Vhavenda, the Mapulana and the Bolobedu;
- determine whether sustainable methods of collecting are being used;
- document the preparation required to render *E. delegorguei* palatable;
- enquire whether harvesters perceive a decrease in availability of *E. delegorguei* in normal versus drought stricken years;
- quantify the economic value of *E. delegorguei*;
- determine who is benefitting from collection of *E. delegorguei*;
- gain an understanding of the market chain and perceived impediments to collecting and selling of *E. delegorguei*;
- discuss the potential for adding value to the resource or increasing economic returns.

1.9 Structure of thesis

Chapter one introduces the study, describes its broader context and provides the project rationale, aims and objectives. A slightly different version was published as a review paper in the journal African Entomology. The introduction begins by describing the broad field of study termed ethnobiology and its application to plants and animals including insects. Ethnoentomology is discussed further with regards to its role in human welfare and insect conservation by adding to scientific knowledge and management of exploited insect populations worldwide. The position of the current study within the discipline of ethnoentomology is highlighted. The chapter then describes the study species (*E. delegorguei*), its taxonomic designation and existing information and gaps in knowledge prior to this study.

Chapters two to five are stand-alone scientific papers. Different aspects of *E. delegorguei* biology and use are covered in these papers with unique data which targeted diverse international journals. Chapter two was published in the Journal of Applied Entomology, chapter three in the Journal of Ethnobiology and Ethnomedicine, chapter four in Society and Natural Resources and chapter five has been submitted to the Journal of Applied Entomology. Some repetition between chapters may occur in the description of study sites and study species as each needed to be understood separately. For chapters three and four the vegetation type Sour Lowveld Bushveld (van Rooyen and Bredenkamp 1996) was purposefully used as this broad unit sufficed for the content of the papers and allowed the length of the chosen journal to be achieved. In chapter five the finer scale divisions of the vegetation types used by Mucina and Rutherford (2006) were used as this is the scale that conservation managers or climate change modellers would operate on.

Chapter two describes the life-history, behaviour and host plants of *E. delegorguei*. It is a vital chapter as it provides new scientific knowledge on the distinction between food and perch plants. Previously it was not known that *E. delegorguei* enters diapause during the winter season or is threatened by an egg parasitoid. The first author was responsible for the literature survey, for setting up the outdoor insectaries, collecting and analysing data and writing the manuscript and associated tables and figures. The second author edited the paper and improved content and grammar up to acceptance level by the journal. The third author proposed the study, discussed the objectives and provided start-up funding.

In chapter three indigenous knowledge systems, harvesting and preparation of *E. delegorguei* in South Africa were documented in three geographically separate ethnic groups. Chapter four focuses on the economic significance of this natural resource and discusses opportunities for market expansion and threats to sustainability. In chapters three and four, the principal author was responsible for the experimental design, data collection and analysis, production of tables and figures and write-up. The two co-authors contributed, as for chapter one.

The fifth chapter covers the use *of E. delegorguei* throughout sub-Saharan Africa and collates the findings of previous chapters. It defines the current winter niche and makes predictions of changes relating to climate change. The first author collected GIS co-ordinates of harvesting areas, sourced and collated museum data, challenged the identification of Malawian stinkbugs, analysed data and prepared the manuscript. A new second author brought cutting edge specialist input with regards to the MAXENT analysis and current and predicted distribution maps in the context of climate change. The third author provided editorial and scientific inputs on the manuscript being prepared and formatted for submission to the Journal of Applied Entomology. The fourth author prepared the climate data surfaces for the data input region used in the MAXENT model.

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CHAPTER 2: LIFE-HISTORY TRAITS OF THE EDIBLE STINKBUG *

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2.1 Abstract

Little is known of the life history of the edible stinkbug, *Encosternum delegorguei*, although it is an important food for people living in north-eastern South Africa and southern Zimbabwe. The present study aimed to establish key elements influencing long-term sustainable harvesting. Outdoor insectaries of two sizes were constructed to observe: daily activity, utilization of plants, copulation, oviposition, eclosion and survival from May 2006 to February 2007. The rest of the annual life cycle was observed in the field in March and April 2007 and identified as univoltine. In autumn (May) *E. delegorguei* entered reproductive diapause and aggregated within the escarpment mist-belt where it survived the winter on vapour condensation without feeding. Monthly dissections showed that abdominal fat content was highest in June. In spring (September) *E. delegorguei* fed on sap of the trees *Combretum imberbe, Combretum molle, Peltophorum africanum* and to a lesser degree on *Dodonaea viscosa* and the grass *Pennisetum clandestinum*. Copulation occurred in October and November. An overall total of 1752 *E. delegorguei* eggs were laid by 103 females and incubation time averaged 18.7±9.0 days (range 7–37) at outdoor temperature ranging from 11^{o}C to 25^{o}C. The mean number of eggs in 64 egg masses was 27.4±13.9 (range of 2–56 eggs). Shade cloth (68.8%) was the most commonly used substrate for depositing eggs followed by *P. clandestinum* (12.5%), *C. imberbe* (7.8%), *P. africanum* (6.3%), *D. viscosa* (1.6%), *C. molle* (1.6%) and *C. erythrophyllum* (1.6%). The parasitoid wasp, *Anastatus* sp. (Hymenoptera: Eupelmidae) infected 57% of the eggs deposited by captive females. Availability of food plants in combination with parasitoid threat may be a reason for seasonal migration between overwintering sites within the mist-belt and summer oviposition sites. Diminishing harvests could be attributed to fuelwood harvesting of food plants in the summer sites.

Keywords: Aggregation, beneficial insect, diapause, egg parasitoid, overwintering

2.2 Introduction

Considerable research on the harvesting impacts of plant species has been undertaken in southern and east Africa (e.g. Dzerefos *et al*. 1999; Dzerefos and Witkowski 2001; Dovie *et al*. 2002; Letsela *et al.* 2002; Botha *et al*. 2004; Luoga *et al*. 2004; Williams *et al.* 2007), but there are few similar studies done on edible insects. *Encosternum* (=*Haplosterna*) *delegorguei* Spinola is one of 10 species of Tessaratomidae (inflated stinkbugs) in southern Africa (Picker *et al*. 2004) one of the less researched families of the pentatomoids (Scholtz and Holm 1986; Schaefer and Panizzi 2000). *Encosternum delegorguei* deserves investigation as it is an economically and culturally important insect eaten by locals (Mjele 1934; Faure 1944; Makuku 1993; Toms 2007), and providing a source of protein, including some important amino acids, vitamins and minerals in high risk malnutrition areas (Teffo *et al*. 2007).

Encosternum delegorguei is widely distributed in subtropical open woodland and bushveld (Picker *et al*. 2004) but in South Africa, there are only three areas around Thohoyandou, Ga-Modjadji and Bushbuckridge, where it aggregates in sufficient quantities to be harvested (C. Dzerefos, unpublished data). Benefits of insect aggregation include enhanced mating opportunities (Hibino 1985) and shelter, reduced desiccation (Lockwood and Storey 1986; Vulinec 1990), maintenance of body temperature (Hagen 1962) and combined chemical defence against predators (Cocroft 2001). Aggregating *Biprorulus bibax* (Breddin) (Hemiptera: Pentatomidae) were found to be bigger and contained more lipids than lone bugs (James 1990). In *Musgraveia sulciventris* (Stål) (Hemiptera: Tessaratomidae) single rather than aggregated females were easily chased away suggesting that group behaviour provided a sense of security (Cant *et al*. 1996b). Aggregation, however, can increase incidence of parasites, parasitoids or pathogens in pentatomid populations (Nishida 1966; Weber *et al*. 1996; Jones and Westcot 2002; Colazza *et al.* 2004; Squitier 2005*).*

Dodonaea viscosa Jacq. var. *angustifolia* (L.f.) Benth. (Sapindaceae) and *Diospyros mespiliformis* Hochst. ex A.DC. (Ebenaceae) have been recorded as the principal food plants for *E. delegorguei* in Ga-Modjadji, South Africa (Teffo 2006). Other studies suggest that *E. delegorguei* adults did not feed on plant sap in winter but subsisted on vapour condensation (Faure 1944; Makuku 1993).

Acacia ataxacantha DC. (Fabaceae) was recorded as a perching tree for *E. delegorguei* in Mpumalanga Province (Faure 1944; Quin 1959). In Zimbabwe, winter host plants were *Uapaca kirkiana* Müll. Arg. (Euphorbiaceae) and *Oxyanthus speciosus* DC (Rubiaceae) (Picker *et al*. 2004) but in summer eggs were laid on grass stems and twigs of *Combretum imberbe* Wawra and *Combretum apiculatum* Sond.(Combretaceae) (Mawanza 1999). To determine the threat from fuelwood harvesting or land use change the food plants of *E. delegorguei* must be known.

For long-term sustainable harvesting of *E. delegorguei*, an understanding of its life history, dispersal, aggregation and requirements for survival are needed to assist conservation authorities and local communities to manage the resource. The following key questions were posed: (i) what is the observed daily behaviour? (ii) which plants are used as perches, food and oviposition sites? (iii) when do mating, oviposition and eclosion occur? (iv) how do fat reserves change seasonally? (v) how many eggs and nymphs are produced?

2.3 Study site

Encosternum delegorguei were collected from communal lands in Ga-Modjadji and reared in captivity in Haenertsburg (fig. 2.1). Both sites are located on south-westerly to north-easterly hilly spurs of the Drakensberg escarpment which decrease in altitude into the drier Lowveld plains towards the east (Table 2.1). Rainfall increases with altitude in the mountains due to orographic lift and Scheepers (1978) estimated that the escarpment mist-belt was at approximately 1 050 m amsl. About 85% of the rainfall occurs in summer from October to March and about 15% in winter from April to September. Rainfall data for the region indicate below average rainfall for long periods and above average rainfall for short periods (Mucina and Rutherford 2006).

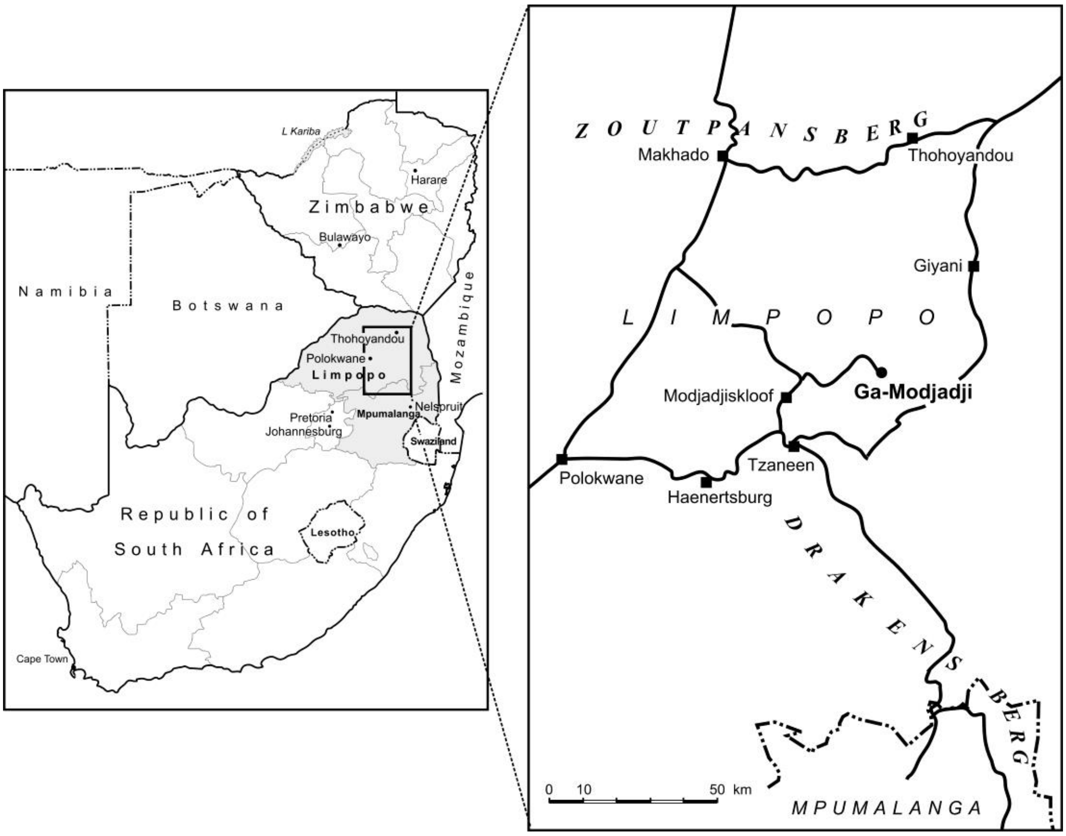

Figure 2.1: The Ga-Modjadji harvesting site and the Haenertsburg captive breeding site for *Encosternum delegorguei* located in the foothills of the northern Drakensberg escarpment, Mopani District, Limpopo Province, South Africa.

Table 2.1: Site specific data for Haenertsburg, where *Encosternum delegorguei* was reared, and the source area Ga-Modjadji, Mopani District, Limpopo Province, South Africa

Site data (Coordinates)	Haenertsburg (23°56'28" S 29°56'35" E)	Ga-Modjadji (23°38'05.4" S 30°20'55.7" E)	Source
Altitude (m amsl)	1380	1046	-
Average annual rainfall (mm annum^{-1})	1166	1041	Mucina and Rutherford 2006; G. Lunt, Boshoek Farm, pers. comm.
Mean number of frost days when temperatures were below 0°C	7	1	Mucina and Rutherford 2006
Mean annual temperature (°C)	16.6	19.7	
Average maximum summer temperature (°C)	22.4	26.3	Letaba Fire Protection Association; SA weather bureau
Average minimum summer temperature (°C)	13.2	14.3	
Average maximum winter temperature (°C)	20.1	23.2	
Average minimum winter temperature (°C)	6.9	11.4	
Mean annual potential evaporation (mm)	2097	2005	Mucina and Rutherford 2006

2.4 Materials and Methods

2.4.1 Mini insectaries on *Dodonaea viscosa* Jacq. var. *angustifolia*

Two hundred *E. delegorguei* adults were collected from Ga-Modjadji in May 2006 and transported in a loose weave plastic, 1 x 0.5 m bag. Once adults had been sexed, four netted 0.5 x 0.25 m polypropylene bags (mesh size 0.9 x 0.3 mm), each with 50 adults were secured on vertical branches of *D. viscosa* shrubs (fig. 2.2). Each of the four mini insectaries had different percentages of direct sun exposure: (i) 'full sun' had >85% exposure; (ii) 'moderate sun' had 50-84% exposure; (iii) 'partial sun' had <50% exposure and (iv) 'shaded' had 0% exposure. Change in colour and greasiness of body surface, behaviour (feeding, aggregating or reproductive) and mortality, as well as general weather conditions (temperature, incidence of frost, wind and precipitation) were recorded thrice daily (7:30 am, 1 pm and 4:30 pm) from May to December 2006. Greasiness was a subjective assessment of gloss and clear liquid deposit that rubbed off when the insect was handled.

2.4.2 Large insectary with nine woody plant species

Bauhinia galpinii N.E.Br. (Caesalpiniaceae), *Combretum erythrophyllum* (Burch.) Sond., *Combretum molle* R.Br. ex G.Don and *C. imberbe* (Combretaceae), *D.mespiliformis, D. viscosa, Kirkia acuminata* Oliv. (Simaroubaceae) and *Peltophorum africanum* Sond. and *Philenoptera violacea* (Klotzsch) Schrire (Fabaceae) were identified as potential host plants from literature (Mawanza 1999; Teffo 2006) or from twelve 'walk and talk' interviews with harvesters. They were planted and enclosed in a wooden frame encased in 30% black shade cloth (2.5 x 1 x 1 m) (fig. 2.2). The herbaceous layer in the insectary comprised the alien Kikuyu grass, *Pennisetum clandestinum* Hochst. ex Chiov. (Poaceae). In August 2006, the insectary was stocked with 298 adult *E. delegorguei* collected from Ga-Modjadji. A random sample of 36 were sexed and the broadest part of the pronotum measured. To control ant predation a trap containing a pyrethroid, Deltamethrin, was placed in the insectary. Change in colour and greasiness of body surface, behaviour and general weather conditions were described as for mini insectaries and predation was an additional factor recorded. Commencement of feeding, copulation, oviposition and eclosion as well as substrate on which eggs were laid, egg mass pattern and parental behaviour were recorded *ad hoc*.

2.4.3 Post-eclosion

Within 24 h of eclosion a fine paint brush was used to place 314 first nymphs in fine netted bags (mesh size 0.1 x 0.1 mm) on *D. viscosa*, *C. erythrophyllum*, *C. imberbe, C. molle* or *P. africanum* to protect them from predators (fig. 2.2). These plants had either been fed on by adults or had been used for oviposition. On hot days, in excess of 32^{o}C, a fine spray of rain-harvested water was applied to prevent dehydration. A control of 314 nymphs were left at the oviposition site. Due to high mortality of nymphs, 10 of them were transferred to a transparent glass container (diameter 90 mm, depth 300 mm) with mesh lid for aeration in December. For food, green bean *Phaseolus vulgaris* L. (Fabaceae) pods were washed in rainwater, dried and replaced every 3 days. From mid-January, unhatched eggs were isolated in transparent glass containers (diameter 90 mm, depth 300 mm) with mesh lids to contain the emerging egg parasitoids. The adult parasitoids were preserved in 70% alcohol and identified by Dr G.L. Prinsloo of the Agricultural Research Council, Pretoria.

2.4.4 Abdominal fat content

Male and female adults were sourced from each of the three mini insectaries each month, from May to December 2006, resulting in a total sample of 48 (fig. 2.2). The fully shaded insectary was excluded as all the nymphs died. Dissection commenced with cutting the abdominal edges of the insect cuticle up to the metathoracic region. Half the ventral abdominal wall was opened at a time and the attached viscera were scraped off with a blade. Ventral rather than dorsal dissection resulted in a more robust specimen. The ventral abdominal wall was removed and abdominal fat content categorized as: (i) 0%, (ii) 1-25%, (iii) 26-50%, (iv) 51-75%, (v) 76-100% fat.

2.4.5 Statistical procedures

Cramer's V nominal by nominal procedure was used to test the strength of association or dependency between eclosion and substrate used for ovipositing. Kendall's tau-b test was used to determine whether there was a relationship between the four categories of abdominal fat content and season (ordinal by ordinal variables). As no dissection showed 0% fat this category was excluded from statistical analysis. The abdominal fat content data were grouped into (i) ≤50% or (ii) >50% abdominal fat, for the winter season from May to August and the summer season from September to December and analyzed by means of Pearson's Chi-square as well as a risk estimate. The two abdominal fat content categories were cross-tabulated with gender. Pearson's Chi-square was used to determine if abdominal fat content (in %) and gender were associated. The Statistical Products and Service Solution, Inc., Chicago, IL, USA (SPSS) 13.0 program was used to analyze the data.

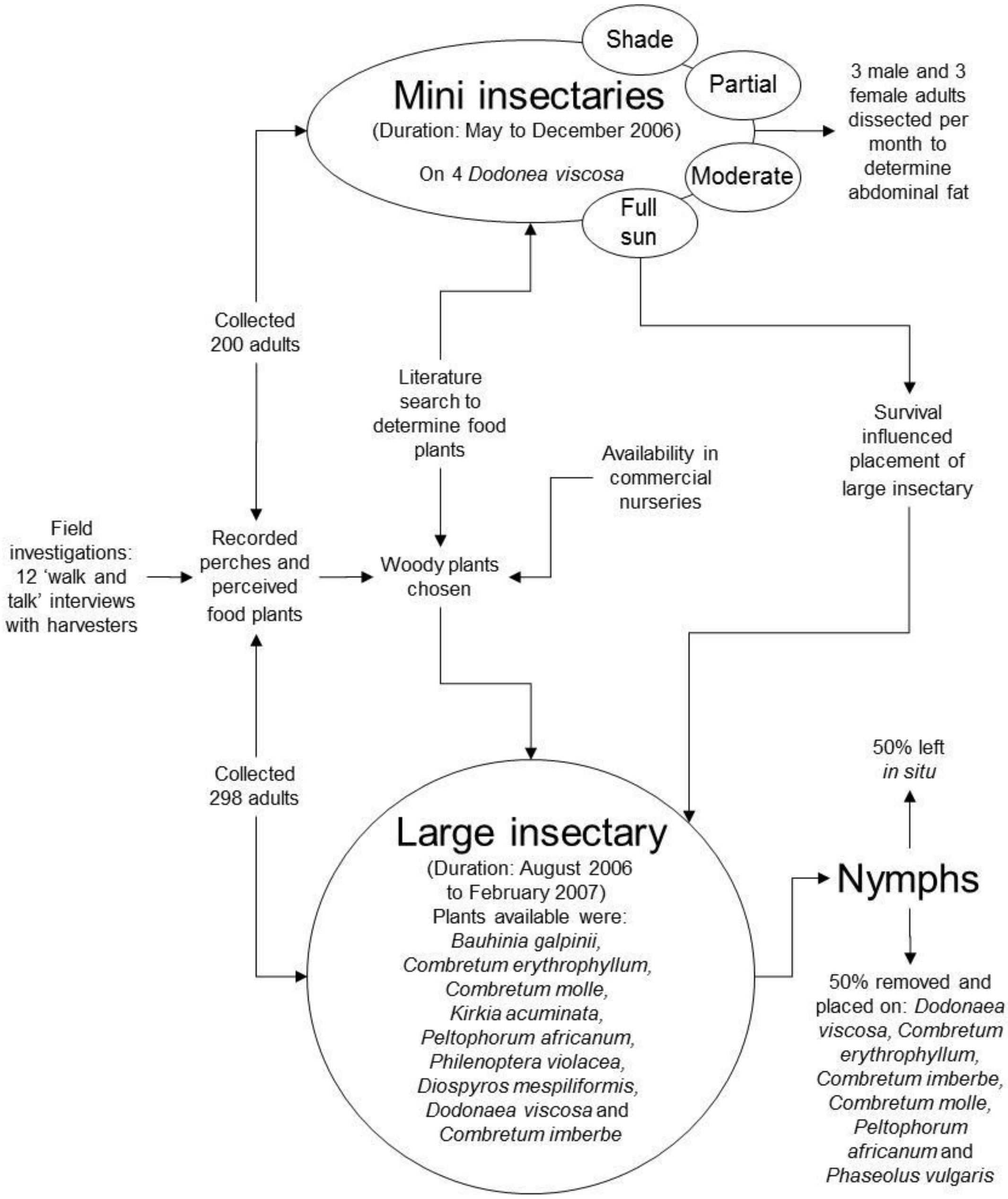

Figure 2.2: Design of captive rearing trials for *Encosternum delegorguei* using four mini insectaries and one large insectary in Haenertsburg, Mopani District, Limpopo Province, South Africa.

2.5 Results

2.5.1 Hosts and feeding behaviour

Encosternum delegorguei were wild sourced from *B. galpinii*, *Catha edulis* (Celastraceae), *C. apiculatum*, *Combretum collinum* (Combretaceae), *C. erythrophyllum*, *C. imberbe*, *C. molle*, *D. mespiliformis*, *D. viscosa*, *K. acuminata* and *P. africanum*. Within the insectary *D. viscosa* and *P. africanum* retained green foliage throughout winter and *E. delegorguei* aggregated in clusters of 6-40 on apical growing points or under leaves. By end of winter (August) all captive *E. delegorguei* clustered on *P. africanum* (64%), *D. viscosa* (29%) or the western most corners of the insectary (7%). *B. galpinii*, *C. imberbe*, *C. molle*, *D. mespiliformis*, *K. acuminata* and *P. violacea* may have been briefly visited by individuals but no clusters formed on them.

In winter (May to August) drinking from water droplets but not feeding was observed in the insectaries. Feeding damage to mature leaves was visible as brown speckles on *C. imberbe* and *C. molle* from mid-September, while superficial necrosis appeared on *D. viscosa* and *P. clandestinum* leaves. Feeding on apical shoots of *P. africanum* resulted in withering but the plant recovered as the growing season progressed and the population of *E. delegorguei* suffered natural mortality. *Bauhinia galpinii, C. erythrophyllum, K. acuminata* and *P. violacea* were not used as food plants.

