Distribution of Mantodea in South Africa and biological studies of selected species

BM Greyvenstein

orcid.org / 0000-0003-2033-7173

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Promoter:	Prof J van den Berg
Co-promoter:	Prof MJ du Plessis

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"A human being is a part of the whole called by us universe, a part limited in time and space. He experiences himself, his thoughts and feeling as something separated from the rest, a kind of optical delusion of his consciousness. This delusion is a kind of prison for us, restricting us to our personal desires and to affection for a few persons nearest to us. Our task must be to free ourselves from this prison by widening our circle of compassion to embrace all living creatures and the whole of nature in its beauty."

Albert Einstein

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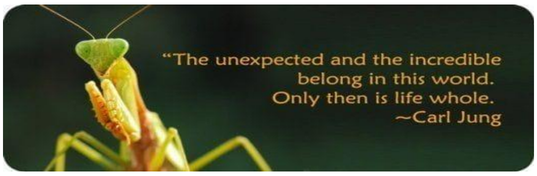

ABSTRACT

Despite human fascination with the Mantodea or praying/preying mantids over millennia, very little is known about of their diversity, biology and ecology, especially in South Africa. Praying mantids are not only important because of the ecosystem services they provide, but it is also suggested that they have a “mystical‘’ status and are regarded as a kind of oracle in some cultures. Acknowledgement of the cultural importance of the Mantodea may contribute to a positive change in people’s perceptions of arthropods, which may lead to an increase in insect appreciation. Due to the cultural value associated with Mantodea, these insects could be used as a flagship or gateway species to advance peoples’ awareness of insects, increase their appreciation and ultimately conservation. The Mantodea is a small order of insects with approximately 2400 species worldwide. The very limited literature on South African Mantodea includes a species list compiled 20 years ago. The aim of this study was to determine which species occur in South Africa and to study the biology of selected species. A checklist of the Mantodea of southern Africa was compiled from approximately 4000 specimen records, collected from 1849 to 2019, and which are kept in six national museums in South Africa. This checklist included 198 species, 60 genera and 11 families, with new distribution records for one genus and 20 species. Distribution maps were developed for 178 spp. of which 91 were regarded to be “rare” species. Museum records were further used to assess species richness thus compare mantid species diversity between different biomes of South Africa. Mantids seemed more prevalent in the Savanna, Grassland and Indian Ocean Coastal Belt biomes. Various hotspots were identified throughout South Africa and its biomes and indicated areas of "rare" mantid species conglomeration. Species that occurred in only one biome were identified since these species could be habitat specialists or possibly be rare or endangered. The distribution of *Galepsus lenticularis* (Mantodea: Tarachodidae), *Popa spurca* (Mantodea: Mantidae) and *Harpagomantis tricolor* (Mantodea: Galinthiadidae) were described and their biology studied under captive rearing conditions. The duration of male and female nymphal stages of *G. lenticularis* were similar but longevity of adult females were three times longer than that of males. This phenomenon as well as a long period (20 days) between oviposition of different oothecae, together with an incubation period of 20 days suggests a survival strategy that reduces competition between siblings. The mean number of eggs per ootheca was 49.8. Eleven *Galepsus* spp. were recorded in southern Africa and the first record of *Galepsus centralis*, in South Africa was established. The nymphal development period of *P. spurca* however differed between the sexes and adult longevity was significantly longer in females. The average lifespan of a *P. spurca* individual was 332 days. Oothecae contained an average of 84 eggs and the mean incubation period was 35 days. The mean duration of the lifecycle of *H. tricolor* was 191 days and the incubation period of oothecae was 144 days. This study not only provides a glimpse into a group of insects that has been overlooked in the past, but addressed a group that has basically never been studied in South Africa. Fundamental knowledge about the distribution and diversity of South African mantid fauna was developed and can be used to guide future research on the ecology of the Mantodea and to identify and mitigate possible threats.

Key words: Mantodea, biodiversity, biomes, life history

PREFACE

This thesis follows the article format style as prescribed by the North-West University. Therefore, articles appear in published format, while manuscripts and other chapters were adjusted according to the instructions to authors of internationally accredited, scientific journals. As an additional requirement by the North-West University, Table A details the contributions of authors for each article/manuscript and provides consent for use as part of this thesis.

The following Chapters were included in this work:

Chapter 1- Introduction and thesis structure. **(NWU Harvard style)**

Chapter 2 - Literature review. **(NWU Harvard style)**

Chapter 3 – Article 1 (Published) **Insects (MDPI)**

Chapter 4 – Article 2 (Published) **African Zoology (Taylor & Francis Online)**

Chapter 5 – Article 3 (Submitted) **Check List (Pensoft)**

Chapter 6 - Article 4 (Submitted) **Oriental Insects (Taylor & Francis Online)**

Chapter 7 – Article 5 (Submitted) **Austral Entomology (Wiley Online Library)**

Chapter 8 – Article 6 (prepared) Insect Diversity and Conservation **(Wiley Online Library)**

Chapter 9 – Article 7 (prepared) Journal of Insect Conservation **(Springer)**

Chapter 10 - Conclusions and future recommendations. **(NWU Harvard style)**

Submitted chapters were each prepared according to the intended journal while chapter 1, 2 and 10 were adjusted according to a derivative of the NWU Harvard style. Appendix A includes the licensing and instructions to authors of the journal *Insects* of the accepted article. Appendix B is the proof of the acceptance of article 2 (Chapter 4) by the journal African Zoology. Appendix C contains the proof of submissions to the various journals of Article 3, 4 and 5. An excerpt of each of the instructions to authors of the associated journal to which the chapters were submitted or prepared for can be found in Appendix D. Lastly, Appendix E contains the declaration that the work presented within this thesis has been language edited.

Table A: Contributions of authors and consent for use.

Author	**Article**	**Contribution**	**Consent**
BM Greyvenstein	1-7	Principal investigator: Responsible for study design, field sampling, and data analysis and interpretation. Specific responsibilities also included sourcing of data, filed collecting individuals of specific species, museum visits and data analysis. Served as the first author and was responsible for writing of manuscripts.	
J van den Berg	1-7	As promotor, supervised the design and execution of the study. Also provided intellectual input on data analyses and writing of articles and thesis.	J van den Berg
H du Plessis	1-7	As co-promotor, supervised the design and execution of the study. Also provided intellectual input on data analyses and writing of articles and thesis.	du Plessis

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Chapter 1

Introduction and thesis structure

1.1 Introduction

Biodiversity is an essential part of the earth's natural capital that sustains life and ecosystems. All ecosystems include individuals at different levels, each performing a particular task, which not only creates a food web but also establishes the delicate balance of life that is required. Different functional groups, i.e. primary producers, consumers and decomposers, perform these different tasks (Petchey *et al*., 2010).

Many species of predacious arthropods exist and even though they seem to be vastly abundant, they each play a different role which contributes not only to the health of an ecosystem but also to its resilience (Calcagno *et al*., 2011; Dale and Frank, 2018; Moretti *et al*., 2006). Predatory arthropods are also employed as biological control agents, which is defined as the use of beneficial species (natural enemies) at different trophic levels, to suppress pest species in agricultural ecosystems (Begon *et al*., 2006; Riechert, 1999; Bianchi *et al*., 2006). The importance of the role of predacious arthropods is increasing due to the increase in resistance of pests to pesticides and genetically modified crops with insecticidal properties, especially because the mechanisms of resistance are not yet understood (Peterson *et al*., 2018).

Not only arthropods but various other species are influenced by agricultural activities. Maxwell *et al*. (2016) estimated that of the 82 845 cases in which the threat-status of species were assessed, 62% were affected by land use change for the purpose of agriculture and associated food production activities. Agriculture has been described as the second "big killer" which threatens biodiversity and it is estimated to have a more devastating effect on biodiversity than climate change (Maxwell *et al*., 2016). The third "big killer" or threat to biodiversity is urban development, followed by invasions, disease and pollution, which make up the five biggest threats to biodiversity (Maxwell *et al*., 2016).

Conservation is the main mitigation tool against these various biodiversity threats. The effectiveness of conservation is influenced by various factors that relate to human psychology and perceptions (Odenbaugh, 2013; Oksanen and Pietarinen, 2004). Arthropod species are also in need of conservation, however, due to the nature of the human-arthropod relationship and negative perceptions people have of arthropods, conservation efforts are even more difficult (Simaika and Samways, 2018; Roy *et al*., 2015).

Mantodea or praying mantids are one of the insect groups that have fascinated people for millennia. Various cultural and social facets include mantids (Keimer, 1938; Prete *et al*., 1999; Fourie, 1993; Foster, 2015). Despite this fascination, however, very little is known about the biology, ecology, diversity and behaviour of mantids, especially in South Africa.

1.2 Problem statement

South Africa has a very rich biological diversity. The country has been ranked the third most biologically diverse country in the world (Cadman et al., 2010), even though it only occupies 2% of earth's surface (CBD, 2018). Only a few biodiversity studies that generated baseline data on biodiversity and distribution of arthropods (Mantodea especially) have been conducted in South Africa in the past, even though scientific information is essential if the threat status of species are to be established. Information on the life-history, habitat requirements and distribution of species are needed for conservation efforts.

The Mantodea is an example of one of the groups of which not much is known regarding their biology, distribution or ecology, especially in South Africa. This lack of knowledge regarding the Mantodea is illustrated by the little information available on this topic in the Scopus database (www.scopus.com). The latter database lists only seven studies relating to mantids in South Africa that were published during the last 50 years. This lack of information and the low number of species (180) reported from a biodiverse country such as South Africa, indicate that there could be significantly more species, especially considering that South Africa's endemism rate for invertebrates is estimated to be 70% (CBD, 2018), however is should be noted that this percentage of endemism could be influenced by the lack of knowledge about invertebrate endemism rates in other African countries. The cultural importance of Mantodea could be an important mechanism through which arthropod conservation can be advanced. Shipley and Bixler (2017) described mantids as a gateway bug which creates the opportunity to sway the human-arthropod relationship toward a more positive association with arthropods and through this, benefit conservation efforts. This study will establish baseline data on southern African Mantodea species which is crucial for any future studies or conservation efforts.

1.3 Rationale

Mantodea should not only be studied because of their historical and popular appeal but also because of their ecological importance. Ecological and distribution data will facilitate monitoring of possible future changes in mantid richness and distribution, and can be used not only to mitigate the threats that they face but also contribute towards future conservation planning efforts (Kremen *et al*., 1993).