2.5.2 Mini insectaries and dissections

Forty-two per cent of adults survived to copulation in the mini insectary with full sun exposure, followed by 40% in partial sun and 17% in moderate sun. The completely shaded insectary had no adults surviving to copulation. Dissections revealed gravid females from October to December. Thereafter live specimens were no longer available. There was no association between abdominal fat content and gender (Kendlall's tau-b = 0.058, P=0.669), as a result gender was disregarded for further analyses. Pearson's Chi-square could not be used to test the association between month and abdominal fat content as >20% of the cells had expected counts <5 (fig. 2.3). The 95% confidence interval for the relative risk ratio (5.6–126.6) did not include 1, indicating that there was a significant difference in abdominal fat content between winter and summer. This was verified by Pearson Chi-square (X^2 = 21.483; df = 1; P < 0.0001) where 87.5% (n = 21) of the adults in winter had high abdominal fat content compared with only 20.8% (n = 5) in summer. In June, abdominal fat content was at its highest with 66.7% of adults having 76–100% abdominal fat content and 33.3% with 51–75% (fig. 2.3). The 76–100% abdominal fat content levels were exclusive to the months of May to July whereas 1–25% abdominal fat content was measured from October to December.

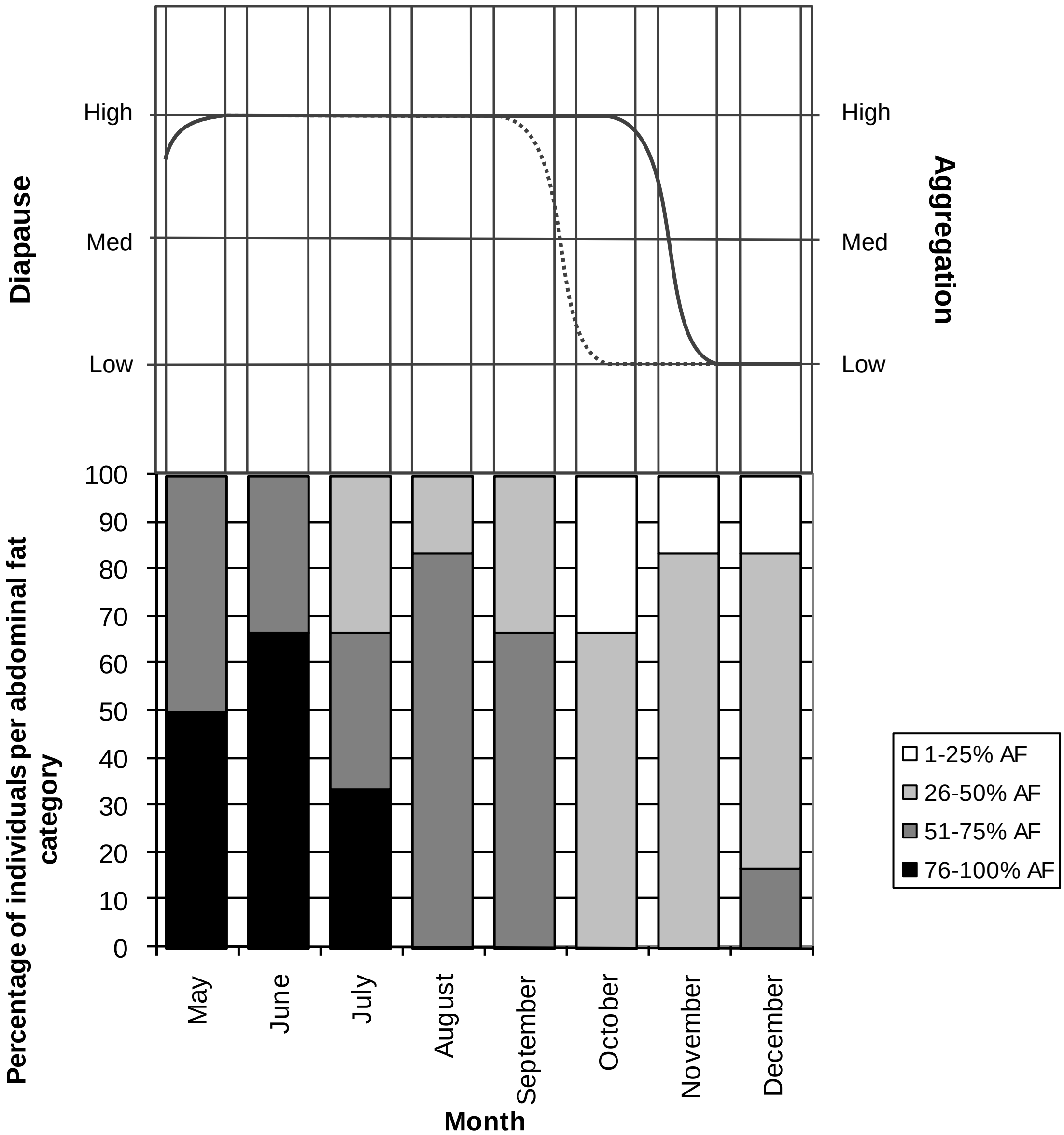

Figure 2.3: Seasonal changes in abdominal fat (AF) content (percent of fat in abdomen) of adult *Encosternum delegorguei* during May to December (3 females and 3 males per month; n = 48; see text for statistical analyses). The dotted line indicates cumulative diapause and the solid line aggregation.

2.5.3 Development and seasonality

Gender is distinguished by a pointed terminal abdominal segment in males and a genital orifice on the ventral abdomen in females. Females were slightly broader

($\bar{x}$ = 14.9 mm; n = 17) than males ($\bar{x}$ = 13.9 mm; n = 19). Random samples of 200 and 298 wild collected adults for captive rearing consisted of male : female ratios of 1:1.02 and 1:1.11. Black markings on the thorax or wing folds or the blackening of the mesosternum between the fore and middle legs appeared in 83% of adults within 5 days of captivity. As autumn changed to winter *E. delegorguei* developed a thin layer of clear, shiny oil predominantly on the dorsal body surface and body colour changed from green-yellow to olive-green. Greasiness disappeared and colours reversed to green-yellow by the onset of summer. In addition, by 15 September, 22% of 36 *E. delegorguei* from the large insectary had a red colour on the legs, antennae and as a v-shape on the hemelytra bordering the scutellum. By 16 October, when the first copulation was recorded, all captive *E. delegorguei* exhibited red legs, antennae and the v-shape while the rest of the insect was green-yellow. Copulation occurred mid-October to late November (spring). Courtship started with males rubbing the tibia of the front legs to produce a clicking sound then moving around the stationary female until the ventral abdomens were in contact. Front legs clutched onto twigs or the shade cloth and the last abdominal segment on the male was pivoted to allow the aedeagus to engage with the genital orifice of the female. During copulation the female was motionless whilst the male, used his hind legs to stroke her abdomen from top to bottom. Time spent copulating ranged from 1 to 6 h. In 13 instances single males pushed couples apart with their legs but re-engaging the female in copulation was only successful in six instances.

Ten days after the first recorded copulation on 26 October, brown truncated eggs were laid (fig. 2.4). The exposed egg surface dried within 15 min. of laying and changed to white. In 45% of oviposition events (n = 32) the male remained near the female. In two other cases, males held the egg with the abdomen until it stuck to the substrate. Shade cloth was the most commonly used substrate for oviposition having 68.8% of the egg masses. In decreasing order plants used for 31.2% of egg masses were *P. clandestinum* (12.5%), *C. imberbe* (7.8%), *P. africanum* (6.3%), *D. viscosa* (1.6%), *C. molle* (1.6%) and *C. erythrophyllum* (1.6%). Oviposition did not occur on *Bauhinia galpinii*, *D. mespiliformis*, *K. acuminata* and *P. violacea.* Forty-six of the egg masses were laid in single rows along a straight thread of the shade cloth, a leaf vein or a twig, 14 were in single irregular rows and four were in two or more rows.

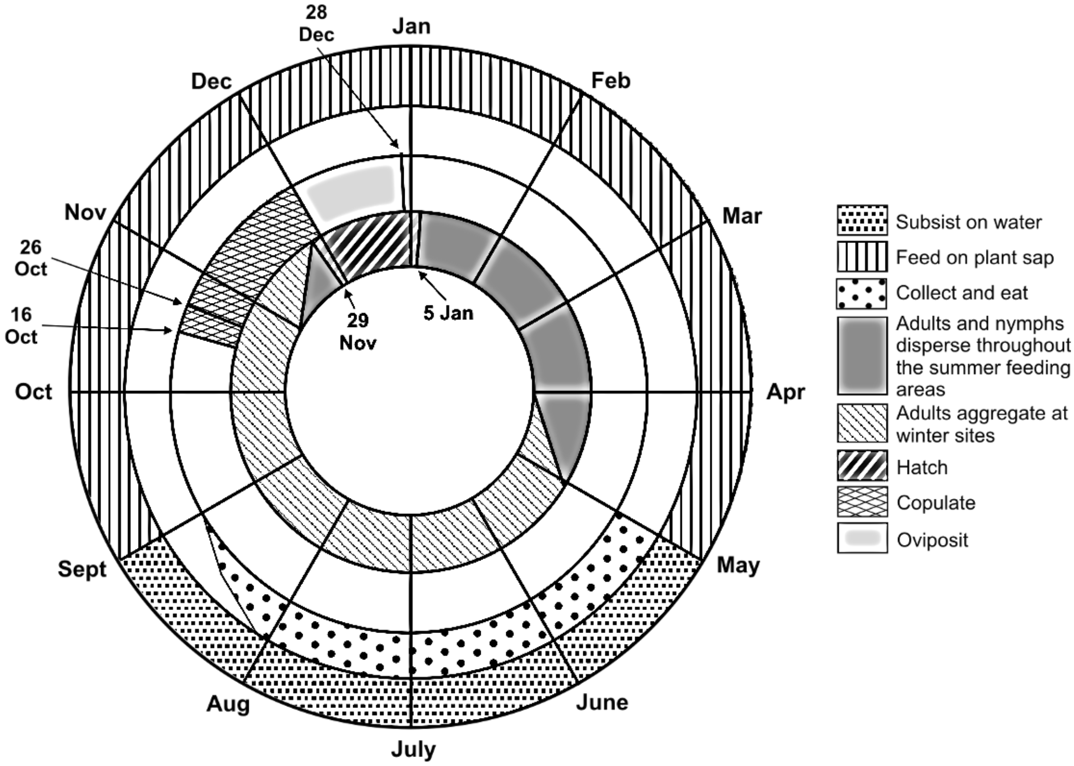

Figure 2.4: Univoltinism and behaviour of *Encosternum delegorguei* in the Limpopo Province of South Africa recorded in captive rearing trials of adults to 1st instar nymphs (1 May 2006 to 13 February 2007) and 3rd, 4th and 5th instar nymphs in the field (March and April 2007). The period recorded for copulation (16 October to 30 November), oviposition (26 October to 28 December) and eclosion (29 November to 5 January) are given.

A total of 1752 *E. delegorguei* eggs were laid by 103 females. The mean number of eggs in 64 egg masses was 27.4$\pm$13.9 (range 2–56) but number of eggs laid per female was not recorded. Incubation time averaged 18.7$\pm$9.0 days (7–37) at outdoor temperature ranging from 11^{o}C to 25^{o}C. Egg eclosion was 100% but declined to 3.2% due to parasitoids. The first instar nymphs were similar to adults except they were two mm long, pear-shaped, red and the stink gland openings were located on the dorsal, apterous abdomen as opposed to the ventral thorax. The longest surviving first instar nymphs caused superficial necrosis on *P. vulgaris* pods and within 34 days attained a length of three mm. Nymphs dispersed during hot weather but aggregated alongside the egg cases as temperatures cooled towards evening. In the field, third, fourth and fifth instar nymphs were found feeding on *C. molle* at Maribe Thema (23^{o}55'45"S

29°51'30"E) near Haenertsburg in April. The first adults started arriving at the Ga-Modjadji winter site in April and on 1 May a large noisy swarm arrived and aggregated in the trees. By November very few widely dispersed adults could be found at Ga-Modjadji.

2.5.4 Parasitoids

The parasitoid wasp, *Anastatus* sp. (Hymenoptera: Eupelmidae) hatched in mid-January 2007 from eggs in the large insectary. A total of 997 parasitoids, 36 *E. delegorguei* and 91 aborted eggs were produced from 68.8% of egg masses. A nominal by nominal test indicated no significant relationship between oviposition substrate and egg masses infected (Cramer's V = 0.091; P=0.467), where 65.9% of egg masses attached to the shade cloth and 75.0% attached to plants were parasitized. Wasp emergence holes were smaller, irregular and lidless in contrast to the regular round holes with lids made by emerging *E. delegorguei*. The parasitoid wasp exhibited strong sexual dimorphism with winged males and brachypterous females having body lengths of 1.5 and 4 mm respectively. In 12 egg masses the gender ratio was 1:1.3 in favour of females and in 16% of the egg masses only females emerged.

2.6 Discussion

Encosternum delegorguei adults commence feeding in spring (September) on *C. imberbe, C. molle* and *P. africanum* and to a lesser degree on *D. viscosa*. These woody plants occur in communal areas where they are harvested for fuel, building, carving and medicinal use by locals (Shackleton 1993; Anthony and Bellinger 2007). The decline of these plants (Kirkland *et al*. 2007) could be a reason for *E. delegorguei* harvests declining. There is no phytophagy during winter but *E. delegorguei* uses a wide range of indigenous trees and shrubs as winter perches including *B. galpinii, C. edulis, C. apiculatum, C. collinum, C. erythrophyllum, C. imberbe, C. molle, D. mespiliformis, D. viscosa, K. acuminata, P. africanum* and *P. violacea* as well as exotic fruit and timber trees. Overwintering at high altitude (1 046 m at Kheupeni) where the escarpment mist-belt is used to prevent desiccation and feeding in lower lying areas (572 m at Mamogadi) in the summer was recorded for *E. delegorguei* near Ga-Modjadji.

Body colour is not a consistent indicator of abdominal fat content and may be indicative of captive rearing stresses, e.g. a mean annual temperature 3.1°C lower than the source area and exposure to seven times more days of frost (Table 2.1). Only 20.8% of *E. delegorguei* adults in summer had high abdominal fat content compared with 87.5% in winter. Studies on the Southern green stinkbug *Nezara viridula* (Hemiptera: Pentatomidae) showed that fat deposits were higher in the colder seasons (Banerjee and Chatterjee 1985; Jones and Westcot 2002).

Abdominal fat content in captive *E. delegorguei* peaked in May and June and corresponded with aggregation and reproductive diapause (fig. 2.4). Increased body fat (Toscano and Stern 1980; Shiga and Moriya 1989), change of colour from a summer state to a winter state and wax secretions are good indicators of diapause (Tauber *et al.* 1985; Musolin *et al.* 2001, 2007). Diapause is a suspended state of development involving a physiological change to survive unfavourable environmental conditions in a temperate zone (Gullan and Cranston 2000). Many pentatomids undergo winter diapause to survive cold (Fielding 1990; Musolin *et al.* 2001; Numata and Nakamura 2002; He *et al*. 2004) but in tropical and sub-tropical climates they may continue to feed year round (McPherson and McPherson 2000) unless diapause is evolved to survive another environmental extreme such as aridity (Tauber *et al.* 1985). Savanna trees for example *C. imberbe, C. molle* and *P. africanum* lose their leaves due to winter aridity (Mucina and Rutherford 2006) resulting in reduced food source for *E. delegorguei*. The Squash bug, *Anasa tristis* (DeGeer) (Hemiptera: Coreidae) (Fielding 1990) and the Colorado potato beetle *Leptinotarsa decemlineata* (Say) (Coleoptera: Chrysomelidae) (Boiteau and Le Blanc 1992), were shown to enter diapause when availability and quality of food plants deteriorated. Diapause allows *E. delegorguei* to synchronize copulation, oviposition and eclosion with the onset of rain, higher temperature and growth of deciduous food trees.

Copulation in *E. delegorguei* is initiated by males producing clicking sounds with the fore legs but could involve auditory cues and host plant vibration as recorded for other pentatomids (Ota and Čokl 1991; Čokl and Virant-Doberlet 2003). *Encosternum delegorguei* pairs copulate facing the same direction with the ventral abdomens engaged so males are in position to use the hind legs to stroke the female's abdomen. Harris and Todd (1980) reported a similar leg movement during copulation in *N. viridula* which could last for minutes or days (Squitier 2005). Copulation lasted 1–6 h in *E. delegorguei* which is shorter than the 4 days recorded for *M. sulciventris* (Cant *et al*. 1996a).

As in other tessaratomids (Monteith 2006) the eggs of *E. delegorguei* were barrel-shaped but unlike *M. sulciventris* (Cant *et al*. 1996b) were predominantly laid in single lines rather than rows or clumps. Hatching is severely reduced from 100% to 3.02% by parasitoids. Similarly, 12-32 eggs were laid by *M. sulciventris* and 85% hatched successfully (Schaefer and Panizzi 2000). The agricultural pest *N. viridula* had higher fecundity and produced 30-130 (Squitier 2005) or 395-482 (Musolin *et al*. 2007) eggs. *Nezara viridula* (Squitier 2005) and *M. sulciventris* (Schaefer and Panizzi 2000) oviposited on the ventral leaf surface which may also increase chances of survival unlike *E. delegorguei* which laid eggs on exposed surfaces such as twigs and the dorsal leaf surface. On average *E. delegorguei* eggs hatched after 18.7 days at outdoor temperatures ranging from 11^{o}C to 25^{o}C. In two cases *E. delegorguei* males assisted during oviposition by holding the egg until it attached to the substrate with the dorsal abdomen.

Sixty-eight percent of *E. delegorguei* eggs were oviposited on the shade cloth instead of potential food plants as captive rearing prevented gravid females from dispersing. As nymphs are flightless a successful oviposition site should meet nutritional requirements of the number of eggs deposited (Damman 1991) but other factors such as presence/absence of predators could account for choosing inferior oviposition sites (Price 1997; Brodin *et al*. 2006). *Encosternum delegorguei* eggs have been reported on *C. apiculatum* and *C. imberbe* in field surveys in Zimbabwe (Mawanza 1999) and on *C. imberbe* in Tshikombani (22^{o}54'58.1"S 30^{o}13'22.6"E) near Thohoyandou (C. Dzerefos, unpublished data). These oviposition plants are not well represented in the Ga-Modjadji winter aggregation site, which is used to prevent desiccation in the dry winter months, so spring dispersion of *E. delegorguei* could be necessary to find sufficient high quality food. In addition, summer dispersal minimizes egg parasitoids locating *E. delegorguei* eggs.

Outdoor mortality of first instar nymphs of *E. delegorguei* could be attributed to low humidity, a factor which significantly affected survival and growth in *N. viridula* nymphs in laboratory studies (Lockwood and Storey 1986) as well as predation and sudden onset of colder weather. First instar nymphs of *E. delegorguei*, like *M. sulciventris* (McDonald 1969; Schaefer and Panizzi 2000) remained near the empty egg cases for the first week. Mawanza (1999) observed four nymphal instars within 4 months for *E. delegorguei* where body colour changed from bright red in the first instar nymph to more green-yellow with each moult whereas in this study five nymphal instars were observed.

This first record of the parasitoid, *Anastatus* sp., infecting *E. delegorguei* eggs provides a new reason for sporadic harvests. *As E. delegorguei* females were unable to leave the insectary but the parasitoid was able to enter, the risk of the egg masses being detected and parasitized increased. It has been shown that parasitoid wasps such as *Chrysonotomyia ruforum* Krausse (Hymenoptera: Eulophidae) were attracted by host plant volatiles released during oviposition (Hilker *et al*. 2002). Similarly, *Trissolcus basalis* (Wollaston) (Hymenoptera: Scelionidae) was attracted by plant volatiles released when *N. viridula* laid eggs and fed on the same plant (Colazza *et al.*2004). Parasitization of *N. viridula* eggs by the wasp *T. basalis* prevents population expansion in Florida (Squitier 2005) and Hawaii (Jones and Westcot 2002) but was ineffective in controlling widely dispersed *N. viridula* eggs which could not be reached within the wasp's short life span (Jones and Westcot 2002). In comparison to *E. delegorguei*, which is a strong, directional flier*, Anastatus* females are flightless and move short distances by jumping (Gibson 1986).

To forecast future harvests and improve captive rearing of *E. delegorguei* further research into the reproductive biology, natality, survivorship, population dynamics and parasitization is required. Production of 'minilivestock' such as insects under controlled conditions could prevent over-harvesting in the wild, constitute a commercial enterprise (Hardouin 1995) in a rural area and decrease malnutrition (Harris and Salisu 2003; Teffo *et al*. 2007).

Knowledge about the effect of day length on growth, development and reproductive diapause would also be important for captive rearing. The effect of climate change on *E. delegorguei* should be monitored as negative repercussions for montane species such as the stag beetle, *Colophon* spp. (Coleoptera: Lucanidae) which also relies on escarpment mist-belt have been predicted for southern Africa (Samways 2005).

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CHAPTER 3: COMPARATIVE ETHNOENTOMOLOGY AND SUSTAINABLE USE OF THE EDIBLE STINKBUG **

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3.1 Abstract

Insects, such as stinkbugs, are able to produce noxious defence chemicals to ward off predators, nevertheless, some ethnic groups have recipes to render them delicious. We provide an example of edible stinkbugs (*Encosternum delegorguei*) used by two locally separate ethnic groups in South Africa, the Vhavenda and Mapulana, with a third group, the Bolobedu using them for commercial purposes. Structured interview schedules and observations with 106 harvesters were conducted to determine differences in use, nomenclature and oral history, methods of collection and preparation as well as perceptions pertaining to availability. The stinkbugs' foul defence chemical and flight response necessitates nocturnal harvesting when the insect is immobilised by cold. The defence chemical stains the skin and affects vision yet protective gear is not worn. Damage to host trees was recorded when harvesters poached from plantations or private land, whereas, in communal-lands, sustainable methods were preferred. The legitimisation of stinkbug harvesting and introduction of a collection funnel could reduce conflicts with managers of plantations and private land. Two methods to remove the defence chemical for increased palatability were used. Preparation methods differed in whether or not water was used and also whether the head was left intact or removed. Stinkbugs have numerous medicinal uses, in particular as a hangover cure. Awareness and optimal use of beneficial insects, such as stinkbugs, in rural areas could lead to a reconsideration of current environmental management strategies, where harvesters act as habitat stewards and clearing, grazing or burning indigenous vegetation is kept to a minimum.

Keywords: Defence chemical, Edible insects, Entomophagy, Ethnomedicine, Sustainable harvesting, Traditional food

Spanish Abstract

Superar el temor a la chiche hedionda e implicaciones para una gestión ambiental sostenible Insectos tales como las chinches hediondas son capaces de producir defensas químicas nocivas para mantener alejados a sus depredadores, a pesar de ello, algunos grupos étnicos han desarrollado recetas para transformarlas en un manjar. Aquí presentamos un ejemplo de chinches comestibles (*Encosternum delegorguei*) utilizadas por dos grupos éticos geográficamente separados que habitan en Sudáfrica, los Vhavenda y los Mapulana, y de un tercer grupo étnico, los Bolobedu, que utilizan estos insectos con fines comerciales. Se llevaron a cabo una serie de observaciones y entrevistas estructuradas con 106 recolectores con la intención de determinar las diferencias en uso, nomenclatura, transmisión oral de conocimientos, métodos de recolección y preparación, así como percepción en relación a la disponibilidad de estos insectos. Debido a las nocivas defensas químicas que posee la chinche hedionda y a su capacidad de vuelo, se hace necesaria la recolección nocturna, cuando el insecto se encuentra inmovilizado por el frío. Sus defensas químicas tiñen la piel y afectan la visión, a pesar de lo cual los recolectores no hacen uso de ningún tipo de protección. Se registraron daños a los árboles hospedadores cuando los recolectores desarrollaban su actividad de manera furtiva en cultivos y terrenos de propiedad privada mientras que en terrenos de propiedad comunal se observó una preferencia por métodos sostenibles de recolección. La regularización de la recolección de las chinches junto con el uso de un embudo para la misma podría reducir los conflictos con los gestores de cultivos y terrenos privados. Se registró el uso de dos métodos distintos para eliminar las defensas químicas de las chinches y aumentar así su palatabilidad. Los métodos de preparación difirieron en el uso o no de agua y en la extirpación o no de la cabeza. Las chinches hediondas tienen muchos usos medicinales, en particular, se utilizan como remedio para la resaca. La concienciación y el uso óptimo de insectos beneficiosos tales como la chinche hedionda en áreas rurales podría permitir un replanteamiento de las actuales estrategias de gestión ambiental en el que los recolectores actuarían como custodios del territorio y actividades como el clareo, pastoreo o quema de la vegetación indígena se reducirían al mínimo.

3.2 Introduction

Ethnoentomology investigates the many, varied interactions between humans and insects [1]. Within the dichotomy of friend or foe, insects can be medicine or a source of poison [2-4], a free food source with protein levels on par or better than meat [5] or a competitor for plant crops [1]. Almost 2000 insect species are consumed globally [6] of which many are regarded a delicacy [7] and could be eaten in preference to fresh meat [5]. In sub-Saharan Africa, 250 edible insect species have been documented in rural areas [8] and can be accessible when areas are drought-stricken and plant crops fail to thrive [9,10]. In Bushbuckridge, South Africa, entomophagy was prevalent in 72% of households (n = 300) (W. Twine, unpublished observations) while towards the north-east in Mametja, 93% of 110 households used 19 insect species such as grasshoppers, termites or flying ants [11]. Data for two villages in Limpopo Province and one in Kwa-Zulu Natal Province, South Africa showed that 68% of 150 households used edible insects [12]. In comparison to entomophagy and medicinal plant research few studies have focused on medicinal insects particularly in Africa.

One of the most unexpectedly sought after edible insects in southern Africa is a species of stinkbug, *Encosternum* (=*Haplosterna*) *delegorguei* Spinola (Hemiptera: Tessaratomidae) (Figure 3.1). It is consumed as a delicacy in south eastern Zimbabwe [13,14] by the Shona people as well as by two geographically separate ethnic groups in South Africa, the Vhavenda [15,16] and the Mapulana [17] (Figure 3.2). A Shona legend recounts the origins of stinkbug use [18]. Nemeso is exiled by his father the chief because he has four eyes. His fortitude is rewarded by the ancestors revealing the secret of rendering stinkbugs palatable.

Stinkbug 'connoisseurs' are separated geographically by areas inhabited by people not using stinkbugs. Bolobedu harvesters from Ga-Modjadji, South Africa are an exception as they have recognised that stinkbugs are a high-value food commodity to the Vhavenda [16] and earn substantial annual income of up to US$ 1105 from sales [19]. Stinkbugs are usually abhorred as they squirt a foul defence chemical smelling of rancid almonds [13]. This stains human skin, stings eyes [9] and may cause temporary blindness [17]. Nevertheless, Tessaratomidae and Pentatomidae stinkbugs are collected and eaten raw or cooked in Malawi [20], India [3], Laos [21] Mexico [22] and Papua New Guinea [23]. Analyses of the stinkbugs *E. delegorguei* [16], *Atizies taxcoensis* A and *Euchistus sufultus* S [22] indicate good nutritional value. Stinkbugs in southern Africa are 'harvested' from trees in woodlands and plantations when the insects aggregate into football-sized clusters, during the winter dry season. This is very convenient for harvesters because at this time of year home grown produce and wild edible plants are scarce [10,24]. The apparently increasing availability of stinkbugs for sale in South Africa has led to a concern that harvesting could be unsustainable [25], and it is therefore crucial to have reliable information on their usage.

The aim of this paper is to provide the first ethnoentomology study on stinkbugs in southern Africa where ethnic differences in local knowledge, nomenclature and use are compared. Specifically, the following key questions have been posed: (1) What does nomenclature and oral history tell us about the use of stinkbugs? (2) Are sustainable methods used to collect stinkbugs? (3) How are stinkbugs prepared to make them palatable? (4) Do users perceive that availability of stinkbugs is changing for some reason? (5) Are stinkbugs available during a drought? (6) Can we suggest measures to assist harvesters and to ensure the sustainable use of stinkbugs and their habitat?

Figure 3.1: Dorsal view of the adult stinkbug, *Encosternum delegorguei.*

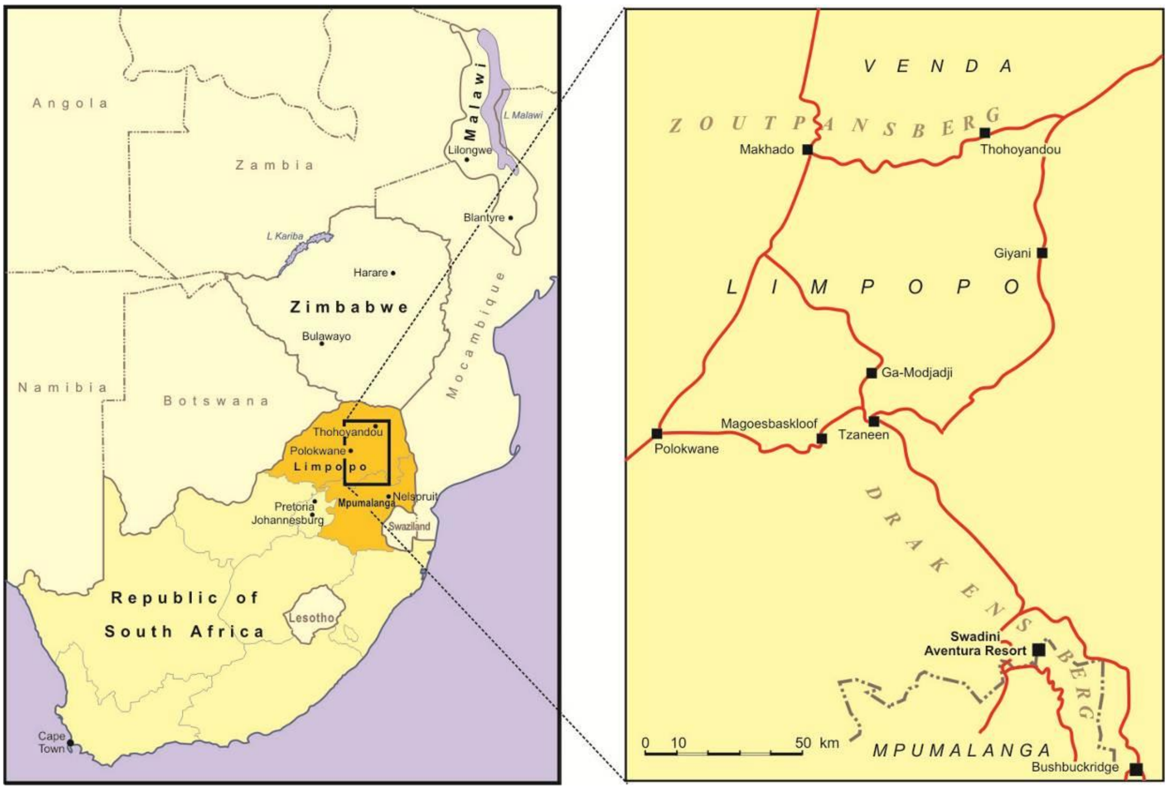

Figure 3.2: Edible stinkbug, *Encosternum delegorguei*, harvesting occurs in the foothills of the eastern Zoutpansberg escarpment near Thohoyandou, in the northern Drakensberg at Ga-Modjadji, in Limpopo Province, as well as Bushbuckridge, in Mpumalanga Province, South Africa.

3.3 Study area

Stinkbug aggregation areas around Thohoyandou and Ga-Modjadji in Limpopo Province and Bushbuckridge in Mpumalanga Province, South Africa, were investigated [19] (Figure 3.2). The sites occur in the transition hill-zone between the escarpment and low-lying plains where winter fires are lit to provide grazing for cattle and goats. The vegetation type is Sour Lowveld Bushveld, of which about 76% is transformed [26] due to natural resource extraction, urban sprawl, subsistence agriculture and commercial crops [27]. A small percentage of the vegetation type is conserved, notably in the Ga-Modjadji Cycad Reserve, the Thate Vondo Forest and the Blyde River Canyon Reserve. Invasive alien plant spread in disturbed areas or along river courses, bush fires, tree felling and overgrazing are negative environmental impacts arising from proximity to growing rural settlements in the study area.

Stinkbug harvesters come from communities with high illiteracy and unemployment [28]. Linkages to urban centres are strong as family members often work there and visit periodically. Although harvesters distinguish themselves ethnically as Bolobedu, Mapulana and Vhavenda other groups such as Sotho and Shangaan are also represented in the villages leading to cultural assimilation. While the convenience of modern shopping is spreading in rural areas, many still use the natural environment for sustenance, medicine and fuel [11,12,15,24,29]. Christianity is widespread but intermingled with ancestral intermediaries to an all-powerful God [30-32]. Even so superstitions and belief in witchcraft is prevalent [33]. Unmonitored access to harvest stinkbugs occurs in plantation forests, communal lands or protected areas [19]. Wildlife is frequently hunted for meat and use in traditional medicine [34]. Water and electricity provision and road infrastructure to rural areas has improved in the last decade but sewage systems remain primitive.

3.4 Materials and methods

From May 2006 to August 2007, 106 stinkbug harvesters were located through word-of-mouth referrals, local print media and revisiting previously described sites [16,17]. Of these, 37 were Mapulana from Bushbuckridge, 29 Bolobedu from Ga-Modjadji, 37 Vhavenda and three Shona from Zimbabwe trading in the Thohoyandou area. A key informant interview schedule (Appendix A) was vetted and approved by the University of the Witwatersrand Human Research Ethics Committee (H060524). It was completed with the assistance of field translators. Stinkbug harvesting techniques and post-harvest preparation were documented through experiential observation and semi-structured interviews. Results from interview schedules were presented to harvesters for discussion at a subsequent participatory workshop. Field workers competent in the vernacular languages (Table 3.1) assisted with translation. Where a household was engaged in stinkbug harvesting, the response of the entire household was entered as the response of one harvester instead of multiple respondents.

Table 3.1: Summary of differences between four ethnic groups utilising *Encosternum delegorguei* in southern Africa where n could refer to a household engaged in stinkbug harvesting or individual harvester.

Parameters	**Mapulana (n = 37)**	**Vhavenda (n = 37)**	**Bolobedu (n = 29)**	**Shona (n = 3)**
Origin and description of ethnic group	Mapulana are a sub-group of the northern Sotho	East African and Karanga (Zimbabwe) origins. Of eight Vhavenda sub-groups the Vhatavhatsindi, Vhambedzi and Vhangona eat stinkbugs	Karanga origins, settling first in Venda and finally at Ga-Modjadji. Bolobedu are the people of the Rain Queen and are also known as Balobedu or Lovedu	Karanga
Common vernacular	SePulana	TshiVenda	Lobedu	Shona
Location	Bushbuckridge Local Municipality, South Africa	Thohoyandou and surrounding villages, Thulamela Local Municipality, South Africa	Ga-Modjadji, Greater Letaba Local Municipality, South Africa	Bikita, Zimbabwe
Colonial era names	Mapulaneng	Venda	Duiwelskloof	Rhodesia
First use of stinkbugs and origin of current use	Recorded in 1944 [17]; pensioners claim to have learnt from grandparents	± 1930; pensioners claim to have learnt from grandparents	1982; claim to have learnt from co-workers at Middlekop tea estate	Recorded in 1905 [13]
Naming	Tsonônô = he farts and is fat	Thungulifha, Dzhovhe, Mbilimedzi from vhilimedza = running after them, Dzama = to die, Fhela = they are scarce, Mbilimedzi khuluvhali = it is hot/very bitter/chillie flavour, Murotho = chemical secretion	Thongolifha, Podile = it is rotten, Morotho = chemical secretion	Harugwa, Harurwa = bitter caterpillar
Collection bag used	A fruit bag with loose weave similar to shade cloth	A maize meal or fruit bag	A maize meal bag	
Storage method	Live stinkbugs kept in fruit bag	Prepared stinkbugs displayed in open containers/spread on bags		
Shelf-life of stinkbugs	After two weeks captivity stinkbugs taste bitter [25]	After six months the stinkbugs tasted stale/mouldy		

Interview schedule responses were analysed by comparing (1) preparation methods, (2) perceptions of availability within the last five years, (3) availability in drought years (4) cooperation amongst harvesters and (5) uses. Percentage scores were calculated and where relevant, graphed according to a three-way split across ethnic groups. It should be noted that “no response” data were entered as “don’t know”. Some questions had multiple replies, for example where harvesters identified reasons for stinkbug availability changing and, as a result, over 100% was therefore reflected in these cases.

The Predictive Analytics software (PASW) 18.0 was used for cross-tabulations and Pearson’s Chi-square to determine if harvester ethnicity was associated with perceived availability: (1) in drought years and (2) over the last 5 years. Statistica statistical package V.6. [35] was used for K-Means Cluster analysis, a non-hierarchical cluster method using binary data pertaining to whether or not harvesters (1) consume stinkbugs; (2) sell stinkbugs; (3) remove dead from live stinkbugs; (4) remove the head to prepare living stinkbugs; and, (5) remove the head to prepare dead stinkbugs. Data from the three Zimbabwean harvesters were excluded from statistical procedures due to the small sample.

3.5 Results

3.5.1 Nomenclature

Vhavenda harvesters use the traditional TshiVenda name “thungulifha” for stinkbugs whereas SePedi speakers use the derivative “thongolifha” (Table 3.1). Respondents indicated that the Bolobedu started harvesting stinkbugs in Ga-Modjadji communal-lands in 1982 after learning about the commercial value of stinkbugs from Vhavenda co-workers at the Middlekop tea estate in Magoebaskloof. This study identified two Bolobedu households that for the last decade have hosted three to seven Vhavenda harvesters during the stinkbug season. Twenty-two percent of Vhavenda harvesters travel to Ga-Modjadji for collecting. The Vhavenda have a rich vocabulary relating to stinkbug prevalence and taste. An additional movie file documents a Vhavenda woman’s song [see Additional file 1 http://www.ethnobiomed.com/content/9/1/20/additional], used after a successful harvesting trip, to inform the community that stinkbugs are available and stating “we will eat dzhovhe (stinkbugs) and mutuko (sour pap) on the other side of Mutale (a river in Venda)". In Lwamondo, one of the Vhavenda harvesting sites, it is bad luck to say "thungulifha" and the name "mbilimedzi" is used. "Dzama" refers to gravid (having eggs), inedible females that are common from mid-August. The Tshivenda term "fhela" is used to indicate when stinkbugs are scarce. "Mbilimedzi khuluvhali" is used when the stink has not been removed either because the stinkbug was dead on collection or preparation was incorrect. "Mbilimedzi khuluvhali" were said to have a chillie flavour and were known by all ethnic groups to cure hangovers. A Mapulana harvester cautioned that "if you eat the unprepared one it will kill taste for a month". "Podile" is a SePedi generic term for all stinkbugs and is widely used amongst non-eaters.

3.5.2 Harvesting techniques

Harvesters showed us their hands where short-term exposure to the stinkbugs' defence chemical stained the skin orange-brown and caused local swelling. They claimed that long-term harvesting (over a decade) caused nails to lift off the nail bed and wart growth. No protective eye-gear was worn, although harvesters said that a direct hit to the eyes burns and affects vision for three days. To protect themselves from the stinkbugs, harvesters usually wore multiple layers of clothing with the neck and sleeves tightly closed. Very few used protective hand-gear such as rubber gloves, woollen mittens or plastic bags as these tended to tear on thorns or slowed-down the collection.

As insects are cold-blooded, the cooler temperatures between dusk and dawn immobilise the stinkbugs. When they are warmed by the sun, stinkbugs fly-away or drop to the ground and fake death or scurry beneath leaf-litter to escape harvesting. Harvesters climb trees or use wooden crooks up to three-metres long to bend branches and access clumps of stinkbugs. Occasionally branches are sawn-off. The end of a branch is placed in a 25-litre bucket and stinkbugs are brushed-off with the free-hand. When the bucket is about 8-cm full the stinkbugs are transferred to a cord-tied bag (Table 3.1). The bag is shaken before opening so the stinkbugs are disorientated and cannot fly-away. Shaking causes the stinkbugs to release their defence chemical and the energy involved in this process heats up the bag. Bags are secured onto the harvester by a scarf or jacket.

Pines or indigenous trees were felled surreptitiously to access stinkbugs from Komatiland plantations in Venda and Bushbuckridge and a privately owned farm called Ravenshill (23°36′02.4″S; 30°16′36.5″E) near Ga-Modjadji. Trees next to firebreaks or roads were vulnerable to illegal felling as they fall into a clearing and can be picked clean. Apical points of small pine trees could be damaged when harvesting stinkbugs which prevents straight tree growth. In Ga-Modjadji, harvesters said they did not fell trees as the traditional authority had to give permission. Instead harvesters climb trees or hook branches. Some Bolobedu harvesters indicated that the trees should be retained so that stinkbugs would return each year. A Vhavenda harvester confirmed that in Ga-Modjadji, unlike Venda, there is no change in the stinkbug crop as the Bolobedu are not felling trees.

3.5.3 Availability of stinkbugs

Stinkbugs overwinter in large numbers in clusters and are easily harvested . Almost half the harvesters (48%) indicated that since 2002 the availability of stinkbugs had decreased whereas 19% perceived an increase (Table 3.2). There was no association between ethnicity of harvester and the perception of availability over the last five years (X^2 = 8.401; df = 4; P= 0.078). Diverse reasons pertaining to anthropogenic change (plantations, crops, fire and over-exploitation) and weather patterns (strong winds, too much/too little rain) were given for perceived change, although 33% of harvesters could not provide a reason. Most harvesters believed drought had influenced a decrease in stinkbugs and this perception was dependent on harvester ethnicity (X^2 = 25.569; df = 2; P < 0.0001) and cited by 59% Bolobedu, 22% Mapulana and 10% Vhavenda.

Table 3.2: Harvester's perceptions on whether availability of *Encosternum delegorguei* had increased or decreased from 2002 to 2007

	Mapulana (n = 37)		Vhavenda (n = 37)		Bolobedu (n = 29)		Total (n = 103)	
	n	%	n	%	n	%	n	%
Increased	4	11	6	16	10	34	20	19
Don't know	20	54	14	38	0	0	34	33
Decreased	13	35	17	46	19	66	49	48
Top three reasons given for decrease	Don't know (54%), drought (22%), removal of plantations (8%)		Don't know (46%), planting crops (16%) or plantations (16%)		Drought (59%), fire (21%), no other reason given		Don't know (33%), drought (27%), fire (7%)	

3.5.4 Stinkbug preparation

Post-harvest sorting of live from dead stinkbugs was done by 89% of harvesters, 10% didn't sort and 1% occasionally did. The removal of the defence chemical is paramount to stinkbugs being a table delight and two methods of preparation have been documented (Table 3.3). The Mapulana, and occasionally the Vhavenda (Table 3.4), used the traditional time-consuming method of removing heads and stink glands (Figure 3.3) and eating the stinkbugs on the day of preparation. The Vhavenda may also use the modern water-method favoured by the Bolobedu and Zimbabweans (Table 3.3; Figure 3.4). The water-method left the head intact and allowed many stinkbugs to be processed at one time for maximum profit and extended shelf-life. Total respondents, using the two methods were not markedly different, with 45% removing and 55% leaving heads intact (Table 3.4). A Vhavenda source claimed that the traditional waterless preparation method was started by cattle herders when water was unavailable. Storage methods were simple (Table 3.1) and shelf-life of living and dead stinkbugs was less than six months.

Table 3.3: Two methods to prepare *Encosternum delegorguei* for consumption in South Africa

Waterless method (used by Mapulana and Vhavenda)	**Water-method (used by Bolobedu and Vhavenda)**
Steps pre-braising:	
The stinkbug head is held between thumb and forefinger and nicked off on to a flat-rock. Squeezing releases the thoracic contents. Storage does not occur as they proceed to braising immediately.	Bagged stinkbugs are shaken vigorously and dropped into a 25-litre bucket with a perforated bottom. Hot water is poured over the stinkbugs and they are stirred quickly with a long pole or spoon. The stinkbugs release their defence chemical and within five minutes are dead. They are rinsed with a bucket of cold-water and transferred to a pot of water heated to about 50°C for eight minutes. The water is drained off and the stinkbugs are spread on bags on the floor to air dry. Stinkbugs that were dead at the start don't release their chemical and are identified by black markings on the thorax [25] and bitter taste. Blackened stinkbugs are removed. Dried stinkbugs may be stored up to six months.
Final braising:	
The detoxified stinkbugs are braised in a frying pan with salt and eaten as a spicy accompaniment to maize meal or alone as a snack.	

Table 3.4: Summary of differences between the post-harvest preparations (% harvesters) in four ethnic groups utilising *Encosternum delegorguei* in southern Africa

	Mapulana (n = 37)	**Vhavenda (n = 37)**	**Bolobedu (n = 29)**	**Zimbabwean (n = 3)**
Remove live head and scent gland	100	24	0	0
Use water on live stinkbugs leaving head intact.	0	76	100	100
Remove dead head and scent gland	8	22	0	0
Use water on dead stinkbugs leaving head intact	0	78	0	0

K-means cluster analysis identified three homogenous user groups that correlated with the ethnic groups, and also identified respondents that were using stinkbugs in ways not consistent with the rest of their group (Figure 3.5). The Vhavhenda displayed more variation in their utilisation patterns (73% behaved ‘modern’, 24% traditional, and 3% commercial), whereas the Mapulana utilisation patterns varied the least and were mostly traditional (97%). Modern users ate stinkbugs and used the quicker water method of preparation which left the head intact. The Mapulana only used the waterless method of preparation and all but one harvester consumed stinkbugs. The Bolobedu dominated the commercial group which tended to not eat stinkbugs. Eight Bolobedu were in the modern group, which was dominated by Vhavenda and included the three Zimbabweans.

Figure 3.3: A Vhavenda woman removes heads and squeezes out the stink glands of edible stinkbugs (*Encosternum delegorguei*) onto a flat-rock.

Figure 3.4: Bolobedu women cause live edible stinkbugs (*Encosternum delegorguei*) to release their defence chemical before dying by pouring hot water over them and stirring with a wooden stick. The contaminated water drains out of the perforated bucket and the air is foul from the released chemical.

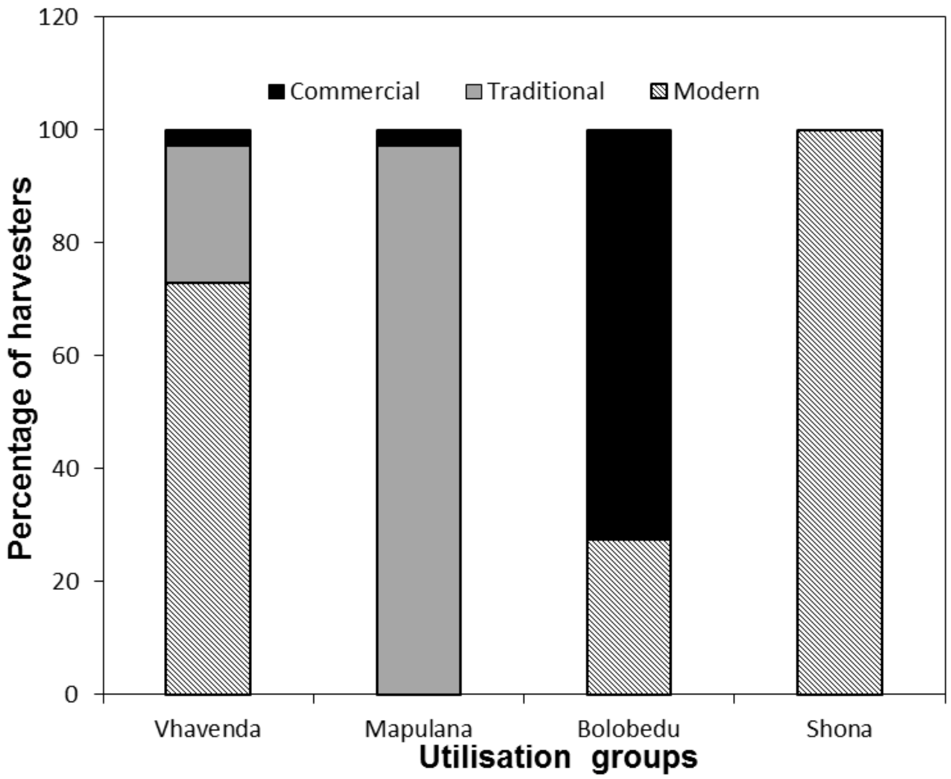

Figure 3.5: Edible stinkbug (*Encosternum delegorguei)* utilisation groups (i.e. modern, traditional or commercial) determined by K-means clustering analysis and based on preparation methods and whether harvesters eat and/or sell stinkbugs, where n = 106 harvesters.

Dead stinkbugs were used to cure hangovers, thrown away or prepared and eaten by some Vhavenda (22%) and Mapulana (8%). A variety of traditional medicinal uses were mentioned such as curing headaches and sore throats, controlling diabetes, treating arthritis or skin cancer. The blackish water left from preparing the stinkbugs was deposited in a corner of the yard. The Vhavenda believe that throwing the dirty water on paths or places where people walk will bring bad luck or poison trees.

Stinkbug harvesting tended to be matriarchal with 73% Vhavenda, 62% Mapulana and 100% Bolobedu and Zimbabweans being women harvesters. Cooperative harvesting occurred with 59% of harvesters while 28% would sell together and 17% prepared stinkbugs together (Figure 3.6). Mapulana harvesters were the least likely to cooperate with one another. Sixty-six percent of Bolobedu prefer cooperative selling to sole trading as then one harvester would travel to Thohoyandou to sell while the rest continued harvesting.