Various arthropods groups such as Odonata, Lepidoptera and Coleoptera have been studied for decades. Threatened species in these groups have been identified, and, to an extent some conservation efforts have been implemented (Steytler and Samways, 1995; Terblanche *et al*., 2003; Samways and Lu, 2007; Hayward *et al*., 2010). Lepidoptera, specifically butterflies, have received much attention and a Red data list has been compiled and conservation efforts implemented (Edge and Mecenero, 2015). The Brenton blue butterfly (*Orachrysops niobe* (Trimen)) (Lepidoptera: Lycaenidae) is an example of a local critically endangered species on which ecological studies have been conducted in an attempt to ensure its conservation (Henning *et al*., 2008; Edge, 2005). Some beetle species, for example *Circellium bacchus* (F.) (Coleoptera: Scarabaeidae) and *Colophon* spp. (Coleoptera: Lucanidae) in the Cape Floristic region are also regarded as endangered. However, no other groups or even species within the above mentioned groups have received much attention regarding conservation. Hayward *et al*. (2010) indicated that the limited information on the distribution of the above mentioned dung beetle species impacted negatively on conservation efforts. Geetsema and Owen (2007) also indicated the importance of biological background information for the effective conservation of *Colophon* spp. Spider fauna in South Africa is being addressed by various fieldwork surveys that have been completed and that are still underway. Furthermore, the threat status of all spider species are also being assessed accoreding to the IUCN criteria for red-listing of species (Dippenaar-Schoeman et al. 2015.). Knowledge of biology, ecology and distribution of arthropods is important in order to identify and understand the risks they face and to mitigate threats against these species.

Without fundamental knowledge of Mantodea biology, ecology and distribution, the effects of climate change and other threats are difficult to monitor and impossible to anticipate and mitigate. The key to understanding the complexities of any ecosystem hinges on the basic biological information of a wide variety of species. Generating baseline data about Mantodea in South Africa should be done as it is critical for future conservation efforts.

1.4 Aims and objectives of the study

The aim of this study was to generate data of biology and distribution of Mantodea in South Africa. This study focused on two main objectives:

- to investigate the diversity and distribution of Mantodea species in South Africa, using historic data from insect collections throughout the country.
- to study the biology of three mantid species that occur in the Highveld grasslands of South Africa.

1.5 Thesis outline

This thesis is written in a research paper format, since several chapters have been published or submitted to scientific journals for review. Some of chapters within this thesis have been written in the intended journal format and will be submitted in due course.

Chapter 1 provides the general background as well as problem statement, rationale, aims and objectives, and thesis outline.

Chapter 2 is the literature review and introduction which focusses on the importance of biodiversity and conservation and the various aspects that influence these concepts. Knowledge gaps regarding Mantodea biology and ecology are identified and information provided on their role in the natural environment as well as their associated cultural and social roles and values. *Chapters 1* and *2* are referenced according to a derivative of the NWU Harvard style.

Chapters 3 and *4* are articles that have been accepted by various journals and are thus in the style of the associated journals.

Chapter 5, 6 and *7* are manuscripts that have been submitted for publication and were prepared according to the journal requirements.

Chapters 8 and *9* are manuscripts that have been prepared according to the various journal requirements and will be submitted in due course.

Chapter 10 is the conclusion which highlights the gaps identified in the literature, results of this study and how some of the gaps were addressed by information generated during this study

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CHAPTER 2

Literature review

2.1 The importance of biodiversity

In 1994 the animation film The Lion King was released and in its own simplistic way introduced many people to the way in which nature works. It was explained as a delicate balance which needed to be understood and respected from the smallest ant to the biggest whale. In this film, the delicate balance was ascribed to the dependence of all creatures on each other as well as their environment. Thus every creature depends on another creature in some way and so they are connected in “The Great Circle of Life”. Although simplistic this is none the less quite accurate, yet the way in which organisms depend on each other as well as the delicate balance of an ecosystem is a much more complicated.

Biodiversity is essentially a summary of all life on earth that is part of “The Great Circle of Life”. Biodiversity can be seen as a resource that has important ecological and evolutionary potential and is required to maintain earth’s delicate balance in all ecosystems (Begon *et al*., 2006). Biodiversity is also an essential part of the earth’s natural capital that sustains life and ecosystems. All ecosystems include individuals at different levels, each performing a particular task, which not only creates a food web but also establishes the delicate balance of life that is required. Different functional groups, i.e. primary producers, consumers and decomposers, perform these different tasks (van As *et al.,* 2012).

Many species of predacious arthropods exist and even though they seem to be vastly abundant, they each play a different role which contributes not only to the health of an ecosystem but also to its resilience (Calcagno *et al*., 2011; Dale and Frank, 2018; Moretti *et al*., 2006). Predatory arthropods are also employed as biological control agents, which is defined as the use of beneficial species (natural enemies) at different trophic levels, to suppress pest species in agricultural ecosystems (Begon *et al.*, 2006; Riechert, 1999; Bianchi *et al*., 2006).

It is estimated that about 8.7 million species exist on earth, and of these 2.2 million are marine species (Mora *et al*., 2011). However, as a result of this large number of species and very few taxonomists in each taxonomic group it is estimated that 86% of species on earth are yet to be described (Mora *et al*., 2011). The estimation of the total number of species on earth has been a topic of curiosity for ages but also to generate a reference point with which to gauge current and future impacts on biodiversity (Mora *et al*., 2011). It was also estimated that at the current rate of species discoveries and descriptions, some species might become extinct before these species have even been discovered or described.

2.2 Threats to biodiversity

Extinction of species is a continuous process which takes place throughout history, even before the age now referred to as the Anthropocene (Johnson *et al*., 2017). The rate at which biodiversity is being lost has however never been as high as during the Anthropocene (Johnson *et al*., 2017). The most threatening activities that cause global declines in biodiversity are land use change, modification and overexploitation, in most cases (80% of cases), these are not the only activities that put pressure on biodiversity (Maxwell *et al*., 2016).

Although climate change is an imminent threat, it was estimated by Maxwell *et al*. (2016) that of the 82 845 species for which species assessments are listed on the IUCN red data list, 19% are threatened or near threatened, and are adversely affected by current climatic variations. However, greater threats exist such as overexploitation and land use change for agricultural purposes which respectively affected 72% and 62% of the assessed plant and vertebrate species. Climate change has been reported to affect 1688 species while over exploitation and intensification of agriculture influenced 6241 and 5407 species, respectively (Maxwell *et al*., 2016). Other threats that were listed in IUCN report included urbanization, invasion and disease, pollution, transport and energy production. A recent study by Koen *et al*. (2018) indicated that light pollution, which is somewhat ignored in conservation planning, has increased mostly in areas associated with high biodiversity, thus adding to the list of threats to global biodiversity. As the human population increases and, with it the need for food, it is expected that agricultural production will increase by 7% globally by 2030 (Alexandratos and Bruinsma, 2012). The threat of agricultural intensification and its associated effects will therefore only increase in the future.

Due to the interrelatedness of nature the abovementioned threats can not only cause declines in the diversity of specific species but species interactions which can cause a ripple effect. Thus, these changes in species and their associated interactions can cause changes in ecosystem compositions which in turn affect the function of the ecosystem. If this ripple effect continues it can cause entire ecosystems to deteriorate or even collapse (Johnson *et al*., 2017). An example of ecosystem degradation due to species loss was the defaunation of large vertebrates that occurred in forest ecosystems in coastal Brazil (Bello *et al*., 2015). Due to the defaunation by the large vertebrates, a subsequent decrease in this ecosystem's ability to store carbon from the atmosphere occurred, which decreased the overall functionality of this forest ecosystem (Bello *et al*., 2015). Large vertebrates act as seed dispersers that maintain diversity and abundance of tree species within forests and without their seed dispersal capabilities, a significant decrease in the carbon storage abilities within these forests were recorded (Bello *et al*., 2015). This example illustrates the adverse ripple effects that declining biodiversity can have which emphasizes the importance of mitigating threats to biodiversity. Conservation is vital as it is the main mitigation action against biodiversity threats, which is ultimately responsible not only for the conservation of a specific species but all associated interaction and thus the services that these species fulfil within nature's hierarchy.

2.3 Conservation

Since humans are the only species that can perceive accountability for their actions they are responsible for the effects of these actions (Odenbaugh, 2013). The need therefore exists to determine exactly what the most untransformed state of the environment is because this will determine how to mitigate the effects of any artificial differences that result from human activities (Odenbaugh, 2013). The need to take responsibility for the effects of human activities gave rise to the notion of conservation.

The concept of conservation itself is still being debated (Sandbrook, 2015). Conservation biology, which was described by Soulé (1985), as a crisis discipline and although many of the goals and characteristics are still relevant, other scientists indicate that it should be referred to as conservation science which encompasses the social and natural aspects that influence conservation (Kareiva and Marvier, 2012). Another issue that contributes to this debate is the discrepancies implied in the term ”biodiversity”, since it can be interpreted at different levels, for example genetic diversity, species diversity and ecosystem diversity (Oksanen and Pietarinen, 2004). Beyond these various view points on the basics of conservation, the main issue remains “Why is conservation important?” This question is the fundamental struggle of conservation. It is also inherently more philosophical and influenced by aspects of all disciplines including environmental sciences, culture, psychology and economics. Holland and Rawles (1994) reported that conservation always had to combine not only the biological system but the cultural system as well, and that both of these are constantly changing.

2.3.1 Aspects that influence conservation

Attempts to answer the question “Why is conservation important?” have been a topic of debate among scientists, philosophers and economists for ages and is fundamental to environmental ethics (Oksanen and Pietarinen, 2004). Conservation is seen as an action against development and in some cases it is seen to suppress economic growth due to reduced job creation (Holland and Rawles, 1994). However, since resources to implement conservation are scarce, political will and economic inputs are essential to ensure the success of conservation efforts (Odenbaugh, 2013).

Two major viewpoints governed the need for the conservation of biodiversity in the past, i.e. intrinsic value and benefit value. Recently, however, relational value has created a shift in the conservation sector (Chan *et al*., 2016; Samways 2017; 2018) but the two major viewpoints remain important as these factors are still encountered in conservation.

Intrinsic value is defined as “belonging naturally” and “essential” and Nature in this regard should therefore have the same rights as human beings since it belongs naturally and is essential (Sarkar, 2010; Santas, 2014). This viewpoint is guided by the diversity-stability hypothesis which states that the more diverse a community is, the more stable it would be in the event of a disturbance or threat (Sarkar, 2010). Various issues arise with the notion that nature has intrinsic value since this implies philosophical and moral issues (Colyvan *et al*., 2009). Morals can be related to belief systems and cultures which are subjected to opinions, of which many exist (Colyvan *et al*., 2009).

One of these viewpoints is referred to as Biophilia, a term coined by E.O. Wilson. This term is similar to the concept of friendship proposed by Aristotle’s ethics (Santas, 2014). Biophilia is defined as evolutionary trait in which an individual has a genetically-based nature in which the individual links the value of nature and all living things to the survival of mankind (Santas, 2014). However, Santas (2014) suggests that Biophilia is part of the friendship theory of Aristotle named “philia”, which is as a result of the interconnectedness of all biological entities. Nonetheless, whether or not the intrinsic value of nature is owed to genetically inherited traits or due to its interconnectedness with nature, the reason why nature is valued is a fundamental aspect of conservation. Berto *et al*. (2018) confirmed that there is a connection between aesthetic appeal and connectedness to nature and that the more connected a person perceives him- or herself to be to nature, the more the person is open to the restoration and conservation of nature.