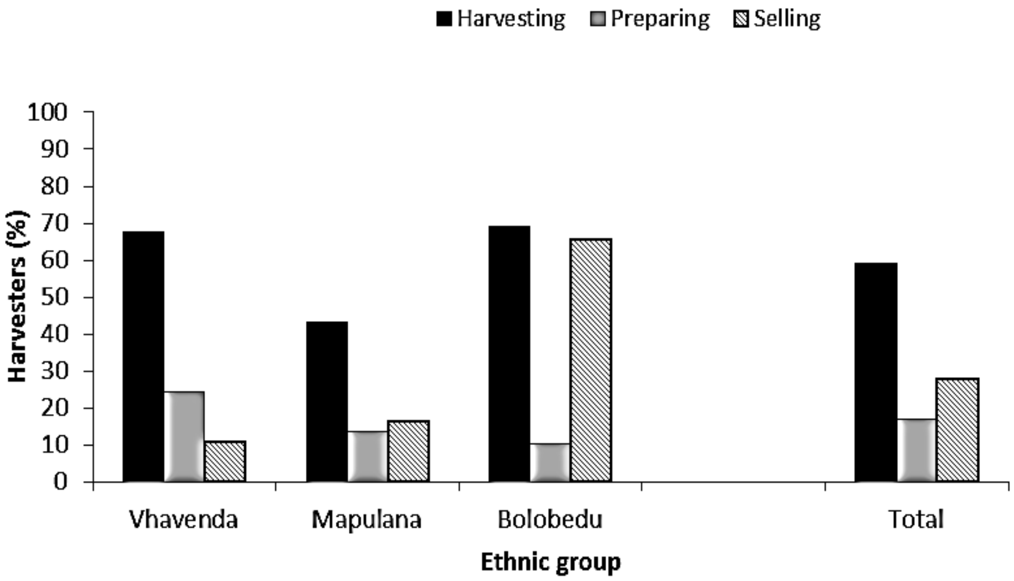

Figure 3.6: Cooperation between harvesters when harvesting, preparing and selling the edible stinkbug, *Encosternum delegorguei,* in three ethnic groups in South Africa, the Vhavenda, Mapulana and Bolobedu, where n = 103 harvesters.

3.6 Discussion

"If you have Thungulifha you can leave the meat!" This startling statement by a Vhavenda harvester demonstrates the significance of stinkbugs as a food, particularly a source of protein, and suggests that large-scale production as a minilivestock has merit. In contrast, Sotho and Shangaan people use derogatory names such as stinkbug or "podile". Such terms do not promote insect conservation which needs to extend beyond the fences of protected areas [36,37] and into private gardens and communal-lands. Stinkbug harvesting represents overcoming a fear-of-nature as it involves eating an organism that is usually abhorred. Fear-of-nature is a common phenomenon in Africa and has inadvertently assisted conservation. Many water bodies [31,38], mountains or forests [32,39] are associated with ancestral spirits [40] or fearsome figures like lions, crocodiles, snakes and mermaids, which keeps these sites revered and pristine [31,41]. Education [29], Christianity [39], population growth, colonial policies, infrastructure development and entrepreneurship are factors that erode fear-of-nature in rural areas. Without such taboos, land-use practices that are not aligned with sustainable environmental management proliferate [29,31,34].

The rich vocabulary used in relation to harvesting particularly by the Vhavenda (Table 3.1) indicates that use may be older than living memory. The Mapulana do not know the TshiVenda name for stinkbugs and *vice versa* for the SePulana name, suggesting that the use developed independently in these groups. Vhavenda and Mapulana harvesters tend to be opportunists who temporarily were in financial straits or were working in an area and came across aggregations of stinkbugs. For example, one respondent stopped selling stinkbugs when she began to receive a child support government grant. Others only harvest when stinkbugs aggregate in plantations rather than indigenous bush, which can be overgrown, thorny or harbour snakes. Another obstacle to harvesting is that stinkbugs are easiest to collect between sunset and sunrise [42] when criminals could target lone harvesters. Consequently many women harvest in groups or involve their families. In Bushbuckridge, school boys wanting pocket money during the school vacations have turned to harvesting. In Zimbabwe income from *I. belina* was used by child-harvesters for school-fees and to purchase stationary [7]. Stinkbug harvesting wanes towards August as the population has been thinned and more effort is required to find them. Harvesters perceived drought to have a negative impact on stinkbug availability.

Climbing trees or hooking and pulling down branches were sustainable harvesting methods observed for collecting stinkbugs. Branches may be cut or accidently breakoff and in Zimbabwe this has resulted in trees with heights below three-metres [9,14]. It is of growing concern that in plantations and private land, poachers damage growing points of young pines and fell mature trees to access stinkbugs. It is important that harvesting in these areas is legitimised so that it can be monitored and the use of a collection funnel [20] could be promoted as an alternative to felling trees. Funnels extend to five-metres and allow for efficient collection of large quantities of stinkbugs [20].

Cooking with salt and spreading out, instead of storing in closed bags or bottles, extended shelf-life of stinkbugs but increased loss to rodents. Insects with a high fat content don't dry out completely [14,25] and are susceptible to mould. Analysis of dried stinkbugs revealed substantial amounts of protein, fat, threonine, valine and minerals [16] even though edible insects with a high fat content lose nutrients when cooked and dried [43]. Alternative methods of preserving such as vacuum-packing, freeze-drying, canning, or pickling could extend the shelf-life, preserve nutrients and allow for marketing beyond national borders.

Identical nomenclature, preparation techniques, the existing market chain and harvesters confirm that the Vhavenda introduced stinkbug use to the Bolobedu in the 1980s but it is possible that the knowledge originates from Zimbabwe (Table 3.1). Today Bolobedu harvesters will taste dried stinkbugs to evaluate preparation and freshness but don't relish stinkbugs as a food [19] although grasshoppers and termites are traditional dishes [32]. The Bolobedu capitalise on the presence of stinkbugs in communal-lands and earn a good income [19].

The domestication of stinkbugs and use as a pesticide and medicine should be investigated further by poverty alleviation programmes to add value to the annual stinkbug crop in rural areas. Waste water from stinkbug preparation is currently thrown away in South Africa but in Malawi it was used as a termiticide [20]. Likewise, the defence chemical of the Litchi stinkbug, *Tessaratoma javanica* Thunburg (Heteroptera: Pentatomidae) killed the ants *Camponotus compressus* (F.) and *Monomorium gracillimum* (F. Sm.) and showed antifungal activity [44]. Another potential source of revenue could be unprocessed stinkbugs with defence chemicals intact. Unprocessed stinkbugs were mostly thrown away but 97% of harvesters said they were a hangover cure. Similarly the Malawian edible stinkbug was used for hangovers [20]. It is known that some insects produce complex compounds that can be fatal or medicinal, such as terpenoids in blister beetles (*Mylabris* spp.) and melletin in bee venom (*Apis* spp.) [4].

3.7 Conclusion

Stinkbugs were found to be a sought after traditional food amongst the Vhavenda and the Mapulana yet their full potential as a minilivestock, medicine or a pesticide has not been fully investigated or marketed. Exploitation can be improved by land managers and harvesters contracted to collect with restrictions to not fell host trees. When a community obtains economic or other benefits from an ecosystem it is likely to be protected from anthropogenic modification [45,46]. In Asia, for example, entomophagy has coincided with decreased pesticide use [47]. In the past, fear-based traditions sufficed for sustainable environmental management but as communities develop, knowledge-based adaptive management [40,42] where the benefits of biodiversity and ecosystems are acknowledged will be needed to prevent environmental degradation and ensure the survival of stinkbugs and associated indigenous plants and animals.

3.8 Acknowledgements

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3.10 Additional file

An additional file showing an old woman singing a traditional TshiVenda praise song to the edible stinkbug was included in the electronic publication (see http://www.ethnobiomed.com/content/9/1/20/additional).

CHAPTER 4: COMMERCIAL USE OF THE EDIBLE STINKBUG **

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4.1 Abstract

The use of *Encosternum delegorguei,* an edible stinkbug with high nutritional value, is restricted to three distinct groups of people in the north-east of South Africa, the Bolobedu, the Mapulana and the Vhavenda. The two latter groups consider stinkbugs a seasonal delicacy whereas the Bolobedu do not enjoy eating stinkbugs but sell them in Thohoyandou and surrounding villages to the Vhavenda. Structured interview schedules with 106 harvesters indicated that an estimated total of 3803 ± 43.4 kg (mean±S.E.) dry stinkbugs was harvested. Difficulties cited by harvesters include distances between harvesting areas or markets and the stinkbug's defence chemical. An annual gross income of $\bar{x}$ =US$ 345 which can be procured from stinkbugs, contributes to improving rural livelihoods. Bolobedu women were the most successful sellers, with a mean annual income of US$ 746. Opportunities to reduce impediments to harvesting and selling in a sustainable framework are discussed.

Keywords: Ecological economics; Entomophagy; Food security; Minilivestock; Non-timber forest products.

4.2 Introduction

In Africa, politics and economics often inform land-use, in particular conservation (Murphree 2009; Suich *et al*. 2009), due to the proximity of communities with limited education and income to biodiversity rich areas (Roe 2008; Fisher *et al.* 2012). Mining, industry, agriculture and tourism in rural areas are enthusiastically promoted as singular developments by government as they offer employment and remuneration (LEGDP 2004; MSOE 2010; MEGDP 2011). In contrast, Torquebiau and Taylor (2009), propose multi-faceted approaches for rural areas which marry development with commonplace traditional practices such as natural resource harvesting (Dzerefos *et al*. 1999; Shackleton *et al*. 2002; Venter and Witkowski 2013). Freely available resources like wood, fruits, herbs, mushrooms, insects and fish provide food security and commercial opportunities for women, children (Shackleton and Shackleton 2004a; Dovie *et al*. 2005; Kaschula *et al.* 2005; Shackleton *et al*. 2011) and the elderly (Botha *et al*. 2004) who are unable to hold formal employment. Researchers have quantified natural resource use (Cousins 1999; Williams *et al*. 2000; Shackleton *et al*. 2008) and the environment's role in sustaining rural livelihoods and acting as a green safety net (Paumgarten 2005; Hunter *et al.* 2007; Dovie *et al.* 2008) but information on the value and use of numerous non-timber forest products (NTFPs) is lacking (Cousins 1999; Shackleton *et al.* 2011), in particular for edible insects (Illigner and Nel 2000; McGeoh 2002; Durst *et al*. 2010).

The edible stinkbug *Encosternum* (=*Haplosterna*) *delegorguei* Spinola, is a traditional delicacy of some ethnic groups in South Africa, Malawi and Zimbabwe. Regional economic or socio-ecological studies (Twine *et al*. 2003; van Huis 2003; Shackleton and Shackleton 2004b; Shackleton *et al*. 2008) do not mention stinkbugs and quantities harvested are unknown (Gardiner and Gardiner 2003; Mapendembe 2005; Makhado *et al*. 2009), possibly because they are only available for a short period in winter, have widely distributed sites and selling occurs quickly and informally (Dudley 2004; Teffo *et al*. 2007; Dzerefos *et al.* 2009).

Lack of baseline information, monitoring and awareness of NTFPs' has led to land-use changes and deterioration of stinkbug habitat in southern Africa. For example, Magoebaskloof, Limpopo Province was a stinkbug harvesting area prior to 1963 but government subsidised a tea plantation in the area which resulted in the removal of indigenous trees and pesticide use. Today the tea plantation has been deserted and edible stinkbugs are extirpated in Magoebaskloof. Moreover in Malawi stinkbug wintering sites were protected from bush fires and harvesting quotas were set (Dudley 2004) but remote sensing indicates large-scale felling of trees, which communities confirmed was to access edible stinkbugs (Mlotha 2001). The aforementioned examples indicate that current bio-resource management regimes, implemented by provincial authorities and community-based structures, may be insufficient to conserve a sought after NTFP such as stinkbugs.

This study aims to provide an understanding of the economic value of edible stinkbugs and the people that are benefitting from their collection. It is a NTFP whose use has never been quantified before. The following key questions were set: (1) What amount of stinkbugs is harvested in a season? (2) How much income was earned from stinkbugs? (3) How do stinkbug harvesters participate in the local economy? (4) Are there mitigation measures for the perceived impediments to collecting and selling of edible stinkbugs?

4.3 Study site

South African harvesting is restricted to three areas within Limpopo and Mpumalanga Provinces (Figure 4.1; Table 4.1) where winter aggregation of stinkbugs occurs in dense sub-tropical vegetation known as Sour Lowveld Bushveld (van Rooyen and Bredenkamp 1996). The sites have a wide variety of savanna trees including *Combretum* and *Acacia* species and are located in the transition hill-zone between the escarpment and low-lying plains. Sales occur at the site of harvesting or further afield in surrounding villages or towns.

Mining, manufacturing, forestry, agriculture and tourism contribute to the local economy but are unable to absorb all school leavers seeking employment (Stats SA 2003). The unemployment rate in Limpopo and Mpumalanga Provinces is estimated to be 23 and 28% respectively (Stats SA 2011). Insufficient jobs result in high migrancy and infrequent family contact (LEGDP 2004). From 1996 to 2004, access to water, sanitation and energy improved but rural services remained inadequate (LEGDP 2004). The socio-economic situation in

Mpumalanga is comparable to that described for Limpopo Province (Shackleton *et al.* 2002; Dovie *et al.* 2005, MEGDP 2011).

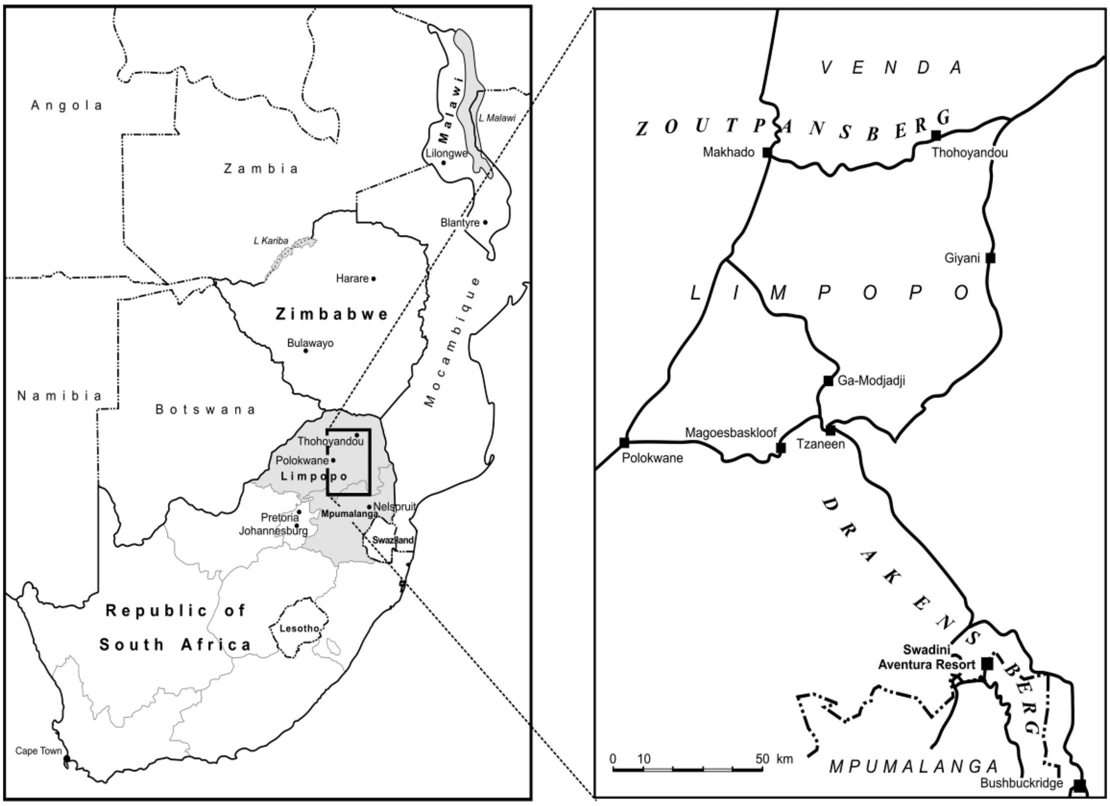

Figure 4.1: Edible stinkbug, *Encosternum delegorguei*, harvesting occurs in the foothills of the eastern Zoutpansberg escarpment near Thohoyandou and in the northern Drakensberg at Ga-Modjadji, in Limpopo Province, as well as Bushbuckridge, in Mpumalanga Province, South Africa.

Table 4.1: Site specific data for three harvesting sites in South Africa for the edible stinkbug, *Encosternum delegorguei*

Site data	Venda	Ga-Modjadji	Bushbuckridge
Local municipality	Thulamela	Letaba	Bushbuckridge
Former apartheid period names	Venda	Duiwelskloof	Mapulaneng
Ethnicity of harvesters	Vhavenda	Bolobedu	Mapulana
Common vernacular	TshiVenda	Lobedu	SePulana
Escarpment	Southern side, Zoutpansberg	Eastern side, Northern Drakensberg	
Regional relief	Medium gradient, east-west mountain ridges	Medium gradient, south-westerly to north-easterly hilly spurs	Medium gradient, east-west mountain ridges
Crops	Tea, tropical fruits, nuts, maize, pine/*Eucalyptus* trees	Maize, tropical fruits, pine/*Eucalyptus* trees	Tea, tropical fruits, nuts, maize, pine/*Eucalyptus* trees
Tourism*	Thate Vondo Forest, Lake Fundudzi	Ga-Modjadji Cycad Reserve	Swadini Aventura Resort, Mariepskop

*All sites are less than 100 km to the world renowned Kruger National Park.

4.4 Methodology

Snowball sampling, a nonprobability method based on referrals, was applied (Rubin and Babbie 2009) in the three areas where stinkbugs were collected and sold. Harvesters were contacted through the traditional and provincial authorities, schools, informal traders, and the agro-forestry sector as well as by placing articles in local newspapers. Harvesters were located at markets in Thohoyandou (Figure 4.1) and on village pension days. These are monthly gatherings where government pensions are provided for elderly and disabled people and informal markets occur (Botha *et al*. 2004). As on-going inquiries didn't yield new contacts it is likely that the sample is close to the actual number of harvesters.

The sample of 106 harvesters comprised 37 Mapulana from Bushbuckridge, 29 Bolobedu from Ga-Modjadji, 37 Vhavenda from the Thohoyandou area and three Zimbabweans that had collected in their country of origin but were selling stinkbugs in South Africa. Seven harvesters declined being interviewed (7% of total), as they were collecting stinkbugs without the landowners permission and feared arrest or losing their work as labourers or security guards. Stinkbug harvesters are unpopular for felling trees to expedite harvest or damaging growing pine saplings in plantations while collecting.

A key informant interview schedule (Appendix A) was approved by the University of the Witwatersrand Human Research Ethics Committee (H060524). The schedule covered details on harvesters, household and commercial use, quantities collected, gross income, pricing and marketing and distances travelled to harvest and sell. Seasonal labour allocation was not determined. Amounts in locally meaningful units such as ‘25 kg bucket’ or ‘enamel cup’ were converted to kilograms (Campbell *et al*. 1997; Twine *et al.* 2003). All currency values were converted to US dollars at exchange rate (US$ 1=ZAR 6.8) prevalent in October 2007. Harvesters estimated income earned in a best-month or highest harvest month as well as for the season. The schedule was administered during the winter harvesting season (May to August 2006/7) with the assistance of fieldworkers competent in the appropriate vernacular (Table 4.1).

The route from Ga-Modjadji to the Thohoyandou market was travelled with four Bolobedu harvesters. This allowed free-ranging discussion on transport options, accommodation, prices and the chain of supply. Interactions between harvesters, middlemen and customers were observed and recorded. Where a household was engaged in stinkbug harvesting their responses was entered as one harvester.

The Predictive Analytics software PASW 18.0 and Statistica statistical package V.6. (Statsoft, Inc. 2004) were used for all analyses. Interview schedule responses were also analysed by comparing (1) three ethnic groups, (2) gender, (3) whether harvesting stinkbugs had a commercial purpose or not and (4) top-sellers, defined after data collection, as having a monthly income over US$ 299. Data from three Zimbabwean harvesters were excluded from statistical procedures as their stinkbugs had been harvested in Zimbabwe.

The four variables, ethnic group, gender, commercial use and top-sellers, from all the questions, were graphed according to the two or three-way split between categories. Percentage scores of the resultant sub-samples were taken for interpretation and observance of the scores and to identify possible differences between sub-samples on the answering of each individual question for descriptive analysis. Where appropriate, two-tailed t-tests were used to determine the differences between the averages of two independent sub-samples. Of particular interest is the question of what makes an individual a top-seller or not? To answer this, a logistic regression was utilised to predict commercialisation reported by harvesters, using whether they were top-sellers or not, as the binary response variable (Top-sellers=1; Other=0). Models were estimated using block entry of four predictor variables of gender, price (in ZAR), whether or not they consumed stinkbugs and distance travelled for one harvest (in km) to collect stinkbugs. The best fit used the variables of gender and whether harvesters consume stinkbugs as these showed a significant influence on commercialisation ($P<0.05$; using PASW).

It should be noted that "no response" data were entered as "no response/don't know." It is assumed that harvesters, afraid of sanction or unwilling to reveal income would have declined participation when research implications were explained. Some questions had multiple replies, for example where harvesters identified problems and as a result over 100% was reflected in these cases. One-way analysis of variance (ANOVA) was used to test if average amounts harvested (best-month^{-1} and annum^{-1}) and the average income derived across the three ethnic groups differed significantly. To assess pairwise differences between ethnic groups, the Bonferroni multiple comparisons test was used on price cup^{-1}, amounts harvested (best-month^{-1} and annum^{-1}) and average income. Cross-tabulations and Pearson's Chi-square was used to determine if harvester ethnicity was associated with: (1) food use, (2) commercial use; (3) price cup^{-1} where (a) ≤ US$ 1 or (b) > US$ 1 and (4) income annum^{-1} where (a) ≤ US$ 299 or (b) > US$ 299.

We used a generalized linear model to predict harvesters annual income (in ZAR using 10 categories from R0 to > R7 000). A Poisson error structure and log canonical link was applied as the response variable consisted of counts. The categorised response variables used were (a) harvester gender, (b) distance to harvesting site (from <5 km, 5 ≤ 10 km, 11 ≤150 km or ≥ 151 km), (c) whether stinkbugs were eaten or not, (d) whether stinkbugs were sold or not, (e) whether sales were predominantly rural/urban and (f) selling price cup^{-1} (in ZAR using 8 categories from R0 to R20 cup^{-1}). We explored various combinations of the aforementioned measured predictor variables and the model with the lowest Akaike Information Criterion (AIC) was selected. The AIC uses log-likelihood methods to determine whether the increase in predictive power gained by adding another variable to a model justifies the increase in complexity of the model. low AIC indicates a model with high explanatory power.

4.5 Results

4.5.1 Gender and purpose for harvesting

The gender distribution of harvesters was skewed towards females (72%) (Table 4.2). Ethnicity and stinkbug consumption were associated (X^2=54.6; df=2; P<0.001) as stinkbugs were eaten mainly by Vhavenda and Mapulana and to a much lesser extent by Bolobedu (Table 4.2). Ethnicity and stinkbug commercialisation were also associated (X^2=13.5; df=2; P<0.001), with a much higher percentage of Bolobedu selling them (100%). The logistic model had 84.7% overall predictive accuracy and indicated that top-sellers tend to be Bolobedu females (Wald=4.998; df=1; P=0.025) who do not eat stinkbugs (Wald=8.898; df=1; P=0.003). Females were 7.4 times more likely than males to be top-sellers. We observed that women allocated more time to harvesting and were more willing than men to climb trees or enter overgrown areas.

Table 4.2: Summary of differences between four ethnic groups utilising the edible stinkbug, *Encosternum delegorguei,* in southern Africa

Parameters	**Vhavenda (n=37)**	**Mapulana (n=37)**	**Bolobedu (n=29)**	**South African average (n=34)**	**Zimbabweans (n=3)**
% eating	97	95	28	73	100
% selling	73	62	100	78	100
% women	81	57	79	72	100
Mode of transport to harvest	Walk, sites are near villages, except for 7 harvesters that visited Ga-Modjadji for 2 weeks and hired a small truck	Walk, sites are near villages		-	Walk, sites are near villages
Mode of transport to market	Walk/taxi depending on distance		Five taxi changes to Thohoyandou. Unreliable service could result in 18 hours travel	-	Taxi and buses
Overhead costs (excludes costs common across the board)	Travel to Ga-Modjadji. (Accommodation free due to kinship)	Travel to market	Travel to Thohoyandou/ surrounding villages. Fee to use toilet/rent sleeping space up to 2 weeks stay at markets. Packaging costs US$ 1 for 100 plastic bags	-	As for the Bolobedu but also border bribes from US$ 60 to 179
Selling price cup^{-1} US$ (ZAR)	0.74-3 (5-20)	0.74 (5-7)	0.74 (5)	1.03 (7)	0.74-1.5 (5-10)
Average annual income (US$)	183±199	238±190	581±255	345±159	672±287
Range in average annual income (US$)	30-896	30-746	149-1 105	30-1 105	522-896
% selling at urban centres	38	0	86	41	0
% selling in villages	43	68	24	45	100
Ratio of top-sellers:other	1:8.25	1:6.40	1:1.21	1:5.3	1:1

4.5.2 Logistics for harvesting and selling

Harvesting areas are ≤5 km from harvester's homes for 97% Bolobedu, 51% Vhavenda and 24% Mapulana harvesters (Figure 4.2). Twenty-seven percent Vhavenda travelled almost 200 km explicitly to collect from Bolobedu communal-lands as proximal areas were depleted. One Bolobedu woman and no Mapulana harvesters travelled as far. Those collecting solely for own use did so within 10 km of home. Collection was mainly from communal-lands but some Bolobedu admitted to harvesting from the local nature reserve. Plantation managers and a private land owner complained of trespassers collecting without permission in all three areas. Problems experienced during collecting and selling stinkbugs (Table 4.3), included transport and accommodation difficulties by Bolobedu harvesters and all complained about the stinkbug's chemical. Sales could be at urban centres or surrounding villages (Table 4.2). Bolobedu and Zimbabwean harvesters travelled the furthest to sell.

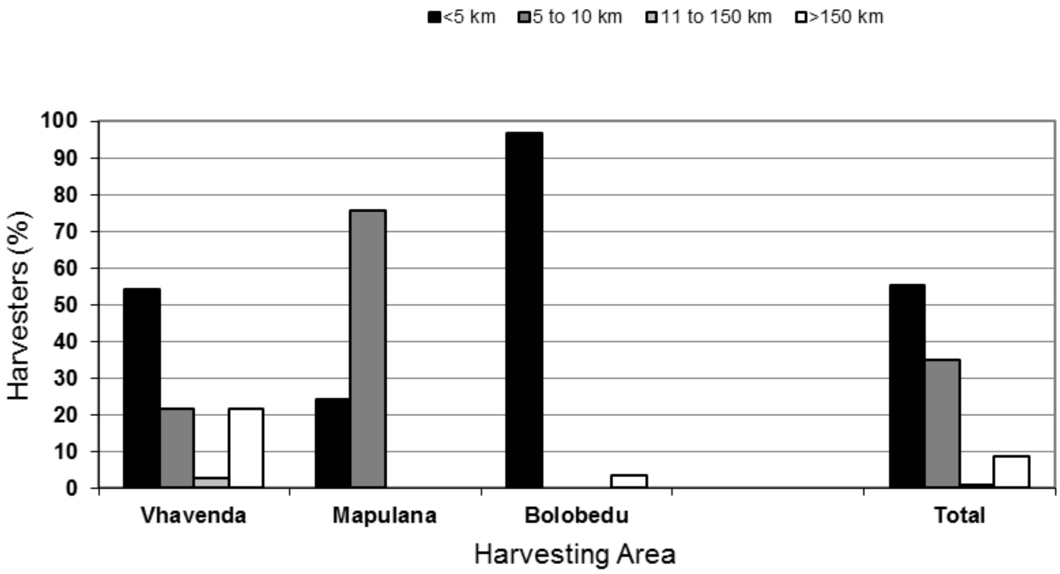

Figure 4.2: Distances travelled to harvest the edible stinkbug, *Encosternum delegorguei,* by three ethnic groups in South Africa, the Vhavenda, Mapulana and Bolobedu, where n=103 harvesters.

Table 4.3: Impediments to collecting and selling edible stinkbug, *Encosternum delegorguei,* in southern Africa (percentage of respondents in each class) as reported by harvesters

Class*	% harvesters				
	Vhavenda (n=37)	Mapulana (n=37)	Bolobedu (n=29)	Zimbabweans (n=3)	Total (n=106)
No problems	27	38	3	0	17
Stinkbug chemical damages eyes/skin	43	27	34	0	26
Bribes at South African border	0	0	0	100	25
Transport / accommodation	8	0	55	33	24
Many harvesters	8	0	7	33	12
Inability to sell stale stinkbugs	5	0	0	33	10
Snakes/thorns encountered harvesting	0	11	14	0	6
Annual harvest fluctuates / seasonal	8	3	3	0	4
Felling of trees for fuelwood/other use	5	8	0	0	3
Abhorred by Zion Christians/youth	11	0	0	0	3
Customers want credit	0	11	0	0	3
Nature reserve/forestry security	3	5	3	0	3
Flu from harvesting in cold weather	0	5	0	0	1
Stinkbugs are lost to rodents	0	0	3	0	1

* Problems have been summarised and simplified

4.5.3 Quantities harvested

An estimated total of 3803 ± 43.4 kg dry stinkbugs were harvested in 2007 by 103 harvesters. Significant differences in the average amounts harvested annum^{-1} and income earned (Table 4.4) by the Bolobedu relative to the other two groups were found. In addition the Bolobedu collected higher volumes, relative to the other two groups (Figure 4.3) with as much as 31% harvesting between 120.1 to 140 kg dry weight season^{-1}. In comparison most Vhavenda (90%) and Mapulana (60%) reported in the 1 to 20 kg dry weight category. The top three best-month harvests by individuals were a Bolobedu harvester at 63 kg dry weight and two Zimbabweans with 56 and 73 kg dry weight.

Table 4.4: Differences in the quantities of *Encosternum delegorguei* harvested (mean ± S.E.) and commercial indicators (mean ± S.E.) across three ethnic groups in Venda, Bushbuckridge and Ga-Modjadji, Limpopo Province, South Africa, where n=103 harvesters. The Bonferroni multiple comparisons test indicated that means without common superscripts are significantly different from each other

	Vhavenda (n=37)	**Mapulana (n=37)**	**Bolobedu (n=29)**	***F*-value**	**Significance**
a) Amounts harvested (kg/harvester)					
Month^{-1}	3.7 ± 0.5^{b}	8.3 ± 1.5^{a}	27.1 ± 2.2^{a}	66.7	$p < 0.001$
Annum^{-1}	10.4 ± 1.8^{b}	19.0 ± 3.6^{a}	93.6 ± 6.9^{a}	107.7	$p < 0.001$
b) Commercial indicators (US$)					
Price cup^{-1}	1.0 ± 0.1^{a}	0.6 ± 0.1^{b}	0.8 ± 0.0^{b}	7.4	$p < 0.001$
Best month income	75.4 ± 22.7^{b}	74.1 ± 14.5^{a}	183.2 ± 18.7^{a}	9.8	$p < 0.001$
Income year^{-1}	133.9 ± 33.6^{b}	157.7 ± 32.1^{a}	580.8 ± 48.9^{a}	41.1	$p < 0.001$

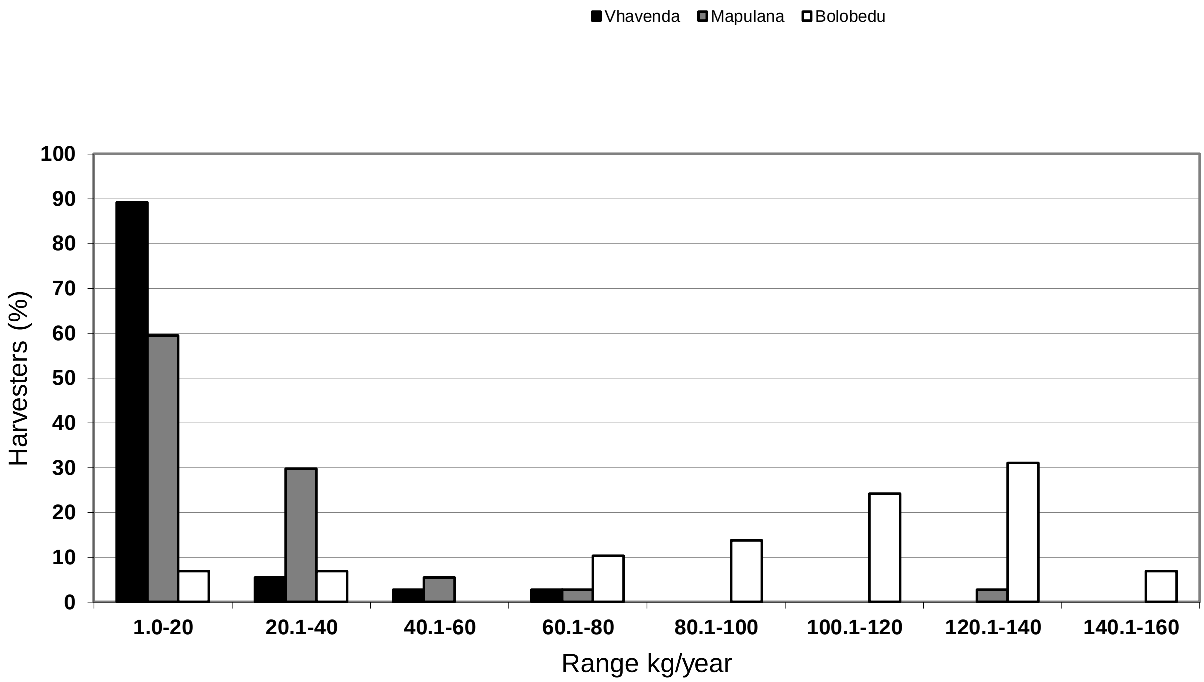

Figure 4.3: Quantities of edible stinkbugs, *Encosternum delegorguei*, harvested in one season (May to August 2007) in South Africa by three ethnic groups, where n=103 harvesters.

4.5.4 Economic benefits

Pearson Chi-square (X^2=92.8; df=2; P<0.001) indicated that price cup^{-1} (Table 4.2) was determined by harvester ethnicity, where 46% Vhavenda and Mapulana sold at one US$ cup^{-1} and 93% Bolobedu for under a dollar. The latter were wholesale prices to hawkers in Thohoyandou, who doubled the resale price. The weight of dry stinkbugs cup^{-1} was 0.087 kg. There were 11.5 cups in a kilogram. Stinkbugs bought on consignment from Vhavenda harvesters fetched the highest prices at US$ 3 (ZAR 20) cup^{-1}. None of the interactions between variables in the AIC model proved highly significant for predicting income. The best model which minimised the AIC incorporated price cup^{-1}, ethnic origin and whether the harvester sold stinkbugs or not. Price cup^{-1} alone had a strong effect on income (P=0.00536) and top-sellers sold many stinkbugs at low prices. Income was also effected by ethnicity with Bolobedu (P<0.001) and Mapulana (P=0.02907) having significantly better annual income than Vhavenda (P=0.03411) and Bolobedu being most likely to be sellers. Monthly price fluctuations didn't occur according to 92% Mapulana, 59% Bolobedu and 51% Vhavenda harvesters. Stinkbugs were not purchased if a taste sample indicated staleness or from August onwards when they had “a sandy taste.”

Stinkbug sellers in South Africa earned a mean annual income of US$ 345$\pm$292 (n=79) and were categorised into four income brackets (Table 4.5). The Bolobedu earned the highest annual income ranging from US$ 149 to 1105 (Table 4.2). Income was seasonal with a definite high-yield, mid-year month related to availability of stinkbugs and at least six months of no income. The Bolobedu reported the highest best-month income ($\bar{x}$ =US$=183; n=29), followed by Mapulana ($\bar{x}$ =US$ 106; n=23) and Vhavenda ($\bar{x}$ =US$=103; n=27) harvesters.

Table 4.5: Gross income distribution of edible stinkbug, *Encosternum delegorguei,* harvesters from South Africa in one season (May to August 2007) where n=103 harvesters

Group	Income Range US$	Harvesters (%)
Don't sell/know	0	30
Marginal	<75	10
Moderate	>75-150	10
Good	>150-300	17
Top-seller	≥300	33

There was consensus amongst 100% Zimbabweans, 97% Bolobedu, 95% Mapulana and 73% Vhavenda harvesters that stinkbugs were prolific in June. A few stinkbugs could be found in March according to 5% Vhavenda harvesters, 5% Mapulana and 7% Bolobedu. According to 27% Vhavenda and 3% Mapulana, a few could be found in October and thereafter not until May. Surprisingly, 3% Bolobedu harvesters found inedible stinkbugs in December.

The majority (73%) of stinkbug harvesters had alternative income sources from selling goods (36%), government grants (26%), temporary employment (18%), formal jobs (6%) or were still at school.

Sixty-one percent of top-sellers don’t eat stinkbugs, 70% had alternative income, 79% harvest <5 km from their homes and 73% sell at urban centres rather than villages. Estimated collection in a best-month by top-sellers was 25$\pm$13 kg (range 1.22 to 62.64 kg) and in one season was 86.2±38.7 kg (range 7.5 to 129 kg). Eighty-two percent of top-sellers sell at ≤US$ 1 cup^{-1} and mean income for a best-month was US$ 425±454 (range US$ 104 to 746). The annual mean income top-sellers expected to make was US$ 746±211 (range US$ 313 to 1 104).

4.6 Discussion

Stinkbugs are a tasty traditional food harvested in three sub-Saharan countries from indigenous woodland and plantation forests. They sell quickly in informal markets during the four months they are available. For example, 2.61 kg dry stinkbugs collected in two hours were sold within an hour next to a secondary road in Bushbuckridge (C. Dzerefos unpubl.). Dudley (2004) aptly called edible stinkbugs “self-advertised” since buyers followed the smell of processing which is necessary to remove the chemical defence. Collection and preparation methods are described in Dzerefos *et al.* (2013). Distances travelled to find stinkbugs, unauthorised collection from private land, health and safety risks experienced while harvesting or selling stinkbugs and consumption by university graduates highlights their status as a delicacy. Similarly, the Mopane worm *Imbrasia belina* (Westwood) (Greyling and Potgieter 2004; Gondo *et al*. 2010) and a lesser known edible caterpillar, *Hemijana variegata* Rothschild (Egan 2013.), were favoured foods.

The overall harvest estimate for South Africa in one season was 3803 kg (range 0.5 to 139.2 kg household^{-1}) and earned an annual income of US$ 345 household^{-1} or about US$ 35500 overall. In comparison in two Zimbabwean villages, Mopane worm harvesting ranged from 19.0 to 53.1 kg household^{-1} season^{-1} and contributed a quarter of household income (Gondo *et al.* 2010). In Bushbuckridge, the selling of NTFPs has been shown to be higher than farm-labour or domestic-workers’ wages and provides opportunities for the unemployed (Shackleton *et al.* 2008). Vhavenda stinkbug harvesters estimate their highest best-month income during the winter season to be US$ 103 month^{-1}, which is higher than income generated locally from wild fruits, herbs, Mopane worms, grasshoppers or wild medicines (Venter and Witkowski 2013). NTFPs reduce migrancy to urban areas and provide an accessible, self-driven cash injection to improve living conditions or assist during unexpected financial setbacks (Shackleton and Shackleton 2004a; Shackleton *et al.* 2008). For example, a Vhavenda woman whose day-to-day needs were met by a child-support grant and selling snacks at a local school, sold stinkbugs for a month in order to construct a long-drop toilet.

Availability, freshness, correct preparation and ethnicity of seller, governed price dispersion. At the Thohoyandou market, Vhavenda middlemen purchased stinkbugs in bulk from Bolobedu harvesters and resold them. This arrangement maximized return-on-investment as middlemen took-over responsibility for maintaining product quality and arranging packaging. Also harvesters didn't require overnight accommodation and could return to harvesting. Another two examples of a locally-based middleman in another province selling on a harvester's behalf were recorded. Although upfront payment was lower than selling direct to customers, Bolobedu harvesters considered the mark down fair as "this was their place" and the Bolobedu were the "visitors". However, when Vhavenda harvesters harvest in the Bolobedu communal-lands, they weren't charged for access or accommodation. The traditional authority should consider charging a fee to be used for sustainable management of stinkbugs as a minilivestock. For example, feed could be purchased instead of winter burning to provide cattle-grazing.

The Bolobedu had the highest annual income and best-month and provided the most reliable data on quantities of stinkbugs harvested as own consumption is minimal. The Vhavenda earned less than the Bolobedu and the Mapulana harvesters, yet set the highest prices cup^{-1}. Top-sellers were highly motivated and determined Bolobedu or Zimbabwean women selling in Thohoyandou and surrounds to Vhavenda people. Bolobedu top-sellers sold 25$\pm$13 kg dried stinkbugs in a best-month at low prices. The annual income that top-sellers earned was $\bar{x}$ = US$ 746$\pm$211. Bolobedu and Zimbabwean harvesters travelled almost 200 km by public transport to markets which were 80 km more than distances travelled in Botswana for Mopane worms (Gondo *et al*. 2010). The Bolobedu (Figure 4.2) and Zimbabweans harvested mainly from communal-lands.

Labour allocation or cost wasn't calculated as stinkbug harvesting occurred in winter when agricultural tasks are few and harvesters have time available. In comparison transport required resources to be redirected and was the principal cost involved, followed by consumables such as fuelwood, salt for preparation and packaging bags. Protective-clothing e.g. gloves, plastic bags, scarves and overalls, tools e.g. buckets, maize meal bags or wooden poles and utensils e.g. basins, pans, pots and spoons were not specifically purchased for harvesting but pre-owned for other uses. We recommend that harvesters purchase protective eyewear and gloves as long-term exposure to the defence chemical could affect health and quality of life.

There was potential for sales to be better co-ordinated to reduce transport and accommodation problems. By collating a database of buyers that could be informed via social media networks such as Mxit, Facebook, WhatsApp, BBM and Twitter when and where *E. delegorguei* could be purchased harvesters could reduce time at market, sell for themselves at higher prices according to orders and cooperate to reduce transport fees. In 2012 a national survey revealed that over 90% of households had a mobile phone in Limpopo and Mpumalanga Provinces (Stats SA 2012) and with basic training harvesters could work more efficiently.

Income generation from stinkbugs can be diversified as stinkbug harvesting has educational value as was demonstrated in Ga-Modjadji, 2011, when ICON productions, United Kingdom came to film their use. Marketing of activities involving stinkbugs could attract tourists as the Japanese edible wasp (*Vespula lewisi* Cameron) festival (Mitsuhashia 1997) and glow-worm *Arachnocampa* spp. excursions in Australia (Rodger and Calver 2005), New Zealand and Malaysia (Meyer-Rochow *et al*. 2008) have done. Tourism can lead to the protection of insect habitat as has occurred for the Monarch butterfly *Danaus plexippus* L. in Mexico (Samways 2005).

Stinkbugs provide a nutritional food (Teffo *et al*. 2007) and an income to rural people and therefore could be a flagship species to promote *in situ* conservation of Sour Lowveld Bushveld. Flagship species are used for attracting funding or encouraging tourism but not to influence communities (Bowen-Jones and Entwistle 2002) who interact with the environment on a daily basis and determine the sustainability of a habitat. Alien invasive plants proliferate in gardens adjacent to stinkbug harvesting areas and are spreading seed into the communal-lands which although utilised for grazing and NTFPs have high indigenous biodiversity present. Conservation of reptiles (Smart *et al*. 2005), rare butterflies (Thomas *et al*. 1992) and other insects (Samways 2005) cannot be achieved in isolated island reserves but require biotic corridors which traverse communal-lands or private gardens. The Bolobedu traditional authority through respected community governance (Mathabathe and Shabangu 2001) has inadvertently conserved stinkbugs by controlling tree felling, ploughing and livestock numbers. In contrast, the other two harvesting areas have communities that now challenge cultural leadership and the traditional local authorities inadequately manage NTFPs (Kaschula *et al.* 2005; Kirkland *et al*. 2007) such that sustainable management is the sole mandate of provincial authorities (Makhado *et al*. 2009) who are city-based and may be unaware of the importance of NTFPs.

The value of stinkbugs is a mere fraction of the ecosystem services that the natural environment provides to rural communities (Clover 2003; Paumgarten 2005) and must be considered when developing environmental awareness programmes (Mutenje *et al*. 2011) or evaluating land-use change (Cousins 1999) in conservation areas, communal-lands or plantations. In the spirit of sustainable development, access rights to stinkbug aggregation sites should be provided with strict guidelines preventing damage to host trees, the starting of fires or poaching of other NTFPs. The Environmental Impact Assessment process, which is a legal requirement for land-use change, should consider the loss of tourism potential and NTFPs to communities before developments are permitted to proceed.

4.7 Conclusions

Stinkbugs are a sought after traditional food and a seasonal capital injection for rural households. On average in a season, a Bolobedu harvester collects four times more stinkbugs than a Mapulana and nine times that of a Vhavenda harvester. Women control 72% of the stinkbug market. The winning formula used by Bolobedu women harvesters optimise income by collecting large quantities of stinkbugs and selling quickly at relatively low prices. Transport and accommodation costs to market could be reduced through cooperation. The positive externalities from stinkbugs and other NTFPs need to be documented and known so that aggregation areas and food plants (Dzerefos *et al*. 2009) are not burned, cut-down or otherwise altered. Reserve and plantation managers and private landowners should manage for optimal yields and provide access rights to harvesters that subscribe to sustainable harvesting practices.

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CHAPTER 5: CURRENT AND FUTURE DISTRIBUTION OF THE EDIBLE STINKBUG *

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* C. M. Dzerefos, B.F.N. Erasmus, E.T.F. Witkowski and D. Guo. (in review). Unlocking the bioclimatic envelope of the winter range of a beneficial insect *Encosternum delegorguei* (Hem., Tessaratomidae) in southern Africa. Journal of Applied Entomology.

5.1 Abstract

Rural communities in South Africa, Malawi and Zimbabwe annually harvest from winter aggregations of the edible stinkbug *Encosternum* (=*Haplosterna*) *delegorguei* Spinola. Using a regional maximum entropy modelling method (MAXENT) for winter field records of *E. delegorguei,* current and future climate scenarios were identified. Winter precipitation and to a lesser degree summer precipitation and winter temperature were the climatic variables found to limit the regional distribution of *E. delegorguei*. The receiver operating characteristic analysis (ROC) yielded an AUC (area under the curve) value of 0.995, indicating a reliable model although interpretations must consider the influence of elevation for this insect. A testable hypothesis regarding future distribution of *E. delegorguei* in the face of climate change has been formulated for its winter range. Predator-prey relationships and food source are also influencing the occurrence of *E. delegorguei* and may override the influence of climate. The modelled current distribution identifies potential new sites which may be unknown to harvesters and identifies areas where mini-livestock development initiatives could be piloted, opening up the potential for extending the commercial opportunities presented by this insect.

Keywords: Bioclimatic envelope, climate change, MAXENT, species distribution modelling, stinkbugs

5.2 Introduction

Despite Africa's small carbon footprint relative to the rest of the world, the Inter-Governmental Panel on Climate Change reveals that Africa is warming faster than the global average (IPCC 2007). Food security and rural livelihoods in sub-Saharan Africa are threatened by increased frequency of floods, stronger winds (Clover 2003) and drought (Brown *et al.* 2008) attributed to climate change. Biodiversity will also be affected (DEA 2013) but species level detail is largely undetermined. A moderate increase in CO_2 emissions is predicted to alter the distribution of 97% of 179 terrestrial species in South Africa (Erasmus *et al*. 2002).

Species-based studies were flagged in a South African report on the progression and impact of climate change, as a means of monitoring predictions and mitigating impacts (DEA 2013). Insects are suitable climate change indicators as their life cycles are completed in a short space of time. One extreme example being the hemipteran *Moritziella castaneivora* Miyazaki which during a period of abundant food was able to complete one generation per week and eight generations in a year (Wang *et al*. 2010). In particular, strong fliers have the ability to disperse widely and possibly track climatic changes by shifting their range. Indeed the Southern green stinkbug, *Nezara viridula* L. was shown to have extended its' distribution northwards in Japan by 85 km in 45 years (Tougou *et al*. 2009). The Monarch butterfly *Danaus plexippus* L. in the western hemisphere is also expected to have a northward shift in range but will not survive in these new areas if its' food plant does not match the predicted shift (Batalden *et al.* 2007).

In southern Africa the inflated stinkbug *Encosternum (=Haplosterna) delegorguei* Spinola, is recognised as an increasingly rare and delicious food and hangover cure (Dzerefos *et al*. 2013). *Encosternum delegorguei* is collected by rural communities for own consumption or trade (Dzerefos *et al.* in press). The life cycle is divided between the resource-rich, summer niche where solitary adults disperse widely feeding on plant sap and the winter niche where adults in reproductive diapause form gregarious aggregations and intake is restricted to water condensing on plant perches (Faure 1944; Dzerefos *et al.* 2009). Low temperatures, as experienced in the winter niche, are beneficial as fat reserves metabolise slower (Tanaka *et al*. 1988), but a minimum threshold temperature below 10°C, common between sunset and sunrise, increases vulnerability as chemical defence or flight are not possible.