Another major viewpoint regarding conservation is that it should be supported because it benefits humanity in some way. For example, species that are considered to be of high value and which can be used for food or medical purposes should be conserved (Sarkar, 2010). This ”human benefit” viewpoint resulted in studies that estimated the monetary or net worth of ecosystem services that are rendered (La Notte *et al*., 2017; Torres and Hanley, 2017; O’Garra, 2017). Through these studies attempts are then made to assign monetary value to services that nature provides and in so doing, to justify the need to conserve it.

Relational value proposes that making decisions are based on not only the above mentioned viewpoints but also on how a person relates to nature. Chan *et al.* (2016) reported that a person's "preferences, principles, and virtues associated with relationships, both interpersonal and as articulated by policies and social norms" should factor into making decisions since this is what influences the perceived need for conservation and the importance thereof.

Paquet and Darimont (2010) indicated that the need for conservation is often disregarded because at the time that anthropogenic activities occur there are no immediate and imminent threats posed to humanity. Thus the human race is part of the global ecological system and is outcompeting wildlife and thus human-based necessities thrive. Despite this, nature has value beyond the resources that are physically unearthed from it, for example water, fossil fuels and oxygen supply. Other values of biodiversity that are mostly overlooked are recreational, educational, therapeutic, historical, cultural and aesthetic value (Samways *et al*. 2020; Samways 2018, 2017; Holland and Rawles, 1994).

Briefly, recreational value refers to outdoor sport and activities as forms of entertainment but also relaxation while educational value refers to understanding the world by studying the processes and individuals that inhabit earth (Holland and Rawles, 1994). Therapeutic values are seen as the benefits people get from interacting with nature for example swimming with dolphins and petting puppies which can cause spiritual upliftment (Holland and Rawles, 1994). A recent review by Nesbitt *et al*. (2017) indicated that physiological health is improved by urban green spaces and that it can cause reduced levels of depression.

Aesthetic appeal of biodiversity is considered to be a luxury and not as a true priority which can also be regarded as part of cultural values (Holland and Rawles, 1994). However, Holland and Rawles (1994) indicated that aesthetic appeal is not only a visual experience but a tactile experience as well. Aesthetic experiences also include other qualities beyond beauty i.e. fear, awe, peace and fascination, for example with arthropods. Due to these qualities, various forms of art have been inspired which include for example, poetry by Leopold (1949): "Wilderness is the raw material out of which man has hammered the artefact called civilization". The aesthetic appeal of a landscape or species has an influence on the human willingness to conserve certain landscapes or species (de Pinho *et al*., 2014).

Cultural value with regards to the environment refers to the historic value associated to a landscape or species within the human culture. Sagoff (1974) indicated this to be as important as a citizen's right to vote. Cultural values influence conservation because different cultures value different qualities of nature (Holland and Rawles, 1994). A vital part of cultural values between different people are their different belief systems. A variety of beliefs exists that consider some animals or habitats to have magical or spiritual properties. Although these beliefs and cultures differ from that of modern western beliefs, these beliefs have an undeniable influence on conservation efforts, regardless of their positive or negative associations (Holmes *et al*., 2017). A multidisciplinary approach such as training of conservationists in aspects of psychology for example, will aid in more successful conservation efforts.

Recently, agricultural intensification and the effects thereof on biodiversity have led to the land sparing versus land sharing issue. This detabte is essentially attempting to find a solution to the problem "feeding the ever growing human population and while trying to conserve biodiversity" (Fischer *et al*. 2013). This can either be done by setting aside land for conservation specifically and thus seperating conservation and agriculture (land sparing) or by setting aside less land and practicing less intensive or more biodiversity "friendly" agriculture (land sharing) (Green *et al.* 2005; Grau *et al*. 2013). This debate does indicate that both conservation and agriculture are being seen as essential and thus strategies should be investigated that could possibly be considered a middle ground. This could be an example of how conservation in future can be adressed.

2.3.2 The future of conservation efforts

Conservation has a unique task of trying to incorporate humanity (with all the various aspects of human behaviour) into actions that will relate to the protection of species that are declining as a result of humanity (Paquet and Darimont, 2010; Biggs *et al*., 2011). This task requires collaboration between various stakeholders, policy makers and scientists.

Biggs *et al*. (2011) suggested the use of mental models to aid in the struggle faced by conservation efforts. Mental models are essentially a framework that humans use to build their world views and it contributes to understanding the world they find themselves in and is shaped by their experiences, culture, beliefs and perceptions (Gentner and Stevens, 1983; Senge, 1992). New information is compared to existing information in the mental model and if the new information coincides with that of model, the model remains unchanged. However, if new information does not fit in with the existing model, the model itself can be changed or the information is rejected (Biggs *et al*., 2011). More often than not, new information is rejected instead of the model being changed to accommodate new inputs. This lack of willingness to adapt and change viewpoints challenges conservation efforts and has been indicated as important contributing factors to failing conservation efforts (Biggs *et al*., 2011). However, incorporating and understanding these mental models could aid in the success of conservation efforts, by attempting to change the model itself, which in turn could change the perceptions or viewpoints of the people involved.

2.3.3 Arthropod Conservation

Arthropods are estimated to represent about 70% of the species on earth. Unfortunately, their numbers are declining (Cardoso *et al*., 2020; Samways *et al*., 2020; Hallmann *et al*., 2019; Sanchez-Bayo and Wyckhuys, 2019; Habel *et al*., 2016), despite them surviving several mass extinctions and various climatic shifts (Samways, 2018). A manifesto has recently been published by Cardoso *et al*. (2020) in which the concern about insect declines and the need for research were reported. All creatures have intrinsic value and insects are no exception.

However, the relational value for insects is only perceived by some people. The instrumental value of insects has become apparent in recent years since services such as pollination has received much attention and human appreciation of these services increased with the realization that these services are fundamental to life as humans know it (Samways, 2018). Arthropods are also an important part of the food web and sustain various other species such as birds, reptiles, fish and frogs. Despite their importance in the natural environment, only 1% of the known insect diversity has been evaluated for the IUCN Red data list, which gives priority to species that should be conserved (Foottit and Adler, 2017).

Conservation of arthropods is hindered by most people'sdislike and fear of most arthropods which results from arthropods lack of aesthetic appeal, thus conservation efforts requires additional persuasion. The relational value of arthropods is the issue in most cases and insect appreciation and psychology is required (Samways *et al*., 2020). Some arthropods such as dragonflies, butterflies and ladybirds tend to be more easily associated with positive human perceptions, since they are associated with positive experiences from childhood (Samways, 2018).

The human-arthropod relationship is complicated, however, if the psychology behind these interactions as well as the perceptions that humans have about arthropods are better understood it may contribute to development of strategies. These strategies, could in future be used to expose people to arthropod species, in a positive way, which in turn will aid in conservation efforts (Samways *et al*., 2020; Simaika and Samways, 2018; Roy *et al*., 2015).

A study conducted by Tam *et al*. (2013) indicated that assigning facial structures to nature (anthropomorphism of nature) (Fig. 2.1) increases the connection sensed by people towards nature, which increases the likelihood of them participating in and supporting conservation efforts (Fig. 2.1).

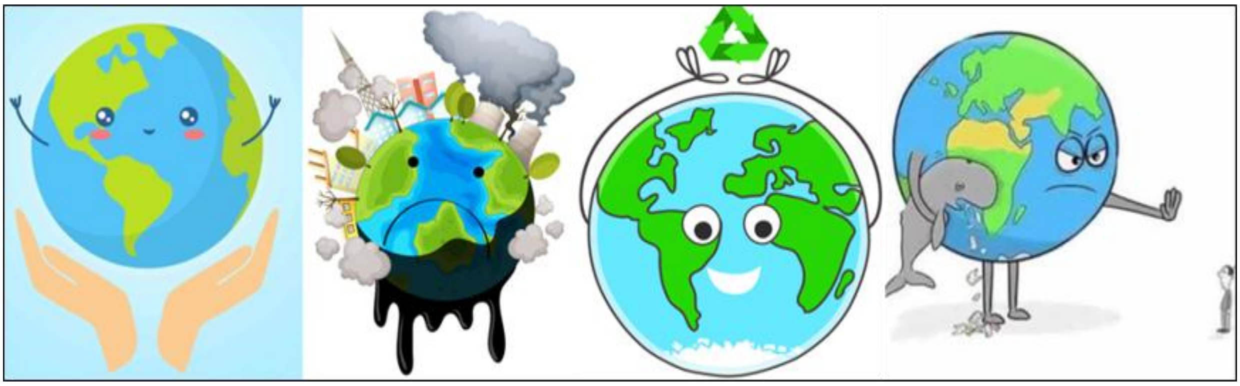

Fig. 2.1. Examples of the anthropomorphism of earth.

Manesi *et al*. (2015) revealed that not even an entire facial structure is required as the eye spots found on some butterfly species can positively and significantly increase the aesthetic appeal of that butterfly species and change the conservation attitude towards the same species. Due to the large and prominent eyes of mantids, this could influence people's perceptions of arthropods and thus the possibility of utilizing them as a gateway of flagship species for conservation does exist. Not only do mantids have prominent eyes but they have fascinated people for generations (Chapter 4).

2.4 Overview of the Order Mantodea

Insects are part of the arthropods that evolved about 600 million years ago during the Precambrian age (Béthoux and Wieland, 2009) (Fig. 2.2). Mantodea formed part of the Dictyoptera (including Blattodea) which is considered as a subordinate taxon of the Polyneoptera (Wieland, 2013). This is supported by various morphological characters as well as genetic analyses (Wipfler *et al*., 2012). Thus cockroaches are the closest relative to praying mantids (McMonigle, 2013; Wieland, 2013).

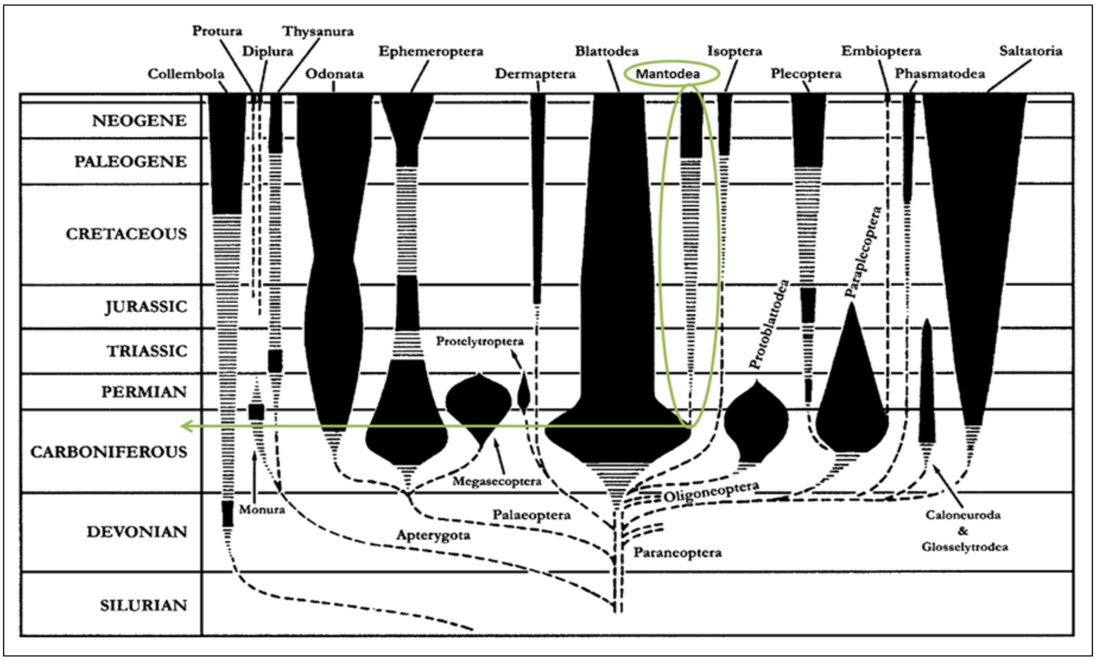

Fig. 2.2. Simplistic diagram of the evolution of insect orders with the Mantodea highlighted in green (Adapted from Grimaldi, 2001).

A recent study described an extinct arthropod order, the Alienoptera, which is considered an extinct sister group to the Mantodea order, that phylogenetically evolved during the "roach-mantis" transition period (Bai *et al*., 2016). Specimens of the Alienoptera have the same characteristic head shape and mouthparts of the Mantodea, while their bodies resemble that of the Blattodea (Bai *et al*., 2015). Even though the Blattodea and Mantodea are sister groups, the distinguishing characteristic between these are the raptorial forelegs of the Mantodea (Fig. 2.3).

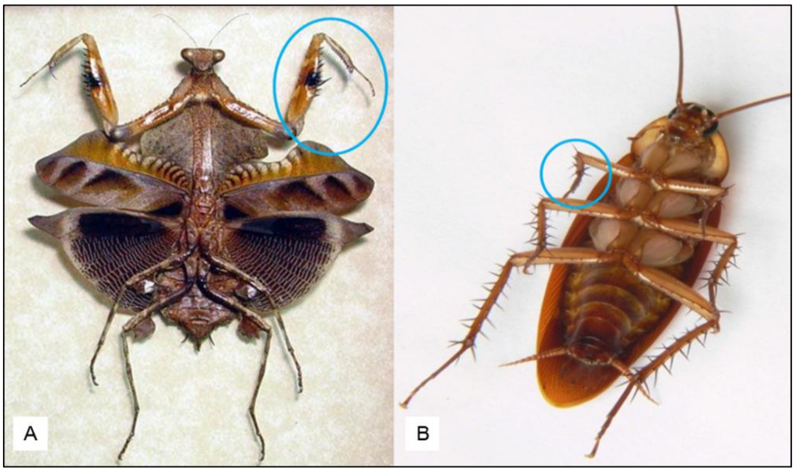

Fig. 2.3. Comparison between Mantodea (left) and Blattodea (right), indicating the dissimilarity in raptorial foreleg morphology (Svenson *et al*., 2012; Hörnig *et al.*, 2018).

Another distinguishing characteristic of these sister groups is the behavioural trait associated with oothecae. The Mantodea cements or attach their oothecae to the most appropriate substrate while it is being produced (Fig. 2.4). Blattodea females on the other hand, either bury the oothecae or retract it where the egg then develops in the brood sac. The Blattodea do however occasionally also cement their ootheca to substrates in their environment (McMonigle, 2013; Wieland, 2013).

Fig. 2.4. Comparison of Mantodea (A) and Blattodea (B) oothecae (Miorelli, 2015).

Despite the agreed upon position of the Mantodea order within the super order Dictyoptera, even the ordinal status of the Mantodea group has received criticism from studies such as that of Lo *et al*. (2007). The latter authors indicated that Mantodea should be encompassed by the Blattodea order. However, Svenson and Whiting (2004) suggested that Mantodea should be in an order of its own since strong morphological and genetic evidence exist which indicates the unique phylogenetic position of this group. The phylogenetic systematics and taxonomy of the Mantodea are also topics of discussion and debate among scientists (Wipfler *et al*., 2012; Wieland, 2013).

An example thereof is that of Béthoux and Wieland (2009) who indicated that the Mantodea evolved during the late Carboniferous age, which, based on forewing morphology, is about 175 million years earlier than previously estimated. The latter study also indicated that the Mantodea diverged from the Blattodea group during the late Carboniferous age, which suggests that both these groups survived the largest mass extinction event which occurred in the Permian period. However, this is in contrast to a more recent study by Gorochov and Topoxob (2013) who suggested that forewing morphology does not support the time scale of mantid evolution as suggested by Béthoux and Wieland (2009). Gorochov and Topoxob (2013) indicated that Béthoux and Wieland (2009) rejected the well-established hypothesis that cockroaches and mantids are related and have several common synapomorphies and that these two orders diverged in the Mesozoic era. This hypothesis (Mesozoic origin of mantids) has been established by fossil records that were uncovered. Yager and Svenson (2008) provided evidence of this hypothesis (Mesozoic origin of mantids) when they investigated the auditory system of mantids, and showed that mantids had the ability to hear ultrasonic sound in the Cretaceous period, well before the appearance of bats (origin of ultrasonic hearing ability) during the Tertiary period (Table 1).

Table 1. Geological time scale indicating various periods in evolutionary history (Craford *et al*., 2009; Gradstein *et al*., 2004).

Eon	**Era**	**Period**	**Millions of years ago**
Phanerozoic	Cenozoic	Quaternary	1.8 - 0.01
		Tertiary	65 - 1.8
	Mesozoic	Cretaceous	144 - 65
		Jurassic	206 - 114
		Triassic	248 - 206
	Paleozoic	Permian	290 - 248
		Carboniferous	354 - 290
		Devonian	417 - 354
		Silurian	443 - 417
		Ordovician	490 - 443
		Cambrian	543 - 490
Precambrian	Proterozoic		2500 - 543
	Archean		3800 - 2500

In a recent study which made use of both molecular tools and fossil records of cockroaches, mantids and termites, Legendre *et al*. (2015) indicated that stem mantids (most primitive mantids) were present in the late Carboniferous period while the more recent diversification of mantids that led to crown mantids, happened during the transitional time from the Triassic to Jurassic period (Legendre *et al*., 2015). This was suggested to be as a result of their predatory behaviour which led to a form of ecological succession.

It is however not only the phylogeny of the Mantodea that is unclear. The taxonomic organization within the Mantodea is also unclear and inconsistencies occur in many of the earlier and important systematic studies such as that of Stäl (1877), Beier (1964) and Erhmann (2002). These studies described various genera and species that suggest that different authors considered different morphological characteristics as important, thus leading to issues with the classification of Mantodea taxa (Svenson and Whiting, 2004).

An example of some of the phylogenetic problems stems from the classification systems implemented by Giglio-Tos (1927) and Beier (1964, 1968), which has been used frequently. This was until the publication of Ehrmann (2002) which rearranged many of the mantid groups and increased the number of families within the order from eight to approximately 36, as well as creating various new subfamilies. This was the accepted classification system until 2005 when more rearrangements and adjustments were made by Otte *et al*. (2020). However, the work done by Otte *et al*. (2020) was not supported by published phylogenies and was criticised by Svenson and Whiting (2004) as not having morphological justifications. These are the typical issues hindering studies of the Mantodea order, especially studies pertaining to their evolution.

Another issue with the use of only morphological traits for classification of Mantodea was raised by Rivera and Svenson (2016) who indicated that ectomorphs occur in some mantid families. For example, the Liturgusidae (Bark Mantids) which is known to hunt on tree trunks, have several characteristics (e.g. flattened bodies and similar behavioural traits), that give rise to specific ectomorph types. However, the Liturgusidae was derived from more than one common evolutionary ancestor (polyphyletic) but this ecomorph (synapopmorphic traits) has been found to have evolved several times independently. The homoplasy (i.e. ecomorphs) within the order of Mantodea thus complicates the use of morphology as a basis for classification (Rivera and Svenson, 2016).

Other discrepancies exist within the Mantodea order exists as a result of phylogenetic studies that were based on the use of only a small number of specimens or only selected groups within the order (Wieland, 2013). This was also the case for various genetic studies that focused on a small group of Mantodea species or studies that did not include the genera that caused the most anomalies such as *Chaetessa*, *Metallyticus* or even families such as the Amorphoscelidae, Toxoderidae and the subfamily Blepharodinae. However, an extensive study was conducted by Svenson and Whiting (2004) which included 288 species representing all Mantodea families as well as 90% of the recognized subfamilies. The overall consensus with regard to Mantodea classification is that homoplasy, which is defined as a specific character trait which is shared by various species but is not found in their common ancestor, is unbridled in this order (Rivera and Svenson, 2016; Svenson and Whiting, 2004; Wieland, 2013). This is thought to be the main reason for complexities within the Mantodea order, which led to the inadequate and misleading morphological classification system. Plesiomorphic traits are also found within the Mantodea order i.e. the three ocelli found in all species of mantids and other charactersitics such as the short prothorax in the genus *Metallyticus* (Wieland, 2008; 2013).

Despite the inconsistencies the current status of the Mantodea classification is that the order consists of 21 families (McMonigle, 2013; Wieland, 2013). The largest of these families is the Mantidae which consists of approximately 1000 species (Fig. 2.5). The following Mantodea families are listed in descending order of species richness (McMonigle, 2013): Hymenopodidae (Flower mantids), Tarachodidae, Thespidae, Iridopterygidae, Amorphoscelidae, Liturgusidae (Bark mantids), Eremiaphilidae (Arid-dwelling mantids), Toxoderidae, Angelidae, Photinaidae, Acanthopidae, Aconstistidae, Empusidae (Cone-headed mantids), Coptopterygidae, Galinthiadidae, Mantoididae, Epaphroditidae, Chaeteessidae, Metallyticidae (metallic-coloured mantids), Stenophyllidae and the three extinct families Baissomantidae, Cretomantidae and Santanmantidae (Appendix 1). There are in total approximately 2500 species of mantids worldwide (Fig. 2.5) (Green, 2014; Wieland and Schütte, 2012; Otte *et al*. 2020).