In 1934, Mjele reported that *E. delegorguei* had returned to Bikita, Zimbabwe, for twenty consecutive years since 1905. Eighty years later the site is still used (NewsDay 2010) yet site suitability determinants or the bioclimatic envelope are unknown. Both *E. delegorguei* (Dzerefos *et al*. 2009) and *D. plexippus* (Batalden *et al.* 2007; Stefanescu *et al*. 2012) return to the same overwintering sites every year and being univoltine are not using memory for site recognition but another cue. Ecological niche modelling of *D. plexippus* has shown that temperature and precipitation, which constitute the bioclimatic envelope of the species, govern distribution (Oberhauser & Townsend Peterson 2003). Apart from climatic variables, migratory coccellids may be returning to wintering sites because of the lingering odour of their faeces and dead beetle remains (Hagen 1962; Nalepa *et al.* 2000).

For the last decade, the maximum entropy modelling method (MAXENT) has been applied, monitored and refined by empirical ecologists into a useful practical tool (Halvorsen 2013). MAXENT is widely recommended for small samples of presence-only data (Phillips *et al*. 2006; Phillips & Dudík 2008; Tognelli *et al*. 2009; Wang *et al*. 2010; Anderson & Gonzalez 2011). Insect distributions have been modelled with success using MAXENT, for example beetles (Hanley *et al*. 2007), fruit flies (Li *et al.* 2009) and aphids (Wang *et al.* 2010) amongst others. An evaluation of eight modelling methods (artificial neural networks, BIOCLIM, classification and regression trees, DOMAIN, generalized additive models, GARP, generalized linear models and MAXENT) for predicting current distribution of 10 Patagonian insects, found MAXENT to be the top performing distribution model (Tognelli *et al*. 2009). MAXENT models are used for future distribution predictions which provide valuable information for land use planning (Tognelli *et al*. 2009; Elith *et al.* 2010; Sánchez-Guillén *et al*. 2013) and integrated control of agricultural (Tougou *et al*. 2009; Li *et al*. 2010) and forest pests (Feng *et al.* 2009; Sobek-Swanta *et al.* 2012) and disease vectors (Olwoch *et al.* 2008).

The aim of this study is to define the bioclimatic envelope of *E. delegorguei* using a regional-scale MAXENT v. 3.3.3k model (Phillips *et al*. 2006). An understanding of the bioclimatic envelope identifies high-priority sites where there is a strong likelihood of discovering new localities. Secondly, areas that a species could use but has not exploited due to dispersal limitations are identified (Araújo & Townsend Peterson 2012). Unexploited areas could be used for mini-livestock production of *E. delegorguei* to enhance rural food security and the local economy. In addition predictions are made on the future distribution of *E. delegorguei,* in anticipation of expected climate change, which are useful for socio-economic upliftment schemes and land use planning.

5.3 Study area

Winter aggregation sites of *E. delegorguei* were confirmed at Nyuni mountain in Zimbabwe, Tsamba Forest Reserve in Malawi, the Zoutpansberg and northern Drakensberg in South Africa (Table 5.1). In the South African range climatic conditions are warm and humid, with a summer rainfall between 450 to 1 500 mm annum^{-1} and negligible frost in high-lying areas (Mucina & Rutherford 2006). The South African sites occur in three vegetation types: Zoutpansberg Mountain Bushveld, Tzaneen Sour Bushveld and Legogote Sour Bushveld. These are transitionary vegetation types between savanna bushveld and afromontane forest and tend to be dense and overgrown with tall trees, short bushes and a reduced herbaceous layer. Edaphic conditions and disturbance regimes maintain the differentiated vegetation of savanna and afromontane forest (Marchant 2010). A common vegetation type Granite Lowveld flanks the vegetation types used by *E. delegorguei* in winter (Mucina & Rutherford 2006) and typifies the major component of the summer niche.

The winter sites are adjacent to rural villages with high illiteracy and unemployment and basic infrastructure (Stats SA 2011; Table 5.1). The South African localities exhibited increasing monocultures of food crops or timber tree plantations and land transformation attributed to natural resource extraction (Marchant 2010), cattle grazing, village expansion and the spread of invasive alien plants (Kaschula *et al*. 2005; Dzerefos *et al*. 2013). Aerial photographs of three villages in Bushbuckridge, Mpumalanga province, over a 23 year period confirmed increased housing developments and reduced tree cover (Giannecchini *et al*. 2007).

Table 5.1: Winter aggregation site data for the edible stinkbug, *Encosternum delegorguei* in Malawi (Morris 2010; MSOE 2010), Zimbabwe (WFP 2003; Chikobvu *et al*. 2010; Kembo 2010) and South Africa (Scheepers 1978; Mucina & Rutherford 2006; Stats SA 2011)

Parameters	Malawi	Zimbabwe	South Africa Venda	Ga-Modjadji	Bushbuckridge
Location	Neno and Thyolo Districts	Bikita-Zaka Highland Communal, Bikita District	Thulamela Local Municipality	Letaba District	Bushbuckridge Local Municipality
Escarpment			Southern side, Zoutpansberg	Eastern side, northern Drakensberg	
Regional relief			Medium gradient, south-east ridges with rain shadow on northern ridges	Medium gradient, north-east ridges	Medium gradient, west-east mountain ridges
Vegetation type	Zambezian Miombo Woodland with *Brachystegia floribunda, Brachystegia spiciformis, Uapaca nitida, Uapaca kirkiana* or *Eucalyptus* plantations		Zoutpansberg Mountain Bushveld, pines, tea and mango orchards	Tzaneen Sour Bushveld and *Eucalyptus*	Legogote Sour Bushveld, *Eucalyptus* and pine
Conservation status of natural vegetation	-	Customary tenure	Vulnerable	Endangered	Endangered
Current protection of natural vegetation	Thambani Forest Reserve and Tsamba Forest Reserve	Jiri Forest, Nyuni mountain	Blouberg, Happy Rest and Nwanedi Nature Reserves	Lekgalameetse and Ga-Modjadji Cycad Reserve and Wolkberg Wilderness	Bushbuckridge, Barberton, Kaapsehoop and Mondi Cycad Reserves
Altitude (m)	918	1045	704-1147	906-1115	597-1147
Rainfall (mm annum^{-1})	725-2500	600-800	450-900	550-1 000	700-1 150
Mean annual potential evaporation (mm)	-	-	2092	2097	1911
Mean annual soil moisture stress (%)	-	-	76	74	69
Max temp (Oct)	-	-	29°C (location unknown)	36°C (measured in Tzaneen)	36°C (measured in Nelspruit)
Min temp (June/July)	-	-	5°C	4°C	1.6°C
Mean annual temperature (°C)	19.2	19.4	18.9	19.7	18.4
Mean frost days	-	-	2	1	2
% no schooling	18	2	17	27	19
% completed schooling	-	40	11	6	7
% unemployed	90	94	44	40	52
Population density (persons km^{-2})	139	72	106	112	53

5.4 Study species

E. delegorguei is univoltine having one generation per annum and migrating in large numbers to winter sites in the escarpment mist-belt. *Encosternum delegorguei* has winter diapause or suspended development (Dzerefos *et al*. 2009). Non-diapause adults are recognised by a large green-yellow shield-shape body with dimensions 24-27x13-15 mm (Faure 1944; Picker *et al.* 2004). Woody plants such as *Combretum imberbe, Combretum molle, Peltophorum africanum* and *Dodonaea viscosa* are a food source in spring (Dzerefos *et al*. 2009). *Encosternum delegorguei* are widely distributed from southern Africa northwards to the Democratic Republic of Congo but are only documented as a food source in South Africa, Malawi and Zimbabwe. Specimens of edible stinkbugs lodged at the Forestry Research Institute of Malawi (FRIM) have been confirmed as *E. delegorguei* (D. Jacobs, University of Pretoria, pers. comm.) not *Nezara robusta* Dist (Morris 2010) (see section 1.6.4 Misidentification of Malawian edible stinkbugs).

5.5 Materials and methods

5.5.1 Species records

Since the geographical distribution of *E. delegorguei* was known only at a broad regional scale or mentioned in publications as a place name, primary field data was required. To determine the current ecological niche of wintering *E. delegorguei*, harvesters had to be found (refer to Dzerefos *et al*. 2013 for details) to indicate the areas where *E. delegorguei* was annually harvested. Sites were often a couple of hours walk from the nearest road. Permission from the relevant traditional authorities was required to sample in the communal areas. No-go areas were identified in Ga-Modjadji and Venda where initiations were in progress or ancestors had been buried. The approximate central point coordinate of the harvesting area was recorded using a Global Positioning System unit and the altitude, vegetation cover, topographic position and slope and aspect of the site was recorded. The steep irregular terrain and thickness of the vegetation at some locations ruled out the possibility of accurate polygon data. A total of 35 occurrence localities were obtained throughout South Africa. An additional location from Zimbabwe was provided by Dr Charity Chenga, University of North

West, while the Malawi location is well documented (Morris 2010; van Huis 2013) and was identified on Google Earth.

Historic distribution data in museum collections from around the world was obtained through email correspondence (Table 5.2). Ten additional institutes replied that *E. delegorguei* was not in their collections. As voucher specimen labels lacked month of collection or only cited country of origin, modelling was restricted to the winter range for which complete data had been collected. The historical data was also circumspect as *E. delegorguei* may have been misidentified as demonstrated with the Malawian specimens and it was not within the scope of this study to check identifications. Moreover, the southern-most records from Pretoria were more likely to have been *Natalicola pallida* Westwood (D. Jacobs, University of Pretoria, pers. comm.). The approach of focussing on the winter range was also taken by Oberhauser & Townsend Peterson (2003) who defined the ecological niche of a migratory species as ‘a succession of conditions that are periodically and regularly occupied.’ The wintering sites are merely one part of the succession and occur at a particular point of the insect’s life cycle.

Table 5.2: Details of the incomplete historical distribution records of *Encosternum delegorguei.* Collector's names have been omitted and colonial era names have been changed to present names

Historical distribution records (number of specimens)	**Date**	**Source**
Ramoutsa, Botswana (1)	1894	National Museum, Bloemfontein, South Africa
Damara, Namibia (1)	Unknown	Iziko South African Museum, Cape Town, South Africa
Damaraland, Namibia (1)	Unknown	
Windhoek, Namibia (1)	Unknown	
Mooketsi, South Africa (1)	Unknown	
Waterberg, South Africa (1)	Unknown	
Bikita, Zimbabwe (1)	Unknown	
Que Que, Zimbabwe (1)	Unknown	
Grootfontein, Unknown (1)	Unknown	
Letsitele, South Africa (11)	1963/12/17	South African National Collection of Insects, ARC Pretoria, South Africa
Mariepskop, South Africa (1)	1944/07/15	
Pretoria, South Africa (1)	1915/05/10	
Pretoria, South Africa (1)	1915/06/01	
Pretoria, South Africa (2)	1915/07/02	
Punda Maria, South Africa (1)	1963/09/23	
Malawi (1)	Unknown	Forestry Research Institute of Malawi, Malawi
Gaub, Otavi mountains, Namibia (1)	1972/11/28	National Museum Windhoek, Namibia
Delagoa Bay, Mozambique (1)	Unknown	Royal Museum of Central Africa, Brussels, Belgium
Luiswishi, Democratic Republic of the Congo (6)	1982/10	
Nairobi, Kenya (1)	Unknown	
Ghanzi, Botswana (1)	1924	Natural History Museum, London, United Kingdom
Ghanzi, Botswana (1)	1925	
Chilanga, Malawi (1)	1936	
Blantyre, Malawi (1)	1910	
Tsumeb, Namibia (1)	1972	
Rietfointein, Namibia (1)	1972	
Dan Sara, possibly Niger (1)	1918	
Pretoria, South Africa (1)	1915	
Bikita, Zimbabwe (1)	1965	
Mashonaland, Mt. Chirinda, Zimbabwe (1)	1907	
Masvingo, Zimbabwe (1)	1918	
Tarkoila Tistar, Unknown (1)	1911	
Montabila , Unknown (1)	1896	
Inhambana, Mozambique (1)	1842-7	Museum of Natural History, Berlin, Germany
Namibia (1)	Unknown	

5.5.2 Environmental data

The distribution of *E. delegorguei* was modelled for Africa south of the equator using calculated seasonal climatic variables extracted from the WORLDCLIM database (v. 1.4; http://www.worldclim.org). The period 1961 to 2000 was used as it provides a useful reference baseline and data has been adjusted for inaccuracies (Hijmans *et al*. 2005). Eight variables for total temperature and precipitation for summer (December to February), autumn (March to May), winter (June to August) and spring (September to November) were included (Table 5.3). The inclusion of temperature and precipitation for sub-Saharan African models concurs with recommendations by Brown *et al.* (2011). The model was restricted to continuous data rather than categorical data such as vegetation and soil type. Vegetation data was not included as *E. delegorguei* occupies both indigenous and plantation forests in its winter range in South Africa (Dzerefos *et al*. 2013) while the Zimbabwe (Makuku 1993) and Malawi (Morris 2010) sites consisted of indigenous trees not found in the South African sites (Table 5.1). Vegetation during winter aggregation has been shown to function as a perch and not as food (Dzerefos *et al*. 2009), consequently minimum height of trees might be more important than the actual species.

5.5.3 Distribution modelling

MAXENT v. 3.3.3k (http://www.cs.princeton.edu/~schapire/maxent; Elith *et al.* 2010) was used on the presence locations (Phillips *et al*. 2006) for *E. delegorguei* to produce a current distribution model. The data input region was Africa south of the equator which included all known winter and summer locations. With MAXENT the environmental variables in 10 000 points per grid cell are cross-checked for similarity with the species presence data (Phillips *et al.* 2006). Twenty-five percent of the data was randomly selected and excluded to conduct statistical analysis of the model. A jackknife method was used to compare the influence of individual variables on the distribution. As the data was considered to be reliable and objective, a receiver operating characteristic analysis (ROC) plot was built with sensitivity and specificity values for all available probability thresholds (Fielding & Bell 1997). Sensitivity values consisted of true predictions divided by the total number of positive predictions while the specificity values were the true negative predictions divided by the total number of negative predictions. Equal weight was given to false positive and false negative predictions (Erasmus *et al*. 2002). In the resultant ROC plot the area under the curve (AUC) statistic measures whether there is a good model fit (≥0.8) or a random model fit (0 to 0.5) (Fielding & Bell 1997; Phillips *et al.* 2006). The standard deviation was calculated as described for equation 2 in Delong *et al.* (1988). A multivariate environmental similarity surface value for each predicted grid cell was calculated to provide insights into the most limiting climatic variable influencing the model (Elith *et al.* 2010). MAXENT was also used to predict which future climate variables contain values outside the training envelope of values.

A long term mean prediction for climatic variables for the period 2041 to 2060 was determined:

$$\text{Change in precipitation } (\Delta_p) = \text{Future/Control}$$

$$\text{Change in temperature } (\Delta_t) = \text{Future-Control}$$

Precipitation and temperature variables were derived differently for the modelled historical climate since there is greater uncertainty in magnitude of rainfall than temperature (Hewitson & Crane 2006). Using the WORLDCLIM data as the observed the following were calculated:

$$\text{Projected future total precipitation} = \Delta_p * \text{observed}$$

$$\text{Projected future temperature} = \Delta_t + \text{observed}$$

Data was used in a regional climate model, conformal-cubic atmospheric model (CCAM), with ECHAM5 GCM parameterisation. The CCAM model is an empirical description of atmospheric thermodynamic conditions including convection and is believed to be a reliable predictor for future climate change in southern Africa at the seasonal scale (Engelbrecht *et al.* 2011). CCAM accurately depicts the west-east rainfall gradient over South Africa and the central semi-arid belt extending from Botswana to the Limpopo River basin, South Africa and into Zimbabwe. However the average daily summer rainfall total should be circumspect as a wet bias of up to two mm day^{-1} was noted (Engelbrecht *et al.* 2011).The model parameters were set using a conventional coupled global climate model (CGCM), in this case ECHAM5 (IPCC 2007). ECHAM5 assumes moderate CO_2 concentrations for southern Africa, and the A2 scenario of the Special Report on Emission Scenarios was used as it most closely aligns recent trends in observed global temperatures (Engelbrecht *et al.* 2009, 2011).

5.6 Results

5.6.1 Sample

The most northern presence record for wintering *E. delegorguei* was in Malawi (15°17'S, 34°35'E) and the most southern sample locality was in Mpumalanga Province, South Africa (20°07'S, 31°01'E). The elevation of the wintering sites in southern Africa ranged from 597 m in Mpumalanga Province to 1147 m in Limpopo Province, South Africa. Presence records totalled 37 locations, but only 25 points were used for model training as six random points were set aside for model testing and a further six were discarded as they had been duplicated within the chosen climate grid resolution. The Zoutpansberg presence localities occur on south-east running spurs while the northern Drakensberg sites run in a north-east direction. On both mountain ranges the spurs or hills discontinue into low altitude vegetation. The flight path between the wintering sites is short (Zoutpansberg to Ga-Modjadji, Drakensberg 60 km, Ga-Modjadji to Mpumalanga, Drakensberg 102 km) and belies the poor road network that limits human harvesters.

5.6.2 Modelled distribution

The eight seasonal variables (Table 5.3) used in the MAXENT version 3.3.3k model were deemed reliable to make predictions (Erasmus *et al*. 2002), as the training AUC was 0.994 and the test AUC value was 0.995 (SD=0.002). The MAXENT output had no modelled current or future locations falling outside the training range.

Table 5.3: Contribution of environmental variables obtained from WORLD CLIM for the MAXENT model

Variable	Codes	Period	% model contribution
Summer precipitation	sum_rain	Dec. to Feb.	30.5
Winter temperature	win_temp	June to Aug.	27.3
Winter precipitation	win_rain	June to Aug.	24.0
Spring temperature	spr_temp	Sept. to Nov.	10.3
Autumn precipitation	fall_rain	March to May	6.8
Spring precipitation	spr_rain	Sept. to Nov.	0.9
Summer temperature	sum_temp	Dec. to Feb.	0.1
Autumn temperature	fall_temp	March to May	0

Analysis of variable contribution with a jackknife process indicated that the environmental variable with highest gain when used in isolation in the model was winter precipitation (Figure 5.1). It is also the environmental variable that decreases the gain most when omitted. In addition, summer precipitation and temperature are also limiting variables influencing *E. delegorguei* distribution but were not as influential as winter precipitation (Table 5.3; Figure 5.2).

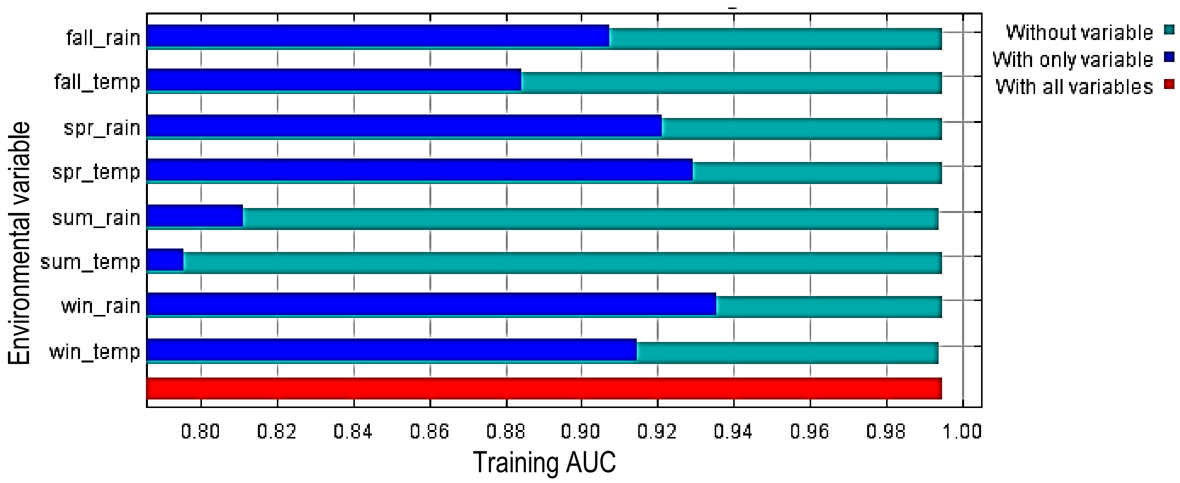

Figure 5.1: Jackknife test of individual environmental variable importance (blue bars) in the development of the MAXENT model relative to all environmental variables (red bar).

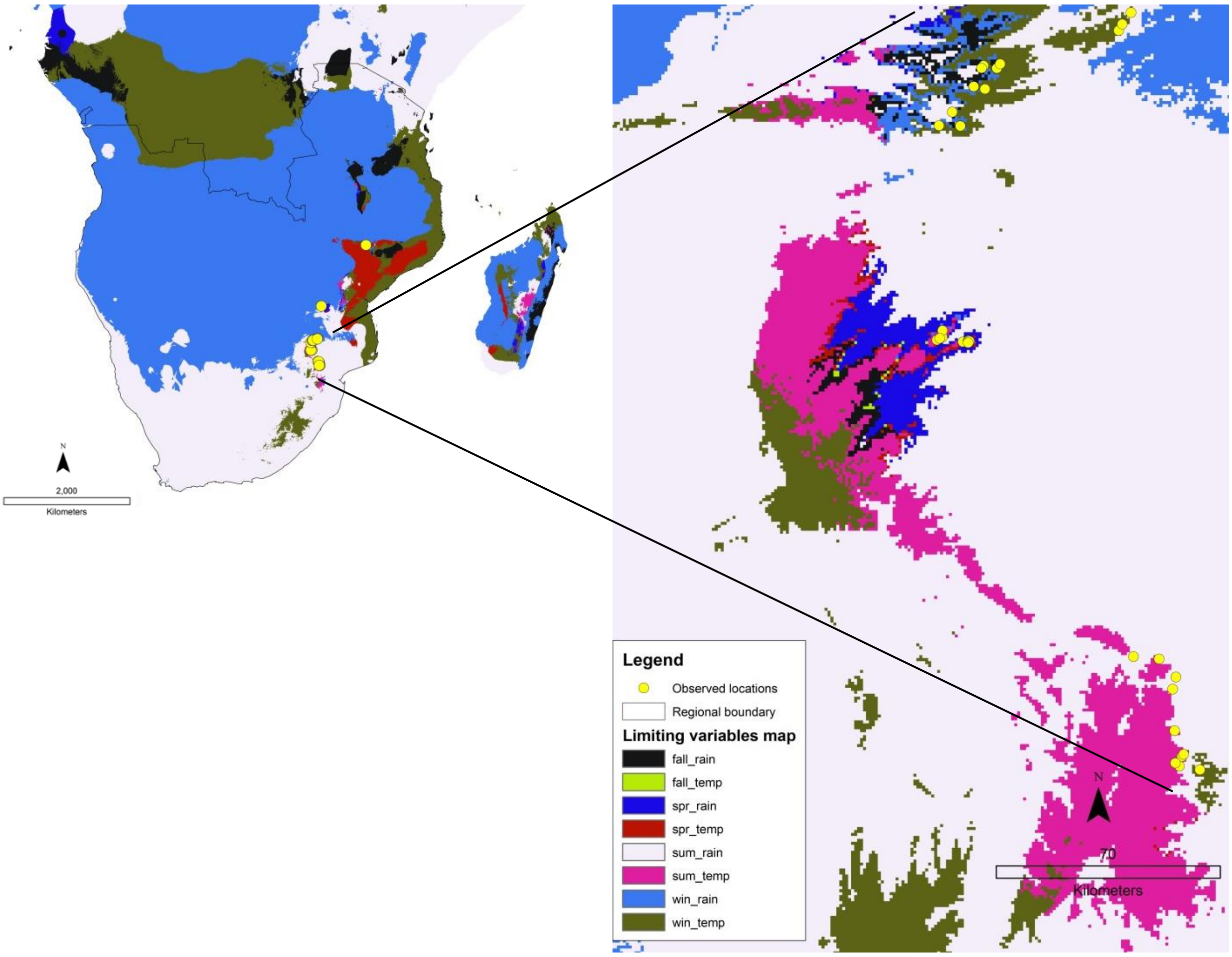

Figure 5.2: Current wintering locations of *Encosternum delegorguei* in Africa, south of the equator, showing a MAXENT projected model based on seasonal temperature and precipitation in spring, summer, autumn and winter. The South African sites along the Drakensberg escarpment in the south and the Zoutpansberg in the north are magnified. Museum records are excluded.