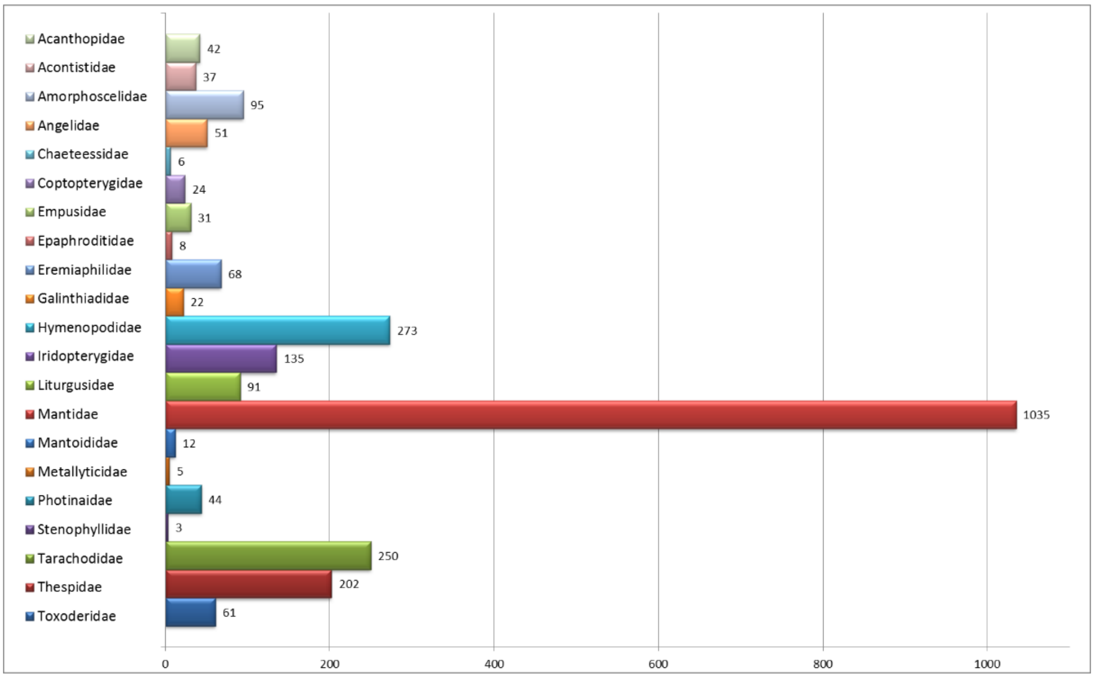

Fig. 2.5. Number of species in each of the families within the Mantodea.

2.5 Mantodea: What we know (Global Perspective)

2.5.1 Diversity and distribution of Mantids

Mantids are thermophilic and their distribution is linked to the more tropic and subtropical regions. As a result of the overlap between mantid distribution and tropical and subtropical regions, Klass and Ehrmann (2003) indicated that this limits mantid species to occur only between 45 North and 46 degrees South latitudes. Exceptions do exist such as *Mantis religiosa* L. (Mantodea: Mantidae) and *Empusa pennicornis* Pallas (Mantodea: Empusidae) which are found beyond the 50-degree latitude in the northern hemisphere. Mantids that occur in temperate regions prefer arid habitats and are as such xerophytic according to Shcherbakov and Savitsky (2015).

Studies indicated that the species *M. religiosa* has shown range expansion due to climatic variation, presumably caused by climate change (Shcherbakov and Savitsky, 2015; Linn and Griebeler, 2016). This species was originally only found in Europe but was accidentally introduced into New York, USA in 1899, on plants shipped to a nursery in this area (Gurney, 1950). *Mantis religiosa* is now reported to occur in Eastern USA and is even the “state insect” of Connecticut. It is also found in southern Canada (Ontario, Quebec and British Columbia) (Cannings, 2007; McMonigle, 2013). In 2001 observations of *M. religiosa* was made in Wisconsin in the northern lake region of the USA (Kisselburg and Cochran, 2001). The European distribution of this species has also expanded from the southern Europe (Spain, Italy and Balkan states) to include France, Germany, Ukraine and southern Poland (Linn and Greibeler, 2015; Zieliński *et al*., 2018). This species was also recorded in Latvia which is estimated to be the most northern distribution of *M. religiosa* (Pupiņš *et al*., 2012). This species also occurs throughout Africa and Asia (Pupiņš *et al*., 2012; IUCN, 2018).

2.5.2 Morphological characteristics

Mantids are identified by an elongated abdomen that usually has eight segments and a short head (Scholtz and Holm, 1985; Wieland and Schütte, 2012) (Fig. 2.6). The head of a mantid is highly mobile and it can pivot up to 180 degrees, contributing to their 300-degree field of vision (Green, 2014).

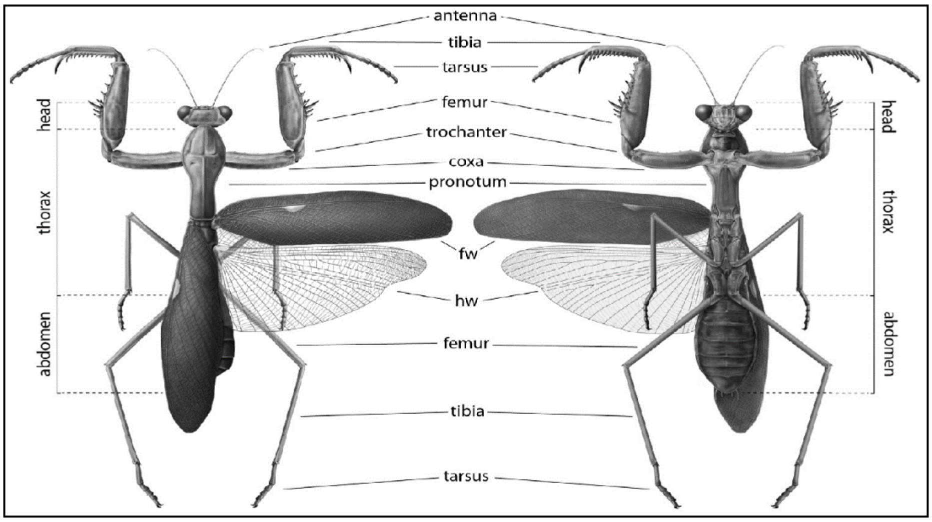

Fig. 2.6. Morphological characteristics of a praying mantid (Illustration by Rebecca Konte in Brannoch *et al*. (2017).

Mantids have compound eyes (consisting of ommatidia) which enables them to distinguish between colour, motion and shape (Green, 2014; McMonigle, 2013). Despite their relatively primitive nature with regards to evolution, they are able to differentiate between a moving object and the background of the particular object (parallax) which is a more primitive version of depth perception (McMonigle, 2013). However, mantids do have limited vision at night, and as such their eyes become darker to absorb as much available light as possible (McMonigle, 2013; Horridge *et al.*, 1981) (Fig. 2.7). Horridge *et al*. (1981) indicated that the light sensitivity or the darkening of the eyes was as result of increased acceptance angles (this refers to the width of a retinula cell which thus allows for the maximum amount of light to reach a retinula cell which leads to the nerve passing to the optic ganglion) in the ommatidia of the mantid, *Tenodera australasiae* Leach (Mantodea: Mantidae). The acceptance angles were found to double at night in this mantid (Horridge *et al*., 1981).

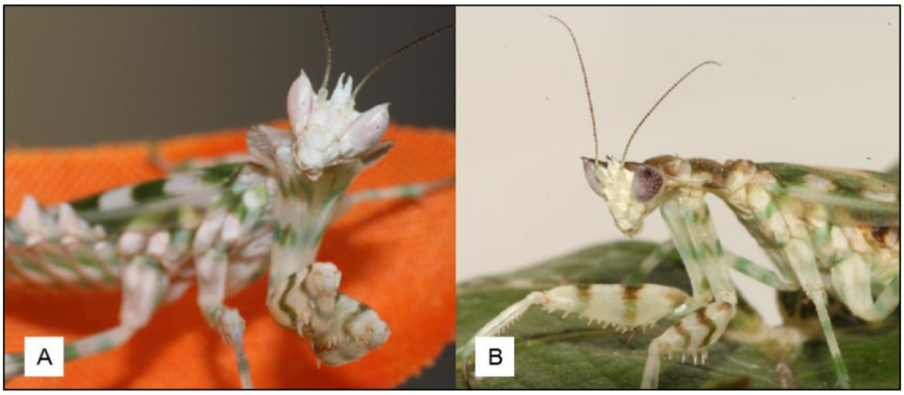

Fig. 2.7. The eyes of a praying mantid (A) as the available light decreases (B), thus increasing their eye colour.

However, Schirmer *et al*. (2014) suggested that the darkening of the eye might be as a result of pigment migration instead of migration of photoreceptors, which was the reason this physiological changed occurred in *Triatoma infestans* Klug (Hemiptera: Reduviidae) which was studied by Reisenman *et al*. (2002). Schirmer *et al*. (2014) also indicated that the colour change might be as a result of circadian rhythm of the mantid species but that the change in eye colour (eye darkening) is absent when subjected to continuous light thus implying that the circadian mechanism which controls the pigment migration is subjective to ambient light availability.

Mantids have pseudopupils (Fig. 2.8) (i.e. a point at which the light refracts within the compound eye of the mantid), which tends to become bigger as a mantid follows the movement of its prey (Green, 2014; McMonigle, 2013). This phenomenon was also verified by Rossel (1979). The enlargement of the pseudopupils under conditions of low light availability results in an increase of the acceptance angles, thus reacting in the same manner in which the rest of the ommatidia of the compound mantid eyes do.

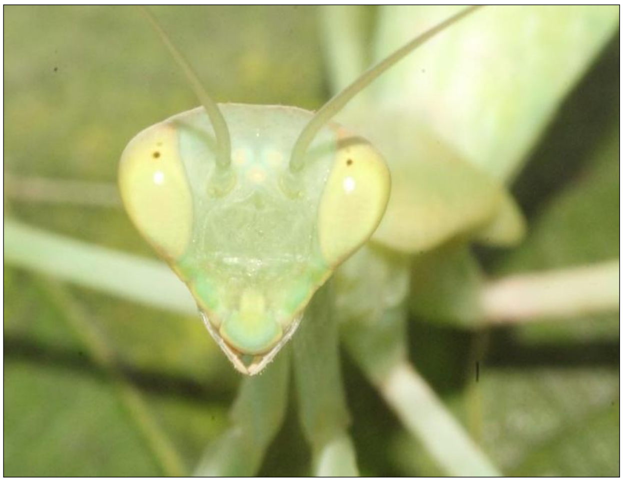

Fig. 2.8. Pseudopupils (black spots inside the compound eye) are present in all Mantodea species.

The shape of the compound eyes varies between mantid species. For example, *Otomantis* species Bolivar (Mantodea: Hymenopodidae) tend to have elongated compound eyes while *Sphodromantis* species Stäl (Mantodea: Mantidae) have no elongations and the compound eyes are round in shape (Fig. 2.9). Despite a species having an elongated eye shape, Brannoch *et al.* (2017) reported that these elongations do not contain ommatidia and that the elongations are therefore non-visual features that might only aid in their camouflage or to intimidate any predators by amplifying confusion during a threat pose.

Fig. 2.9. Mantids with different shape compound eyes. (A) *Episcopomantis* sp. (Mantodea: Tarachodidae) and (B) *Otomantis* sp. (Mantodea: Hymenopodidae) are representatives of the group with elongated eyes while (C) *Oxypilus* sp. (Mantodea: Hymenopodidae) and (D) *Sphodromantis* sp. (Mantodea: Mantidae) represent the group with eyes that are more round and common (Photos by Allison Sharp).

Mantids have five eyes: Two compound and prominent eyes and three simple eyes (ocelli) found between the antennas (Fig. 2.10) (McMonigle, 2013). The ocelli are arranged in a triangular fashion and allow mantids to distinguish between light and dark, which is also the function of the ocelli in various other arthropods (Parry, 1947; Taylor, 1981; Berry *et al*., 2007; Sabat *et al*., 2016; Garcia *et al*. 2017). Ocelli have also been suggested to aid in the estimation of day-night durations as well as orientation of the arthropod body towards a light source (Berry *et al*., 2007). A recent study by Garcia *et al*. (2017) suggests that the ocelli could also to an extent contribute toimproved colour consistency and differentiation in arthropods such as honey bees.