At the fine-scale the distributions of the Zoutpansberg wintering locations stop in the east along with the mountain range. The limiting variables map suggests that the western margin might not have been explored sufficiently as there are considerable valleys and hollows at suitable elevation that fit with the winter precipitation requirements of *E. delegorguei* (Figure 5.3a). No locations were found for *E. delegorguei* in the Mutale River valley and the limiting variables map prioritises an area for further investigation where elevation is suitable (between 597 to 1147 m).

The Ga-Modjadji locations were on either side of the Molototsi River valley at elevations ranging from 906 to 1115 m except for the Ravenshill location having a northern aspect (Figure 5.3b). The limiting variable of winter precipitation suggests seven possible grid cells where new localities could occur for *E. delegorguei* on the northern spur. In Mpumalanga locations began at the lowest monitored elevation of 597 m in the Blyde River valley and reached 1147 m in a *Eucalyptus* plantation. Although the Mpumalanga locations stretched a mere 39 km from north to south they were divided by steep rugged valleys, villages and private farms (Figure 5.3c). Analysing the winter precipitation did not yield any potential new sites to investigate but summer and winter temperature yielded some possibilities particularly along river valleys where a favourable microclimate could exist. Topographically the Zimbabwe (Figure 5.3d) and Malawi locations (Figure 5.3e) are similar to the South African locations, occurring in valleys of the foot slopes of a mountain range and having intact indigenous vegetation and human settlements and activities concentrated in the lowlands.

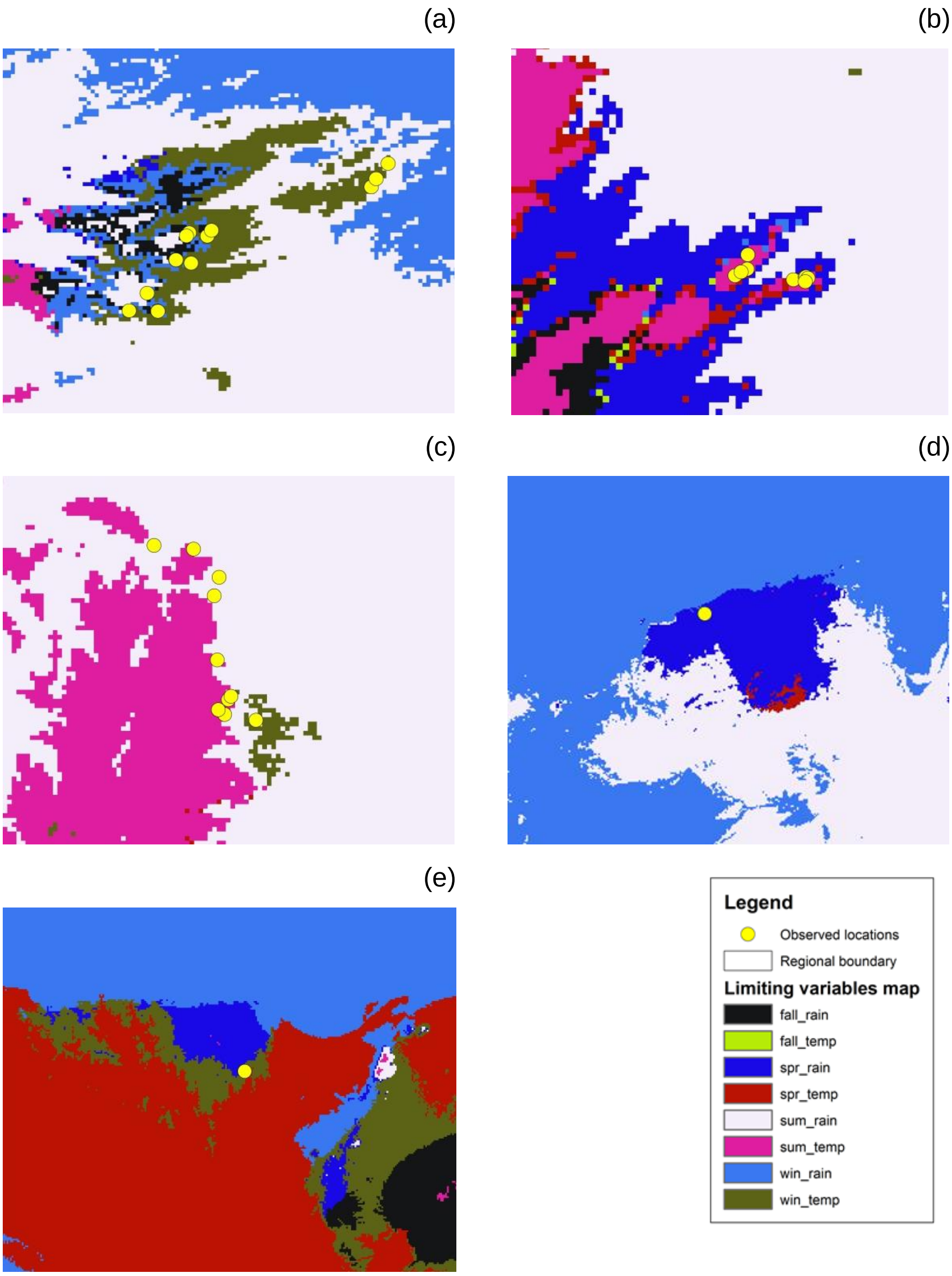

Figure 5.3: A MAXENT projected model based on seasonal temperature and precipitation in spring, summer, autumn and winter of current wintering locations of *Encosternum delegorguei* in a) Zoutpansberg, b) Ga-Modjadji, northern Drakensberg, Limpopo, c) Bushbuckridge, northern Drakensberg, Mpumalanga, South Africa and d) Zimbabwe and e) Malawi, south of the equator.

The future distribution of *E. delegorguei* is predicted to be 82% of the current distribution with an overlap of 67% (Figure 5.4). In addition the range is expected to shift by 16% westwards and southwards. In the region south of the equator there is considerable overlap between the current and future winter distribution of *E. delegorguei*. Although sparse information is available for analysis it appears that the greatest loss of future range occurs in Zimbabwe and Malawi (Figure 5.4a) where the range shrinks and there is little sign of the potential for a range shift to occur. The most promising locations for existing and future populations might be found towards the east of the known locations in Zimbabwe and Malawi at suitable elevations.

The greatest apparent future range gain in South Africa is towards the west and south, most pronounced for Mpumalanga Province (Figure 5.3c and d). Elevation above 1 147 m may prove to be a limiting factor preventing exploitation of new sites.

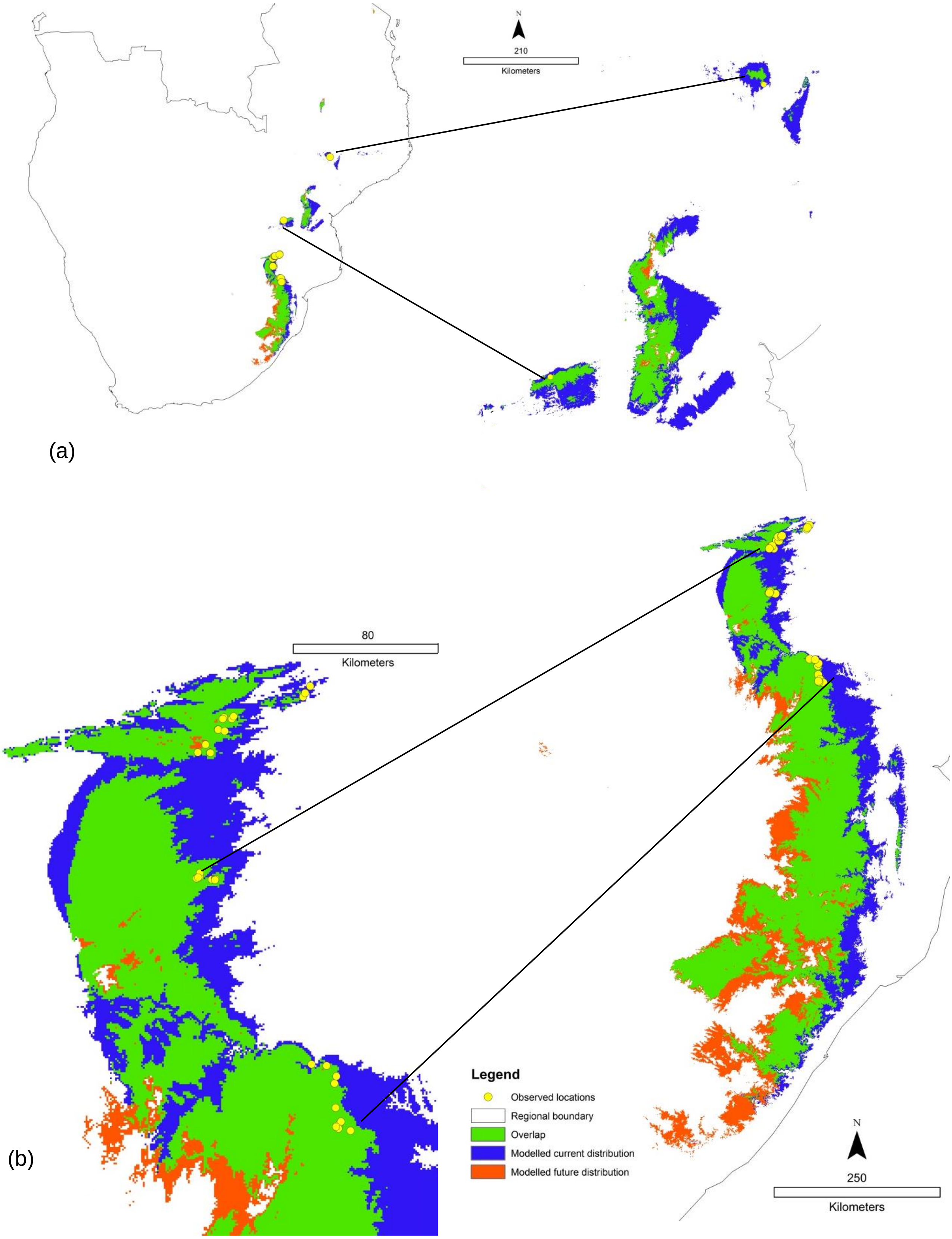

Figure 5.4: Current locations and future suitable areas for *Encosternum delegorguei* in a) Zimbabwe, Malawi and b) South Africa under the current climate and the A2 scenario of the Special Report on Emission for 2041 to 2060, modelled with MAXENT using eight climatic variables. In b) Ga-Modjadji and Bushbuckridge, northern Drakensberg are enlarged.

5.7 Discussion

5.7.1 Model performance and limitations

Migration allows species, like *E. delegorguei,* to exploit a bi-seasonal ecological niche which confers a spatio-temporal advantage through optimal use of resources, avoidance of predators, competitors or unfavourable weather conditions and enhances survival and reproduction (Deveson *et al*. 2005; Bradshaw & Holzapfel 2007). Sufficient primary data to run a MAXENT model was collected for the winter range. Wintering areas were varied in topography with valleys or hills while summer areas were more consistent in elevation. There is a possibility that migrancy is only induced in the southern part of the range where a cold-dry winter threshold is reached. *Encosternum delegorguei* disperses widely throughout its summer range amongst a variety of food trees (Dzerefos *et al*. 2009) where it is well camouflaged and difficult to find. Historical data was unable to fill the gaps in summer presence data as records were incomplete (Table 5.2). This study relied heavily on indigenous knowledge pertaining to *E. delegorguei* winter aggregation sites. Indigenous knowledge systems in the Zoutpansberg and Mpumalanga sites were negatively affected when people were displaced from their cultural lands in terms of the 1936 Native Trust and Land Act no. 18 and the Mountain Catchments Act 70 of 1970 (von Maltitz & Shackleton 2004).

The resultant MAXENT model for *E. delegorguei* showed high accuracy (AUC= 0.995; SD=0.002) and describes the bioclimatic envelope and ecological niche occupied during the winter phase of the annual life cycle. Nevertheless it could be improved by combining the distribution of preferential food trees (Dzerefos *et al*. 2009) as was done for the Bark beetle *Dendroctonus rhizophagus* Thomas & Bright (Mendoza *et al.* 2011) and the Chestnut phylloxerid *M. castaneivora* (Wang *et al*. 2010). The importance of a sustainable food source, namely land that had not been used for agriculture or developed for human settlement, was illustrated in studies on the distribution of the grey long-eared bat, *Plecotus austriacus* Fischer (Razgour *et al*. 2012).

5.7.2 Current distribution

Both the northern Drakensberg and the Zoutpansberg exhibit two distinct rainfall regimes with some parts being in a rain shadow and other parts experiencing higher rainfall. In the case of *E. delegorguei* the drier mountain slopes or higher altitude did not have presence location data for *E. delegorguei*. The model identified winter precipitation as the most important environmental variable influencing the distribution of this species (Figure 5.3). Other limiting climatic variables were summer precipitation and winter temperature which may explain poor harvests reported by local communities during droughts years (Dzerefos *et al.* 2013). As precipitation and temperature data are continuously being generated and recorded, the model can be monitored and validated (Elith *et al.* 2010). *Encosternum delegorguei* forages within a summer rainfall region and with the onset of the dry season migrates to the foothills of mountainous areas where it aggregates in the mist-belt, at approximately 1 050 m for the northern Drakensberg (Scheepers 1978) or in valleys and hollows which concurs with the model outputs. Undulating topography may provide refuge from frost, wind or fire. In the Zoutpansberg the combination of wind, slope aspect and solar radiation in valleys and hollows results in microclimates with increased condensation (Hahn 2002). Clearly, winter niches provide condensed water which allows *E. delegorguei* to remain hydrated in spite of it not feeding at this part of its life cycle (Dzerefos *et al.* 2009).

The MAXENT model was successful in identifying what Elith *et al.* (2010) termed “novel climates'' which determine the winter niche of *E. delegorguei*. At high elevations, above 1147 m, high winter precipitation may cause fungal infection, observed as black patches, while low temperatures, in particular frost, may lead to insect mortalities (Dzerefos *et al.* 2009). Similarly, frost was reported to limit the winter ecological niche of *D. plexippus* (Oberhauser & Townsend Peterson 2003). In contrast the bark beetle, *D. rhizophagus* was limited in its distribution by maximum temperature (Mendoza *et al.* 2011).

The Zoutpansberg sites were widely distributed, spanning a distance of 75 km from west to east, and occupied numerous valleys and hill slopes. In the west climatic variables appear to limit the distribution of *E. delegorguei* and there is a strong possibility that new winter localities could be identified on the basis of winter precipitation being a limiting variable. It is not possible for a species to occupy its entire bioclimatic envelope (Araújo & Townsend Peterson 2012) but there are socio-economic benefits to finding suitable areas for introductions. The false positives occurring in the Mutale River valley and its proximity in the south to positive locations suggest that this might be an area to investigate further for wintering *E. delegorguei*. Should they not occur then exclusion is not based on limiting climatic variables and one explanation could be that migrating *E. delegorguei* find suitable sites to overwinter before reaching the pass into the valley. If this assumption is correct then perhaps this is an area where mini-livestock production could be piloted. Benefits to local communities could be a healthy food source that is culturally important, a source of income and a reason to leave the savanna ecosystem intact, resulting in maintenance of air quality, aesthetics and erosion control. Due to the poor road network many of these areas are remote and unexplored. Traditional taboos related to initiations and burials also prevent people from venturing into some areas. In the east discontinuation of localities is related to lower elevations which rules out the possibility of new locations.

The Ga-Modjadji sites were concentrated on both sides of two spurs flanking the Molototsi River valley. All the location points faced the river except for the Ravenshill location which faced north. The Ravenshill outlier indicates that more information is needed on distances travelled and whether rivers are used as navigation beacons. If this population had come from the same feeding grounds as the other groupings then the insects would have to fly over the highest point of the valley at 1245 m or would have followed a tributary of the Molototsi River via a low saddle. If the river network is being used to navigate then this could assist in narrowing down suitable areas to find stinkbug sites. The possibility that the Ga-Modjadji insects might be flying in from summer locations from the north as well as from the north-east cannot be ruled out as suitable food plants occur in both directions, albeit fragmented by agriculture and urban expansion (Figure 5.3b). Relative to the other areas sampled, Ga-Modjadji would be relatively simple to check on the winter occurrence of *E. delegorguei* as there is a better road network than the other locations and the vegetation has been thinned by fuelwood harvesting, fire and cattle grazing. The model also highlights a few priority areas on the northern most spur.

In Mpumalanga Province, *E. delegorguei* wintering sites are spread north to south along the northern Drakensberg between numerous valleys and foothills that regress from west to east towards the Lowveld. Accessibility to some areas is difficult owing to steep gradients, controlled access through private property or protected land and thick impenetrable indigenous vegetation. The two northern most locations of *E. delegorguei* were found at Swadini Aventura Resort along the Blyde River and above the village of Kampersrus (Figure 5.3c). The other locations are adjacent to burgeoning human settlements where extensive use is made of natural resources. It is highly probable that further sampling of remote valleys and foot slopes could reveal additional wintering sites. The combination of factors such as thick vegetation, poor road infrastructure, inability to access conservation or private land and time limited the area that could be sampled.

5.7.3 Future distribution

There is a 67% overlap between the modelled current and future distributions of *E. delegorguei* in response to a changing climate for the period 2041 to 2060. Thirty-three percent of the current distribution is expected to be unsuitable in years to come unless there is a buffering effect from the mountain range which influences precipitation and temperature (DEA 2013). A model based on summer location data could yield a different response. Predictions indicate that the current *E. delegorguei* distribution could shift by 16% westwards and southwards. This appears to be most conspicuous towards the southern margin of the current range in Mpumalanga Province (Figure 5.4b). Towards the north, particularly Zimbabwe and Malawi, the range appears to reduce in size (Figure 5.4a). Range shifts are limited by numerous factors that are not accounted for in the bioclimatic envelope model (Araújo & Townsend Peterson 2012). For example *E. delegorguei* may be unable to colonise areas quickly enough or at all due to high elevations. Alternatively, energy expended on flight between the summer and winter niche might limit future distribution. There may be insufficient abdominal fat reserves available for returning to the feeding grounds in spring. It is essential to establish where the *E. delegorguei* feeding grounds are in Zimbabwe and Malawi and to understand how these areas may be modified by human activities. For example the *Brachystegia* (miombo) woodlands where *E. delegorguei* overwinter, are noted to have been reduced from 45% in 1973 to 25% of the total land area of Malawi in early 1990 (MSOE 2010).

Anthropogenic modification of the environment is also a serious concern and extirpation of *E. delegorguei* has already been reported in the Magoebaskloof valley (Dzerefos *et al*. 2013). Humans impact indirectly by cutting down food trees and represent a highly efficient predator, able to adapt methods of collection to times when the insect is immobilised and to use tools to reach them (Dzerefos *et al.* 2013). Wintering sites were relatively close to each other, between 60 to 102 km in South Africa and 30 to 100 km in Zimbabwe (C. Chenga, University of North West, pers. comm.) and belies the poor road network that limits human predation. As human populations expand, roads and other infrastructure are likely to be improved to the detriment of *E. delegorguei*. The impact from other predators such as primates, birds, ants and spiders is negligible in comparison to human exploitation. More research is needed regarding the ecological niche occupied by the parasitoid wasp *Anastatus* sp. as it has been recorded infecting *E. delegorguei* eggs that were oviposited in the winter range under artificial conditions (Dzerefos *et al.* 2009). Modification of ecological processes such as fire and species distributions in the savanna biome in response to climate change is also a concern even though it is predicted to expand in size by replacing grassland and forests (Marchant 2010).

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CHAPTER 6: SYNTHESIS

6.1 Introduction

Sustainable rural livelihoods and food security in Africa are threatened by over use of bio-resources, transformation of habitats by urbanisation, agriculture and mining, spread of invasive alien species (Paumgarten 2005; Hunter *et al.* 2007; Dovie *et al.* 2002; 2008; Mutenje *et al.* 2011) and exacerbated by climate change (Opio-Odongo 2013). The savanna plant resources used by rural households in southern Africa have received significant attention (Campbell *et al.* 1997; Twine *et al.* 2003; Matsika *et al*. 2013; Venter & Witkowski 2013) but little in depth research is available on the use of animals. Relative to plants, animals pose a research challenge as use may be illegal (Alves & Souto 2011), they are able to escape, hide or suspend their development while mobility allows the potential for relatively rapid changes in distribution range.

A case study of the edible stinkbug *Encosternum delegorguei* Spinola, an example of a savanna zoological resource, is provided in this thesis. Harvesters are prepared to trespass onto plantations, private farms or nature reserves to collect *E. delegorguei* for food and trade. Moreover it is difficult to locate unless it is in winter aggregation. Prior to this work there were many gaps in the published information surrounding edible stinkbugs in sub-Saharan Africa (Faure 1944; Gardiner & Gardiner 2003; Toms & Thagwana 2003; Teffo *et al.* 2007; Mapendembe 2004; Makhado *et al.* 2009) with empirical and modelling studies being neglected.

The aim of this chapter is to synthesise the research findings of the life history, socio-economics and distribution of *E. delegorguei,* in southern Africa within the broader context of the drivers of environmental change that are operating in sub-Saharan Africa (Table 6.1). The Millennium Ecosystem Assessment defined drivers of environmental change as natural or anthropogenic factors that directly or indirectly resulted in ecosystem alteration (Nelson *et al*. 2006). Further research is proposed to unlock the full potential of this beneficial insect and recommendations to negate threats to *E. delegorguei* and the savanna biome are provided.

Table 6.1: Synopsis of key drivers of environmental change in rural areas of sub-Saharan Africa and linkages with *Encosternum delegorguei*

Drivers of environmental change	Links
• Land use transformation of communal-lands which comprise indigenous vegetation and have mainly been used for cattle and goat grazing and bio-resource collection. Due to expanding human population growth and requirements for planted crops, housing and work opportunities this is an important driver of change.	Local economics of *E. delegorguei* are quantified and hidden monetary streams are highlighted showing that savannas provide ecological services to marginalised communities. Income generating opportunities should be developed. Authorities to consider bio-resource use when decisions to develop an area are made.
• Cultural values and beliefs impact on whether actions, such as methods of harvesting, are focussed on short-term gains or consider long-term impacts and holistic approaches such as biodiversity stewardship, adaptive management and eco-tourism approaches to securing sustainable harvesting.	Current distribution records of *E. delegorguei* from South Africa, Zimbabwe and Malawi (Figure 6.1) allow us to shortlist areas where *E. delegorguei* could occur or be introduced for minilivestock production. Development options for these areas should consider the cultural and economic value of bio-resources to communities.
• Insect species have been shown to reduce, expand or shift current ranges due to climate change with the worst case scenario being extinction.	The future distribution model of *E. delegorguei* allows us to predict and monitor the effects of climate change at the fine-scale.

Figure 6.1: The location of harvesting sites which represent the known winter distribution of *Encosternum delegorguei* in South Africa, Malawi and Zimbabwe.

6.2 Background

6.2.1 Life cycle

Observations of captive and wild *E. delegorguei* have indicated that it is a univoltine, hemimetabolous species having five instar nymphs. It was established that *E. delegorguei* could survive the winter, copulate and lay eggs in an outdoor insectary with planted trees of *Combretum imberbe* Wawra, *Combretum molle* R.Br. ex G. Don and *Peltophorum africanum* Sond., as well as the shrub *Dodonaea viscosa* Jacq. var. *angustifolia* (L.f.) Benth. However captive rearing methods would need to be modified as hatching of eggs was reduced to 3% by a parasitoid identified as *Anastatus* sp. and the instars did not reach maturity.

6.2.2 Summer and winter differentiation of the ecological niche

Winter physiological changes observed in *E. delegorguei* included change of colour, increased abdominal fat content and wax secretions. These changes indicate diapause or suspended development during a time when environmental conditions were sub-optimal (Tauber *et al.* 1985; Musolin *et al.* 2001; 2007). The physiological response concurs with the results of the *E. delegorguei* MAXENT distribution model which identified winter precipitation as the most influential climatic variable influencing *E. delegorguei* distribution. To a lesser degree summer precipitation and temperature also limit distribution. It was established that during winter *E. delegorguei* requires condensed water to drink although it is not feeding off plants at this time of year. Hence *E. delegorguei* has temporal food requirements which are spatially and seasonally distinct (Figure 6.2).