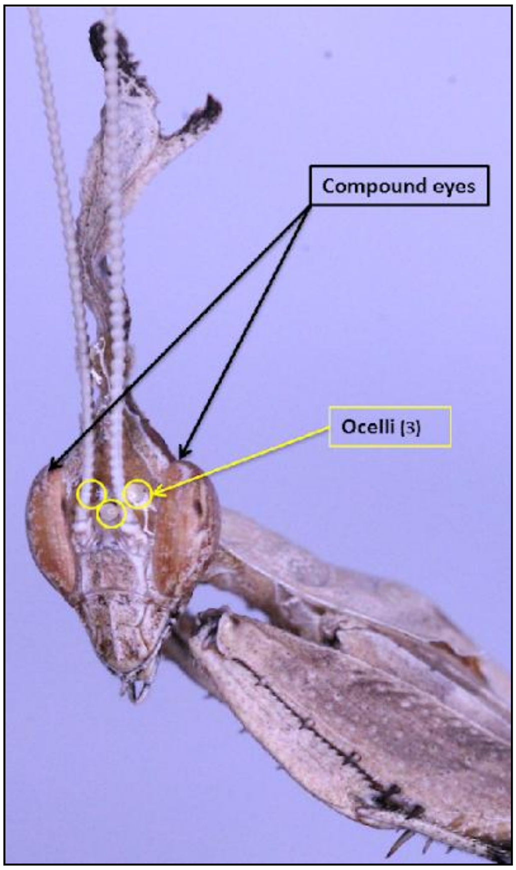

Fig. 2.10. Three dorsal ocelli (indicated by three circles) located between the antennas of a mantid species (*Phyllocrania paradoxa*). (Brannoch *et al*. 2017; Green, 2014).

Mantids are equipped with a femoral brush which is located on each of the profemurs of mantid raptorial forelegs which is used to clean the compound eyes. The vision of mantids enables them to identify prey up to a distance of 18 meters (Green, 2014).

The antenna is the main olfactory sensor of a mantid and aids in detecting prey. Slifer (1968) stated that the female has about 10 000 sense organs on one of her antenna, while the male *Tenodera angustipennis* Saussure (Mantodea: Mantidae) has about 40 000 sense organs on a antenna. These sense organs were identified as chemoreceptors. Slifer (1968) indicated that these chemoreceptors were composed of multiparous sensilla. Faucheux (2008) found that the male *Oxyothespis maroccana* Bolivar (Mantodea: Mantidae) had an abundance of these chemical receptors identified as multiparous sensilla subtype 1. Sexual dimorphism exists with regards to this type of chemoreceptors as stated by Faucheux (2005, 2006, 2008) thus indicating this to perhaps be the sex-pheromone receptors in Mantodea. The olfactory sensors are thus more prominent and intricate in males to aid in finding females and their associated pheromones (Carle *et al*., 2013; 2014; Green, 2014; Faucheux, 2008).

Some earlier studies indicated that the antennae could be used as a taste organ (Roeder, 1935) but since this type of behaviour was only observed in one species (*M. religiosa*) it was later revealed to be unfounded (Faucheux, 2008).

Faucheux (2008) observed that small and sometimes fragile species (e.g. *Tropidomantis tenera* Stäl (Mantodea: Iridopterygidae)) and *O. maroccana* male mantids tend to have 'long-haired' antenna while more robust and sometimes larger species do not (Fig. 2.11). These 'long-haired' antenna also possess sensilla filiformia in abundance (50% of the antennal sensilla) which is not present in the antenna of other males (Faucheux, 2008). Sensilla filiformia also occurs on the cerci of crickets and on the pedipalps of some arachnid species (Christian 1971; Faucheux, 2008).

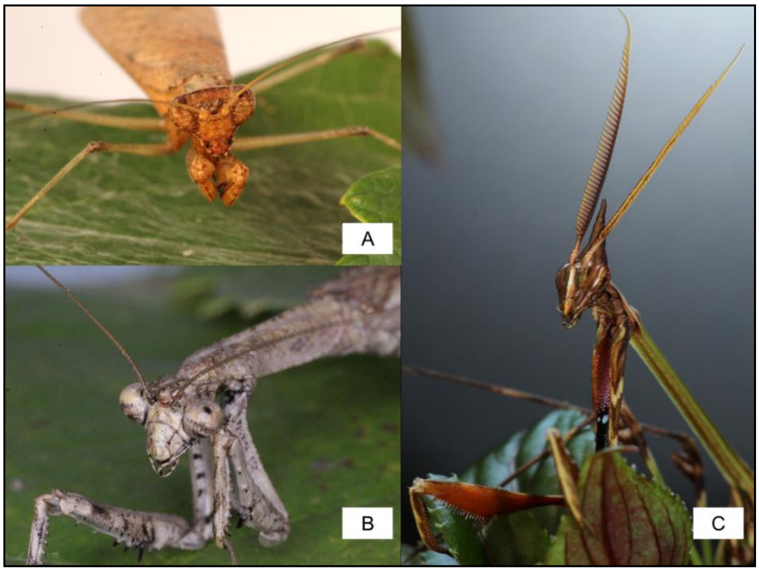

Fig. 2.11. Male mantid specimens with different morphological antenna structures. Specimen (A) *Dystacta alticeps* (Mantodea: Mantidae) and (B) *Popo spurca* (Mantodea: Mantidae) do not have long-hairy antenna while (C) *Hemiempusa capensis* (Mantodea: Empusidae) is an example of a species with long-haired antenna.

The palps of a mantid directs its food into its mouth and is suspected to aid in the tasting of their prey as these palps have secondary odour distinguishing abilities (McMonigle, 2013; Green, 2014).

The ears of mantids are located on the base of the abdomen between the back legs and consist of two tympanic membranes (Fig. 2.12) (McMonigle, 2013; Green, 2014). In general, the hearing of mantids can be divided into three categories: mantids that have tympanal organs, those that are primitively earless and mantids that have no hearing. It is assumed that the latter lost this ability throughout the evolution of the Mantodea order (Faucheux, 2008). Mantids have a total of six different auditory types of which four can be identified anatomically, the remaining two are neurophysiological. The uses of these auditory types are predominantly required in the evasion of predation by bats (Yager and Svenson, 2008). It is suggested that this auditory ability has evolved throughout the Mantodea order, since experiments indicated that different mantid species in flight, respond to ultrasound cues with a change in behaviour (Yager and Svenson, 2008; McMonigle, 2013). This auditory system evolved before bats came into existance which suggests that the mantid ear might have been used in communication or defence with regards to other predators beyond bats, or might aid in prey detection as is the case with dolphins (Yager and Svenson, 2008).

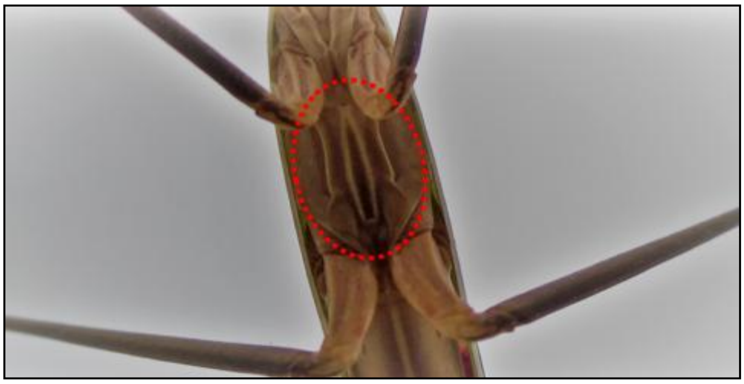

Fig. 2.12. Eardrum of a mantis, located on the ventral side of the abdomen between the first and second pair of walking legs (Photo by USMANTIS, 2018). Source: https://usmantis.com/pages/praying-mantis-insect-diagrams-and-nomenclature

The raptorial forelegs (Fig. 2.13) are characteristic of mantids and are well developed with spines and are very effective at immobilising prey as it is being eaten (Wieland, 2013). These legs are held in a position that mimics praying, hence their name – praying mantis. The arrangement of the spines on the legs plays an important role in the classification and identification of mantids (McMonigle, 2013).

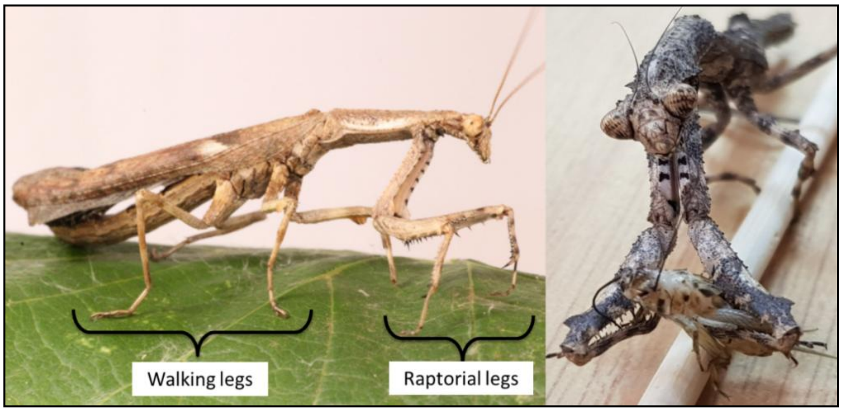

Fig. 2.13. Characteristic raptorial legs of the mantid and an illustration of the use of these legs to hold prey whilst eating.

The four remaining legs might not be used while hunting, but the tarsus of each leg has euplantulae (adhesive pads) which allow mantids to climb most surfaces (McMonigle, 2013). These euplantulae provide a form of adhesion and tend to lose effectivity as mantids age or occasionally during moulting (Green, 2014). The euplantulae of Empusidae individuals, are not effective on smooth surfaces since they are reduced in size in this group (McMonigle, 2013). According to Svenson *et al.* (2015) and Wieland (2013) some genera of mantids (i.e. *Phyllocrania* Burmeister (Mantodea: Hymenopodidae) and *Hemiempusa* Saussure & Zehntner (Mantodea: Empusidae) have a distinctive feature in terms of cuticular expansions on the femur. These expansions are known as lobes and are not a common occurrence within the Insecta class (Figs. 2. 14A and 2. 14B).

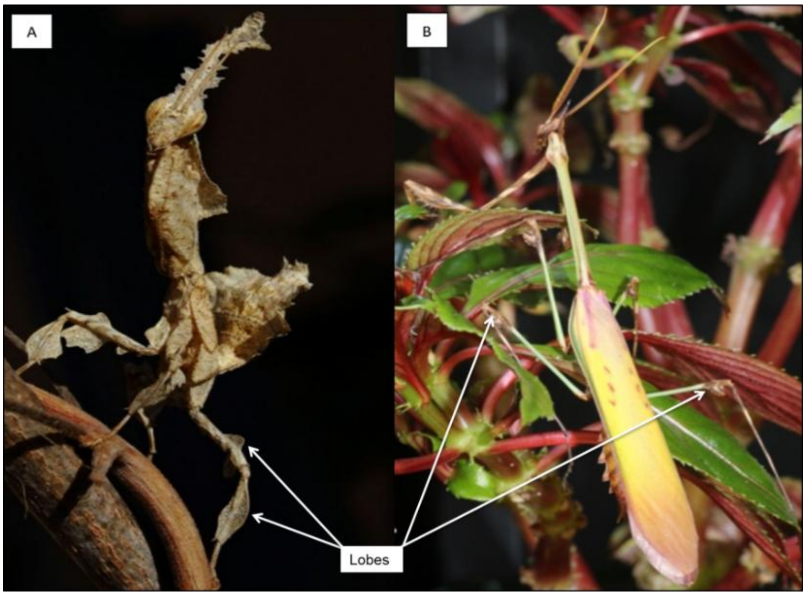

Fig. 2.14. *Phyllocrania* specimen (A) (Photograph A: Allison Sharp) and *Hemiempusa* specimen (B) with clearly visible lobes.

Insect wings are said to have evolved in the Devonian age and consisted only of four thoracic elongations which was first used for gliding (Matthews and Matthews, 1978). Kukalova-Peck (1983) indicated that the first Pterygota with ability to fold its wings was the Diaphanopterodea (extinct order) which existed during the early Late Caboniferous era. The ability to fold wings and different degrees of folding, for example, no folding, longitudinal, transverse and fanwise, or a combination thereof evolved simultaneously in some insect orders, while in others it seems to be an automorphic trait which evolved several times (Fig. 2.15) (Haas, 2006). Of these wing folding types it seems that no-folding or unfolded was the most primitive strategy while the complexity increased with fanwise folding being the most recently evolved type of wing folding (Haas, 2006). The folding of wings is an important factor as it allowed these insects to adapt to their environment in unique ways such as camouflage and avoidance of predators, while in general it still promotes the mobility function of flying (Haas, 2006).

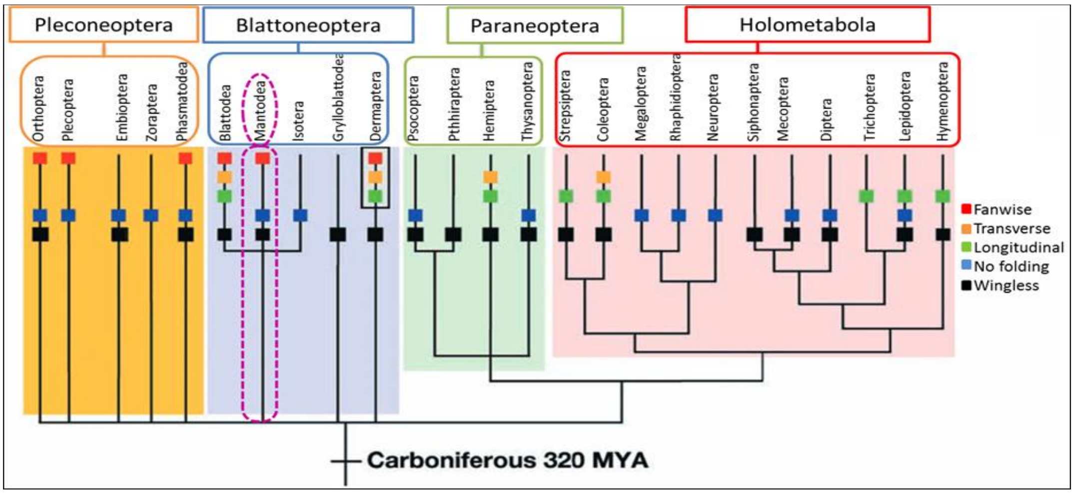

Fig. 2.15. The variety of wing folding types as exhibited by each of the different insect orders, Mantodea has only two types of wing folding, one of which is considered primitive (no folding) whilst the other is considered to be advanced (Fanwise) (adapted from Kristensen, 1991; Haas, 2006).

After megaannums of evolution, the wings of Mantodea now consist of the tegmina which protect the membranous hind wings and together they are folded over the elongated abdomen (Green, 2014). The type of wings or folding that exists within the Mantodea varies largely (Fig. 2.15). Some females have reduced wings or in some species, such as the ground dwelling mantids, wings are absent (Haas, 2006). Females tend to not fly as much as males and their wings are often used in camouflage or defence by many species (Green, 2014). The presence of well-developed wings is usually a sign of a mature mantid individual, however in ground dwelling species wings remain absent despite their maturity (McMonigle, 2013). The nature of the wings that exist in a Mantodean family can be used to assess the evolutionary position of the family, however this trait along with the venation should be compared with a wide variety of molecular samples to increase accuracy (Haas, 2006; Rivera and Svenson, 2016; Svenson and Whiting, 2004; Wieland, 2013).

2.5.3 Biology

Mantids are hemi-metabolic insects and they moult about six to nine times before reaching maturity (McMonigle, 2013). Damaged limbs have been reported to regenerate after moulting but raptorial forelegs tend to lose functionality despite the regeneration during moulting (Fig. 2.16) (McMonigle, 2013; Ramsay, 1990; Roberts, 1937). The regeneration of a limb does however depend on the stage, at which the limb was lost, early instars tend to regenerate most lost limbs by the time they reach the adult stage (Ramsay, 1990; Roberts, 1937). Mantids have a lifespan of between three to eight months, while in captivity they can live up to one year. The lifespan of mantids are however species depended and is influenced by several abiotic factors such as temperature, abundance of prey and humidity (McMonigle, 2013; Harris and Moran, 2000; Younes and Zohdy, 2003).

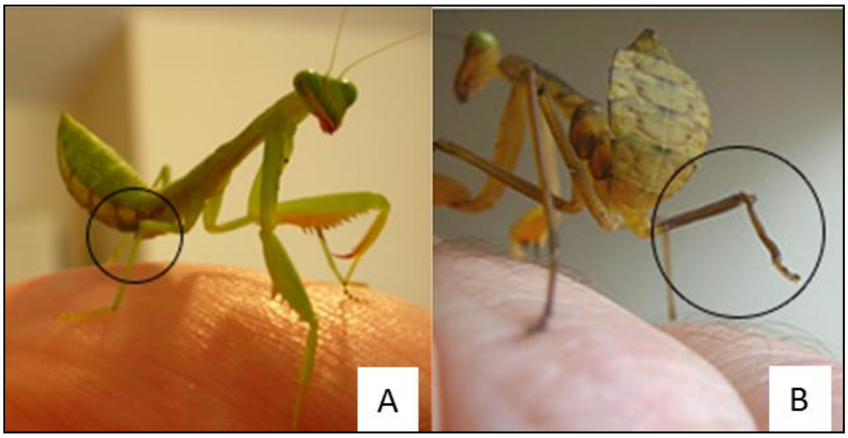

Fig. 2.16. Photo of a mantid with a healthy limb (A), and a photo (B) of the same specimen with a regenerated limb (Adapted from photo by Dave Cooper (*In*: Pulford, 2009).

Mantid adults become sexually mature approximately two weeks after the final moult has been completed. Some mantid species might take longer or males might moult and become sexually mature earlier than females (McMonigle, 2013; Younes and Zohdy, 2003). Sexual dimorphism is a common occurrence within the Mantodea as males tend to be smaller than females. A recent study indicated that female mantids use sexual pheromones to attract males and it is assumed to be the primary mechanism in long range mate attraction (Maxwell *et al.*, 2010). Females tend to arch their abdomens when emitting pheromones to attract males, similar to the posture of female Lepidoptera moths when they emit sex pheromones (Mudavanhu *et al*., 2017). Mating takes place when the male leaps onto the back of the female whilst attaching his forelegs to her thorax (Green, 2014). Mating can last between two to eight hours and usually concludes with the female eating either the entire male or just his head.

Sexual cannibalism is found in most mantid species (McMonigle, 2013; Green, 2014). The reasoning behind the sexual cannibalism was thought to be adaptive suicide, in which the male is seen as a deposition of biomass to increase the fitness of his offspring (Birkhead *et al.*, 1988). However, a study by Hurd *et al.* (1994) suggested that females *T. sinensis* Saussure (Mantodea: Mantidae) keep attracting males not for mating purposes but as prey when food resources are limited. Males are however unable to determine the intent of the female releasing the sex pheromone and are eaten during 17% of these encounters. Hurd *et al.* (1994) also suggested that cannibalism by *T. sinensis* females was the reason for the female biased sex ratio in its population by the end of the season. This is however still a topic of debate with new hypotheses being tested and introduced regularly. However a study by Lelito and Brown (2008) opposes the theory by Hurd *et al*. (1994). Lelito and Brown (2008) tested the honest signalling theory which indicates that an unmated well-fed female will attract more males than mated and hungry females. The honest signalling theory suggests for example that the female with real physical necessity will be more successful than females with no real necessity, and dishonest signalling would therefore be less successful (Johnstone and Grafen, 1993). By testing the signalling theory, the "false mating call" as a method to get food was also investigated. Lelito and Brown (2008) indicated that well-fed unmated females attracted significantly more males than either well-fed or hungry mated females. A similar phenomenon has been reported for *Spodoptera litura* (F.) (Lepidoptera: Noctuidae) where males also preferred unmated females as oppose to mated females (Shi *et al*., 2018). The pheromones released by mated females are suggested to differ in either the composition or quality and are therefore not as attractive to males as that released by unmated females (Prouvost *et al*., 1999; Lelito and Brown, 2008).

The ootheca is a protective structure that consists of protein liquid that is secreted around the ova (Green, 2014). The ootheca is attached to the base of a structure such as a stick and the size and shape varies among the Mantodea families and species (Fig. 2.17). Brannoch *et al.* (2017) indicated that ootheca can therefore be used in taxonomic and systematic reasoning, which was also suggested by Breland and Dobson (1947). The properties of the oothecae (chemical components and physical structure) are suggested to vary between species, making it a possible taxonomic tool but it remains an understudied element of the Mantodea (Brannoch *et al.*, 2017).

Fig. 2.17. Ootheca of *Harpagomantis* sp. (Mantodea: Galinthiadidae)(A) and *Galepsus* sp. (Mantodea: Tarachodidae)(B) attached to various sticks.

An ootheca may contain between 10 and 400 eggs and is constructed during the night to allow the protective structure to harden overnight and to ensure protection during daytime when predators are most active (McMonigle, 2013; Green, 2014). Newly deposited oothecae may vary in colour from blue to yellow and usually change to brown over time. A female mantid only has to be fertilized once after which she can lay up to twenty oothecae (McMonigle, 2013). The time between which the ootheca is laid until the eggs hatch can range from a few days to a few months, depending on the species. Mantid females often lay unfertilized oothecae, which in appearance are the same as fertilized oothecae. The eggs inside oothecae usually hatch six to eight weeks after oviposition. However, some species overwinter in the egg phase (oothecae) and hatching may take place only six months after oviposition (McMonigle, 2013).