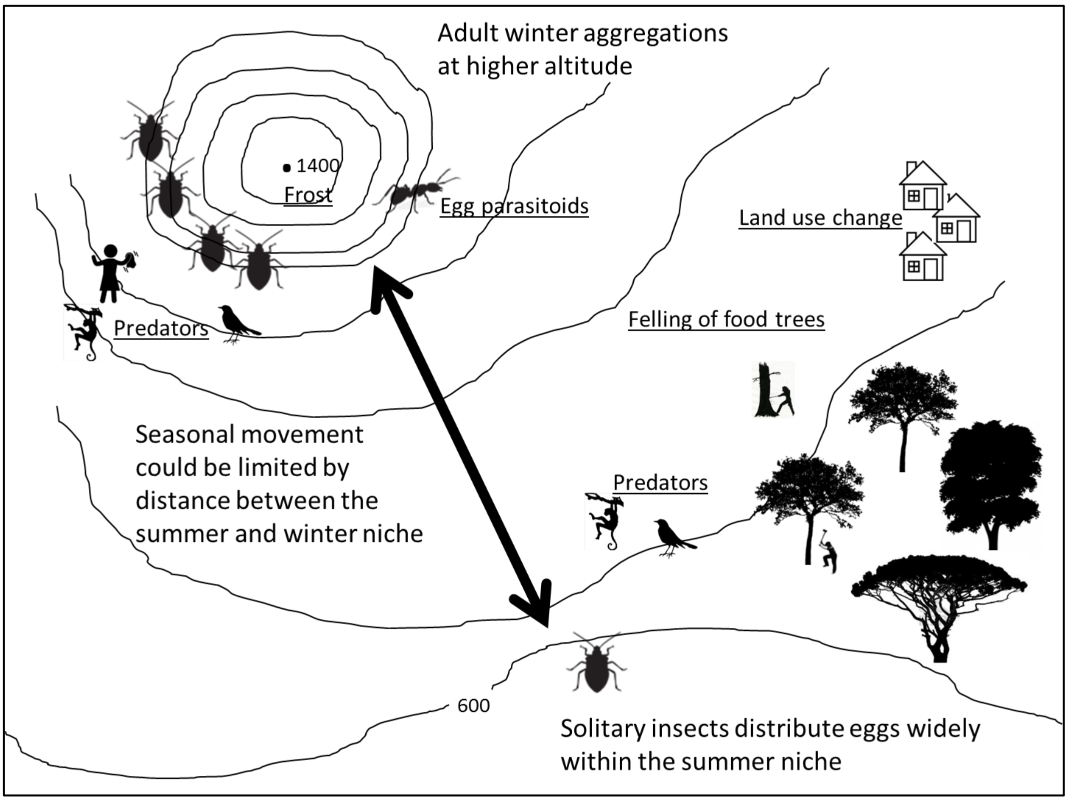

Figure 6.2: A conceptual model showing the winter and summer ecological niche of *Encosternum delegorguei* in southern Africa and the main variables limiting their distribution: namely from predators, felling of food trees, elevation and distances between the seasonally differentiated niches. Threats to the population of *E. delegorguei* are underlined.

Although common, insect migration is not as well understood as bird and large mammal migration (Alerstam *et al*. 2003; Stefanescu *et al*. 2013). There are many examples of Lepidoptera (Batalden *et al*. 2007; Stefanescu *et al*. 2013), Diptera (Israely *et al*. 2005), Orthoptera (Rubenstein 1992; Deveson *et al.* 2005), Coleoptera (Hagen 1962; Nalepa *et al*. 2005), Odonata (Wikelski *et al.* 2006) and Hemiptera (Musolin 2007; Dzerefos *et al.* 2009) migrating to areas from which they did not hatch. The phenomenon of winter migrancy and aggregation of adult *E. delegorguei* has long been known (Mjele 1934) but no previous research had determined the limiting climatic variables.

Winter locations ranged from 597 to 1147 m altitude in valleys and hollows of escarpment foot slopes (Figure 6.2). During winter *E. delegorguei* uses a range of indigenous tree and shrub species as well as exotic fruit and timber trees as perches. Following copulation in spring (September) females search and feed on the trees *C. imberbe, C. molle* and *P. africanum* and to a lesser degree on the shrub *D. viscosa*. These woody plants occur in the Lowveld (low altitude vegetation) communal-lands where they are important sources of fuel and building materials for local communities (Shackleton 1993; Anthony & Bellinger 2007). Trees constitute the primary fuel source of over 70% of sub-Saharan Africans (Matsika *et al*. 2013) and their exploitation may influence the food available for *E. delegorguei.* Food trees should be further investigated and monitored as an important categorical variable limiting distribution. Fortunately being a generalist feeder there may be a range of plants, including coppiced tree or shrub stumps, resulting from responsible wood harvesting, which could be used. The widespread spring dispersal may serve to minimize egg parasitoids locating *E. delegorguei* eggs.

6.3 Drivers of environmental change

6.3.1 Local economic development and land use transformation

The status of *E. delegorguei* as a sought after delicacy is confirmed as harvesters may travel up to 200 km to access it, put their health and safety at risk to harvest and may even trespass. From the onset of the harvesting season (May to August) *E. delegorguei* sells quickly through informal channels and demand exceeds supply (Dzerefos *et al*. in press). In South Africa, the overall harvest estimate for one season was 3803 kg (range 0.5 to 139.2 kg household^{-1}) and an annual income of US$ 345 household^{-1} or about US$ 35500 overall could be earned. Highly entrepreneurial and hardworking individuals earned $\bar{x}$ = US$ 746±211. These figures are paltry by first world standards but are substantial in rural areas where there are few income generating opportunities (Shackleton & Shackleton 2004; Shackleton *et al*. 2008; Venter & Witkowski 2013). The winning formula used by Bolobedu women harvesters was to optimise income by collecting large quantities of *E. delegorguei* and to sell quickly at relatively low prices. This strategy could be improved by co-operative selling and communicating with buyers via cellular network (Dzerefos *et al*. in press).

Regardless of sound environmental legislation, South Africa is struggling to develop sustainably and there is widespread non-compliance or project abandonment in rural areas. For example, the National Environmental Management Act, No 107 of 1998 strongly supports the principle of sustainable development as do provincial government growth and development strategies (LEGDP 2004; MEGDP 2011). Yet in reality there are numerous examples of non-compliance. For example, Marsfontein Mine (24 14'S, 29 17'E) near Mokopane, Limpopo Province, described as a high yielding diamond mine (Mining Weekly 1999) and exhausted in 2000 by a joint venture between De Beers and Southern Era Mining (Field *et al.* 2008), was abandoned without being rehabilitated (Google Earth 2012; C. Dzerefos, unpublished data). On a more positive note, a precedent case was concluded in January 2014 when the managing director of Bathlabine clay mine, in the foothills of the northern Drakensberg escarpment, Limpopo Province, received a sentence of five years for not rehabilitating the area according to the Environmental Management Plan compiled at the start of the project (CER 2014). This highlights the importance of Environmental Impact Assessments (EIA) having detailed closure plans which provide a time frame for rehabilitation and consider the impacts of transforming communal-lands. The contribution of bio-resources to human well-being (Paumgarten 2005), business opportunities from species like *E. delegorguei* and ecotourism potential need to be included in the EIA process as alternative local economic developments.

6.3.2 Cultural values and beliefs

As the distribution of *E. delegorguei* and its most efficient predator, humans, increasingly overlap, the interaction needs to be understood and improved for mutual benefit. There are two dominant perceptions with regards to stinkbugs. Firstly harvesters and consumers consider *E. delegorguei* a tasty traditional food and have an impact through direct exploitation of winter aggregates. Secondly a larger group of people, located in the summer feeding range, perceive *E. delegorguei* to serve no purpose and use derogatory names such as stinkbug or "podile" (Dzerefos *et al.* 2013). Communities in the summer range impact indirectly by altering land use. These communities should be mobilised to extend insect conservation beyond the fences of protected areas (DeFoliart 1995; Samways 2005) and into private gardens and communal-lands where *E. delegorguei* may be using trees to oviposit and feed on. The woody vegetation structure of communal-lands is radically changing due to anthropogenic pressures (Coetzer *et al.* 2010; Fisher *et al*. 2012; Matsika *et al.* 2012; Wessels *et al.* 2013), which suggests that tree planting initiatives and methods promoting coppice (Luoga *et al.* 2004) have a major role in woodland regeneration.

The consumption of *E. delegorguei* is unlikely to decrease with the rise of modernity since it is not shunned by those in the middle class. In the last 30 years, the Bolobedu who previously did not know about *E. delegorguei,* have started harvesting and preparing *E. delegorguei* for the convenience of Vhavenda buyers. Similarly, commercialisation of marula-beer made from the fruit of the Marula *Sclerocarya birrea* A. Rich., can be traced back to 1998 and indicates that traditional practices evolve with economic necessity (Shackleton *et al.* 2008) and market demands. The past and present value of *E. delegorguei* was highlighted in a Zimbabwean newspaper report where the chief of Nerumedzo village said: ''Harurwa is gold here. They were used to pay our mothers' lobola (bride price)'' (NewsDay 2010).

Women control 72% of the stinkbug market. Collection time is an obstacle to harvesting as *E. delegorguei* are easiest to collect between sunset and sunrise when criminals could target lone harvesters. Consequently many women harvest in groups or involve their families. In Bushbuckridge, boys harvest during their winter school break and have an advantage over adults as they can easily climb trees to access *E. delegorguei*. Climbing trees or hooking and pulling down branches were sustainable harvesting methods observed for collecting stinkbugs. Occasionally, branches may be cut or are accidently broken. It is of growing concern that in forest plantations and private land, poachers damage growing points of young pines and fell mature trees to access stinkbugs. It is important that harvesting in these areas is legitimised so that it can be monitored and the use of a collection funnel (Dudley 2004) could be promoted as an alternative to felling trees.

Consumers attributed stinkbug unpalatability in summer to gravid females (Faure 1944; Dzerefos *et al.* 2009) and abdominal dissections showed reduced fat content (Dzerefos *et al.* 2009). Steepness of terrain and remoteness of winter locations, thorny vegetation, fear of snakes or being caught by the police for trespassing, darkness and cold make the harvesting *E. delegorguei* difficult and in combination with the naturally short harvest season maintains low harvesting levels.

Besides commercialisation, another avenue to improve rural livelihoods using *E. delegorguei* would be to latch onto the growing public interest in insects, often proposed as a more healthy protein source for people, and offer stinkbug harvesting and processing tours. The diamond mining multinational De Beers "Biodiversity is forever" publicity campaign of 2008/9 is one example where insects have been used as iconic environmental best practice indicators. The popularity of the annual "Yebbo Goggo" event at the University of the Witwatersrand (Johannesburg), serving of insects in expensive restaurants (Durst *et al*. 2010), establishment of butterfly reserves and farms and a dragonfly trail (Samways 2005) show that invertebrates are gaining popularity in urban centres.

With the democratisation of South Africa, policies have focussed on local community's right of access. This is in line with a global trend commencing in the 1960's where protecting areas by fences and fines was replaced by the promotion of community based resource management systems (Cunningham 1999). In practice a combination of local governance to administer and monitor ground rules, awareness of ecological services and participative management of communal bio-resources has worked in parts of Zimbabwe (Mutenje *et al.* 2011) and Lesotho (Letsela *et al.* 2002). The sustainable utilisation of bio-resources and the alleviation of poverty are difficult to achieve simultaneously but African case studies indicate a greater chance of success if community stewardship prevails (Mapendembe 2004; Roda *et al.* 2005; Soewu 2008; Mutenje *et al.* 2011).

6.3.3 Climate change, biodiversity and ecosystem services

Across the African continent, ecosystem services and biodiversity have been degraded by vegetation cover loss, pesticide use, sedimentation and soil erosion (Opio-Odongo 2013). The future impact of climate change on biodiversity and ecosystem services has been predicted through distribution modelling (DEA 2013), while the development of policy to mitigate impacts on food security and human health are being debated. Expansion of protected areas is a means to promote biodiversity and ecosystem services. At the species level two butterfly reserves have been created in South Africa in recent years to preserve the

Brenton Blue *Orachrysops niobe* (Trimen) and the Roodepoort Copper *Phasis dentatis* Swierstra on land that has high potential for residential development. Before protected areas are declared, distribution models such as a maximum entropy modelling method (MAXENT) should be used to predict whether the area will still serve its purpose in the future. Once a protected area has been declared, law enforcement as well as an adaptive management approach such as Community-based Natural Resources Management needs to be implemented to ensure that biodiversity is indeed safeguarded (Opio-Odongo 2013). In the case of *E. delegorguei* the current and future distributions have been predicted using MAXENT and protected areas should be considered in areas of overlap since other factors such as elevation, distance to feeding grounds or parasitoid threat (Figure 6.2) could prevent colonisation of new areas. The results also provide a robust baseline measure, with an AUC value of 0.995, upon which the modelled predictions can be evaluated and monitored.

Climate change may affect the summer and the winter niches of *E. delegorguei.* The deciduous or leafless period of host trees could change if rainfall tends to occur later in the season and may not synchronise with eclosion. If occurrence and frequency of escarpment mist-belt alters with climate change the availability of vapour condensation during the winter may affect the survival of *E. delegorguei.* Future distribution predictions have been made according to the bioclimatic envelope of *E. delegorguei*. Successful migration requires that these insects have sufficient fat reserves to reach wintering sites, survive the diapause period and return to feeding grounds (Alerstam *et al*. 2003; Bradshaw & Holzapfel 2007). Predictions indicate that the current *E. delegorguei* distribution could shift by 16% westwards and southwards particularly along the southern margin of the current range in Mpumalanga Province.

6.5 Conclusions

6.5.1 Recommendations

Encosternum delegorguei is a sought after traditional food in southern Africa yet full potential as a food crop, medicine or a pesticide has not been fully investigated or marketed. When a community obtains economic or other benefits from an ecosystem it is likely to be protected from anthropogenic modification.

Yet seldom are useful species such as *E. delegorguei* raised amongst communities as a conservation flagship species (Bowen-Jones & Entwistle 2002). The provincial authorities have departments for environmental education and biodiversity protection that should promote flagship species awareness and conservation within communities. There are numerous solutions for provincial conservation authorities to implement with communities (Table 6.2) ranging from local minilivestock production to diversifying and adding value to the current product with possible worldwide distribution. New localities could be sought to increase the harvest or community resource nature reserves could be proclaimed and managed for ecological services. In addition the provincial authorities should not approve EIAs which is a legal requirement for land use change, which have not considered the loss of bio-resources to communities or the potential expansion of markets.

6.5.2 Further research

The socio-economic aspects of *E. delegorguei* have been well reported and future research should be guided by the Millennium Development Goals (MDGs) of poverty and hunger alleviation and ensuring environmental sustainability in sub-Saharan Africa. Contributions to the MDGs can be achieved by considering captive rearing, securing the current harvest and value adding to the product (Table 6.2).

6.5.2.1 Captive rearing

Further research into the effect of day length on growth, development and reproductive biology as well as population dynamics and precautions against parasitoids are required to realise captive rearing. The most space and energy efficient captive rearing model would be to use natural conditions and vertical columns. The MAXENT modelled current distribution identifies areas where minilivestock development initiatives could be piloted, opening up the potential for extending the commercial value of this insect possibly on a global scale. This model could be improved by identifying the ecological niche occupied by the parasitoid wasp *Anastatus* sp. and overlaying the distribution of food trees.

Insects raised for nourishment under controlled conditions could prevent over-harvesting in the wild, constitute a commercial minilivestock enterprise (Hardouin

1995) and decrease malnutrition in rural areas (Harris & Salisu 2003; Teffo *et al.* 2007). An increasing interest in entomophagy has resulted in urban restaurants specialising in exotic edible insects (DeFoliart 1999; Durst *et al.* 2010). In Asia entomophagy (DeFoliart 1995; 1999) including the eating of stinkbugs is widespread (Meyer-Rochow *et al.* 2008). Processing into paté, pastes or powders would make entomophagy agreeable to more people (Durst *et al.* 2010), particularly as insects provide comparable nutritional value but have a lower environmental impact than cattle or poultry (DeFoliart 1995; Durst *et al.* 2010; Yates-Doerr 2012).

6.5.2.2 Securing the current harvest

The current distribution highlights areas where *E. delegorguei* could occur, opening up the possibility of increasing the annual harvest. This opportunity needs to be carefully considered as these unknown populations might be an insurance policy against overharvesting and extinction. In a demographic model Gault *et al*. (2008) show that people desire the uncommon, which can lead to high prices and overexploitation.

The predicted future distribution requires monitoring and adaptive management to ensure the harvest is sustainable. If the winter range shifts or shrinks the population may be spread too widely between the summer and winter ecological niche to remain viable. Radio transmitters attached to dragonflies have successfully allowed distance tracking (Wikelski *et al.* 2006) and since *E. delegorguei* is a large bodied insect could be used to confirm feeding areas and determine flight distances.

Empowerment of communities to be adaptive managers that monitor threats and instigate corrective action to maintain ecological services (Fabricius *et al.* 2007) should be a goal that provincial conservation authorities in collaboration with traditional authorities are striving towards. Specific short-term goals could be to establish no-go areas, woodland monitors to ensure trees are not felled or at least able to coppice, fires are prevented or closing the harvesting season when copulation commences. Medium-term goals could consider harvesting quotas or fees. A harvesting fee could for example be used to purchase feed and negate the need to burn to provide winter cattle-grazing. The implementation of such actions could be evaluated and improved over time.

6.5.2.3 Value adding

The defence chemical might have potential for exploitation as a pesticide or medicine since laboratory analyses of *E. delegorguei* indicated, anti-bacterial and anti-fungal properties (Teffo 2006). Currently specimens with the defence chemical intact are mostly discarded even though 97% of harvesters cited its use as a hangover cure (Dzerefos *et al*. 2013) and it is used in Zimbabwe to combat colds (NewsDay 2010). Waste water from stinkbug preparation is currently discarded in South Africa but in Malawi it was used as a termiticide (Dudley 2004) which warrants further investigation as a means to diversify and add value to the commodity.

Table 6.2: Recommendations for protecting savanna biome biodiversity with *Encosternum delegorguei* as a flagship species.

Threats	**Possible Solution**
• Over exploitation by local communities.	An adaptive management plan that includes the local community is required.
• Over exploitation by third parties able to expand the market widely but excluding local communities.	The development of exploitation and trading norms and legislation (Ramos-Elorduy 2006) by provincial conservation authorities to avoid over harvesting or land use change without proper authorisations. EIAs should consider the value of entomophagy to the local community.
• Pesticide use on macadamia and mango farms, tea and pine plantations adjoining aggregation sites.	Integrated pest management allows farmers to monitor pests and apply pesticides accordingly. For small scale agriculture permaculture methods can be effective. Farmers should know that *E. delegorguei* is not a pest as it does not feed in winter and also has a short proboscis.
• Environmental requirements of local people such as jobs, food security, water, grazing and bio-resources are challenging to realise.	Optimise economic benefits from *E. delegorguei*, exercise control over fire regime, carrying capacity and use of fuel trees. Diversify income streams through ecotourism.

Threats	Possible Solution
• Reduce the use of fuelwood.	Introduce stoves, hay boxes or insulation of fire and pot with a clay wall to reduce amount of wood being used. Promote coal generated power and alternative energy to rural areas (Wessels *et al.* 2013).
• Practice sustainable methods of fuelwood harvesting.	An indigenous tree planting initiative in villages located within the summer niche at homesteads, schools and along roads could secure the food source. The felling of trees should be done at the optimal time, leaving a stump that is most likely to coppice (Luoga *et al*. 2004). This may need to be protected from grazing goats by making a fence around the stump with thorn branches or overlaying bricks.
• Unknown and unregulated poaching from protected areas, private farms and plantations.	Allow harvesters access to harvest sustainably and introduce the use of a collecting funnel to discourage felling of trees (Dzerefos *et al*. 2013).
• Poor returns for huge effort.	Increase overall productivity as a termiticide or hangover or common cold medicine to accrue economic benefits for harvesters.
• Rising transport and accommodation costs and selling at discounted prices.	Form cooperatives as a means of mercantile production to assist each other with sales and avoid middlemen. Set up a database of customers that can be informed when and where *E. delegorguei* can be purchased using cellular networks.
• Expanding human populations and increasing need for food.	Minilivestock production under optimal conditions could increase growth rate or generation time such that the edible harvestable period is prolonged.
• *E. delegorguei* is unknown and labelled as rotten.	Increase knowledge and appreciation of *E. delegorguei* by dissemination of information through talks on local radio stations and posters or flyers in local languages.
• Entomophagy is not widely practiced.	Insects could be disguised in reconstituted health foods such as porridge, bread, muffins or snack bars (Culliney 2013).
• Climate change is altering the distribution of biodiversity at an unknown spatio-temporal scale.	Monitor the predicted current and future distribution in relation to the MAXENT model produced.

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APPENDIX A: PARTICIPANT INFORMATION SHEET, CONFIDENTIAL CONTACT DETAILS AND INTERVIEW SCHEDULE

HARVESTING OF THONGOLIFHA IN VENDA, LIMPOPO PROVINCE

Participant Information Sheet

How does this project affect me?

Please note that participation in the Thongolifha project is voluntary and refusal to participate will involve no penalty or loss of benefits to which the participant is otherwise entitled. The participant may discontinue participation at any time without penalty or loss of benefits:

Why is this research proposed?

This research aims to learn more about Thongolifha. This insect is a delicacy to the Venda people and the Modjadji area is the principal harvesting area in South Africa. Other harvesting sites are no longer used and part of this research will explore and sample these sites to determine why they are no longer suitable for Thongolifha. By knowing more about Thongolifha for instance its food plants and the timing of the different stages of the life cycle the community will be able to manage this resource and ensure that future generations can benefit from it.

How long will this research take?

It is estimated that fieldwork will take place in 2006 and 2007. The data will be analysed and written thereafter.

How can you participate?

Harvesters of Thongolifha are invited to provide responses to an interview schedule which will take about one hour to complete with the aid of a translator. The researcher will ask harvesters if she can accompany them during the harvesting season to observe harvesting techniques and behaviour of the Thongolifha. It is estimated that this will be five hours per harvester. Harvesters will be invited to workshops to clarify results and to get progress reports.

Harvesters will be asked to keep a log book of amounts of Thongolifha harvested per day the details will be discussed with the group.

How will this benefit you?

This research will help the community protect the habitat needed by Thongolifha and ensure continued economic benefits for harvesters.

Who can be contacted?

Cathy Dzerefos from the Department of Animal, Plant and Environmental Sciences, University of the Witwatersrand is doing this research. She lives about 65 km from the study site in Haenertsburg and can be contacted at:

Cell: 083-746-2239

Email: cathy@dzerefos.com

HARVESTING OF THONGOLIFHA IN VENDA, LIMPOPO PROVINCE

Confidential Contact Details

Contact details of harvester.

Name:	
Address:	
Tel and Cell No:	
Gender:	□ Female □ Male
How was contact made?	
Do you know of any other harvesters and how can we contact them?	

Thank you for your assistance!!!!

INTERVIEW SCHEDULE NUMBER:	
DATE OF INTERVIEW:	
INTERVIEWERS NAME:	
INTERVIEWERS CONTACT NUMBER or ADDRESS:	

HARVESTING OF THONGOLIFHA IN VENDA, LIMPOPO PROVINCE

INTERVIEW SCHEDULE

1) What place do you collect Thongolifha from?

2) How long does it take you to get from your home to the harvesting place by foot, bicycle or taxi?

3) List any other places that you know where Thongolifha can be found? How do you know this?

4) Has availability of Thongolifha changed over the last 5 years?

☐ Increased ☐ Decreased ☐ Same

Why?

5) Is Thongolifha available during drought years?

☐ Yes ☐ No

6) Do you or your immediate family eat Thongolifha?

☐ Yes ☐ No

7) Do you sell Thongolifha?

☐ Yes ☐ No

Where do you sell Thongolifha? Is this retail or wholesale?

---

8) How many buckets of Thongolifha do you collect in a good month?

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9) How many buckets of Thongolifha do you collect in one winter season?

---

10) How much do you sell a cup or a bucket of Thongolifha for?

---

11) How much money have you made from Thongolifha in a good month?

---

12) How much money do you expect to make from selling Thongolifha this year?

---

13) Does price change in relation to the month?

☐ Yes ☐ No

Please explain how?

---

14) During which months of the year are there many (M), few (F) or no (O) Thongolifha in Venda? Cross out the letters which do not apply.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
M/F/O	M/F/O	M/F/O	M/F/O	M/F/O	M/F/O	M/F/O	M/F/O	M/F/O	M/F/O	M/F/O	M/F/O

15) Do you have any alternative means of income and if so, what?

____

____

16) What problems have you encountered in the Thongolifha trade?

____

____

17) Do you ever work with other harvesters – collecting, preparing or selling Thongolifha?

____

____

18) After collection is Thongolifha sorted into living and dead?

☐ Yes ☐ No

Why?

____

19) How is Thongolifha prepared to make it edible?

____

____

20) Does Thongolifha have any medicinal use?

____

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