2.5.4. Behaviour

Prete *et al*. (1999) indicated that mantid behaviour is not as simple as previously thought and that there is a higher level of complexity than previously anticipated. Mantids tend to track movement of organisms, which is enhanced by their pseudopupils. This often leads to the illusion that they “watch” their observer, but this is only a component of their behaviour. Beyond this behavioural trait, mantids have different behaviours that range from grooming to courtship, as well as threat poses which acts as a defence mechanism against predators (McMonigle, 2013).

Males have been observed to have a lower tolerance for bitter-tasting prey than females (Carle *et al*., 2015). Females were also observed to eat four times as much as the male *Tenodera aridifolia* Burmeister (Mantodea: Mantidae). The differences in prey preference behaviour might be related to different nutritional requirements thus resulting in the different feeding strategies. The female mantids require prey that will enable them to produce oothecae as well as pheromones to attract males, thus require different nutritional supplements (Carle *et al*., 2015).

A study of the striking-behaviour during capture of prey and locomotion showed that these behavioural traits were influenced by circadian rhythms, in a particular species of mantid, *Hierodula patellifera* Serville (Mantodea: Mantidae) (Schirmer *et al*., 2014). For example, *H. patellifera* were found to have a higher response rate to visual prey stimuli during constant light and night-light conditions. This was suggested to be as a result of the circadian rhythm which influences the sensitivity of the compound eye of this mantid. These circadian influences are however still being debated as this would indicate that the differences of the circadian rhythm responses are controlled by the central nervous system more than changes in photoreceptor sensitivity (Popkiewicz and Prete, 2013; Schirmer *et al*., 2014). The activity of mantids have also been reported to increase during transitional light phases (dusk and dawn), which also points to the influence that circadian rhythms might have on these insects, however the increase in activity can also be associated with mantid calling behaviour and pheromone release (Perez, 2005; Edmunds, 1975).

Defence behaviour is commonly observed in mantids. For example, *T. aridifolia* displayed three behavioural responses (fixation, evasion and cryptic reaction) in a study involving looming objects conducted by Yamawaki (2011). The cryptic response was the result of looming objects approaching directly towards the mantid which caused it to retract/extend its forelegs under its prothorax, however, fixation (rapid turning of the head towards the object) occurred first (Yamawaki, 2011). Striking behaviour only occurred at a certain distance from the potential threat. It should be noted that these mantids exhibited different responses to visual prey simulations, such as birds, lizards and bats, than to looming objects. This suggests that they have a neural pathway that differentiates between different stimuli and can react accordingly. The type of neural pathway that allows this behavioural response is however unknown (Yamawaki, 2011).

2.5.5 Feeding habits and hunting strategies

Mantids are predominantly predators. It has however been noted that mantid nymphs, especially hatchlings, feed on pollen (Beckman and Hurd, 2003), which makes them tritrophic predators. Tritrophic in this regard refers to mantids feeding on pollen as well as prey that is attracted to the pollen food source. However, this behaviour might be as a result of prey limitations especially for hatchlings that can only eat prey of small size. Mantids have three hunting strategies: active, ambush and generalist (Svenson and Whiting, 2004). Active hunting is when mantids search and capture prey, while mantids with ambush feeding strategies sit and wait for prey to cross their path. Mantids with generalist feeding strategies combine these two techniques. The type of hunting strategy employed is thought to be depended on geographic location, genetic constraints and habitat selection. Cannibalism between hatchlings has been reported in cases where resources are scarce (McMonigle, 2013).

Mantids prey on any insect that is generally smaller than itself, however, some species have been reported to catch reptiles and hummingbirds (McMonigle, 2013). *Eumusonia* sp. (Mantodea: Thespidae) have been observed to feed on young tree frogs (*Osteocephalus taurinus*) (Anura: Hylidae) (Fig. 2.18) (Costa-Pereira *et al*., 2010). The latter study reported that due to the small body size and great abundance of juvenile tree frogs in the study area in central Brazil, they were easy prey for mantids (Costa-Pereira *et al*., 2010).

Fig. 2.18. Predation by *Eumusonia* sp. (Mantodea: Thespidae) on a juvenile tree frog (*Osteocephalus taurinus*) (Costa-Pereira *et al.,* 2010).

The Chinese mantis (*T. sinensis*) has also recently been observed gutting (removal of gut and organs) larvae of the Monarch butterfly (*Danaus plexippus* L.) (Lepidoptera: Nymphalidae) before ingesting the prey (Rafter *et al*., 2013). These larvae feed on milkweed plants which is toxic to mantids and other predators. In the latter study a variety of caterpillars where presented to adults of *T. sinensis* and only the toxic Monarch larvae was gutted before being eaten, while other caterpillars were ingested completely (Rafter *et al.,* 2013). It is assumed that the higher ratio of carbon compared to nitrogen within the gut of the larvae that consumed the toxic plant material was the trigger that allowed this mantid species to detect the presence of toxins. A recent study indicated that this behaviour is also common for other mantids species (*Hierodula membranacea* Burmeister (Mantodea: Mantidae)) even when larvae were reared on non-toxic plants. This gutting behaviour suggests that mantids feeding on larvae might remove their gut content to reduce the amount of plant material that they ingest, because mantids digestive systems might be less suited to process plant material (Mebs *et al*., 2017).

Tenodera sinensis was also observed to feed on a poisonous red-spotted newt species (*Notophthalmus viridescens*) (Caudata: Salamandridae) without any ill effects (Mebs *et al.,* 2016) (Fig. 2.19). The newt species has a high concentration of tetrodotoxin, which is a blocker of sodium channels. The study indicated that the toxin did not penetrate the mid-gut membrane of the mantid since it was localized in the gut lumen and not in the epithelial cells and as such, the toxin had no effect on this mantid species (Mebs *et al.*, 2016). Three other mantid species, *S. viridis* Forskal (Mantodea: Mantidae), *H. membranacea* and *Miomantis* *caffra* Sassure (Mantodea: Mantidae) were also reported to have the ability to feed on *Notophthalmus viridescens* (Caudata: Salamandridae).

Fig. 2.19. Chinese Mantid, *T. sinensis* feeding on poisonous a red-spotted newt (Mebs *et al*., 2016).

Mantids have the ability to learn (Carle *et al*., 2015). In the latter study, mantids where offered three types of prey (bees, crickets and mealworms) of which different levels of bitterness were artificially created. The attack rate of mantids on bees was reduced after the artificial bitterness was added. This is despite mantids favouring bees above mealworms before the artificial bitterness was added. This indicated their ability to learn and to avoid bitter tasting prey. The ability of mantids to learn from environmental cues as well as previous experience was suggested to be the hunting strategy of *Hierodula tenuidentata* Saussure (Mantodea: Mantidae) which was able to catch guppy fish (*Poecilia reticulate*) in an semi-natural fish pond (Battiston *et al*., 2018) (Fig. 2.20).

Fig. 2.20. Male mantid (*Hierodula tenuidentata*) feeding on guppy fish which was caught from an artificial pond (Battiston *et al*., 2018).

The same male *H. tenuidentata* was observed catching nine guppy fish over a span of five days, mostly after sunset (Battiston *et al*., 2018). These observations suggested that although mantids are sit and wait predators, the ability to recall a site with abundance of prey could be advantageous and to some extent influence the fitness of an individual (Battiston *et al*., 2018).

2.5.6 Camouflage

Crypsis is the process in which mantids blend into their surroundings. Some species do this by mimicking dead leaves (Fig. 2.21 (C)), grass (Fig. 2.21 (D)), tree bark (Fig. 2.21 (A)) or flowers (Fig. 2.21 (B)) (McMonigle, 2013; Green, 2014).

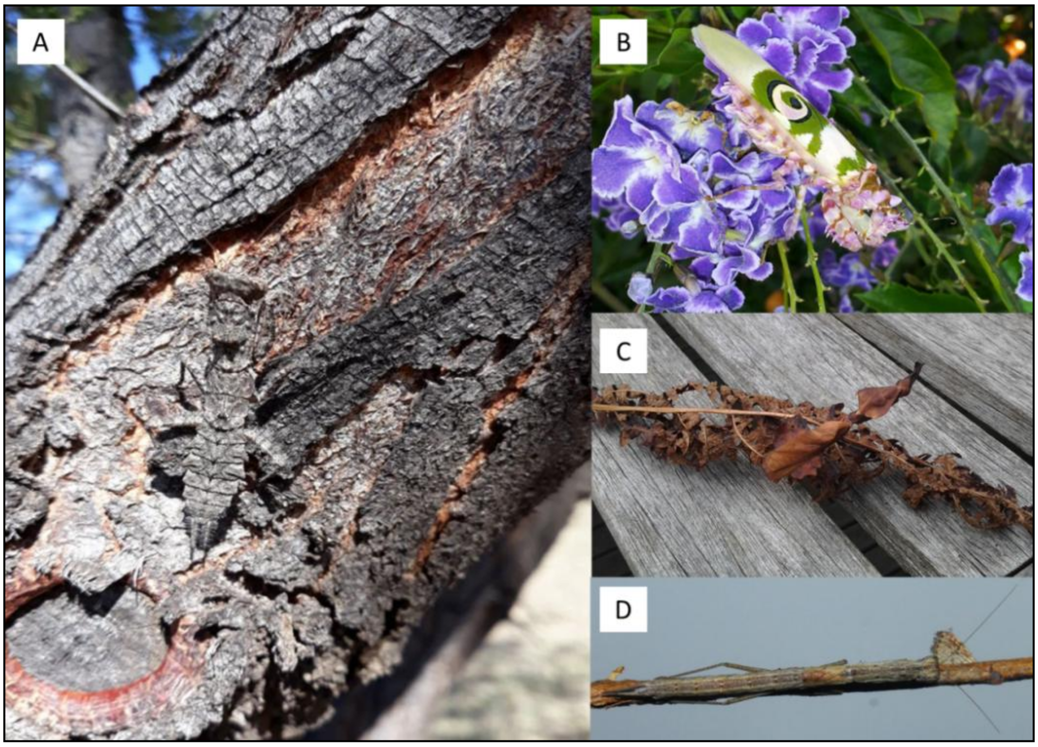

Fig. 2.21. The camouflage abilities of a few mantid species. (A): A species of bark mantid (Mantodea: Liturgusidae) (Photo: Amone Mouton), (B): Eyed Flower mantid, *Pseudocreobotra wahlbergi* (Mantodea: Hymenopodidae) (Photo: Abigail Wolmarans), (C): Ghost mantid resembling dead leaves, *Phyllocrania paradoxa* (Mantodea: Hymenopodidae) and a mantid usually found in grasslands (D) *Galepsus* sp. (Mantodea: Tarachodidae) (Photos: Allison Sharp).

The Orchid mantis (*Hymenopus coronatus* Olivier (Mantodea: Hymenopodidae) resembles the Orchid flower (*Phalaenopsis amabilis* L. (Asparagales: Orchidaceae). However, in an experiment the Orchid mantis was compared to a common *Asystasia intrusa* Blume (Scrophulariales: Acanthaceae) flower and the results indicated that the mantis attracted more hymenopteran pollinators than the flowers themselves (Fig. 2.22) (O'Hanlon *et al*., 2014).

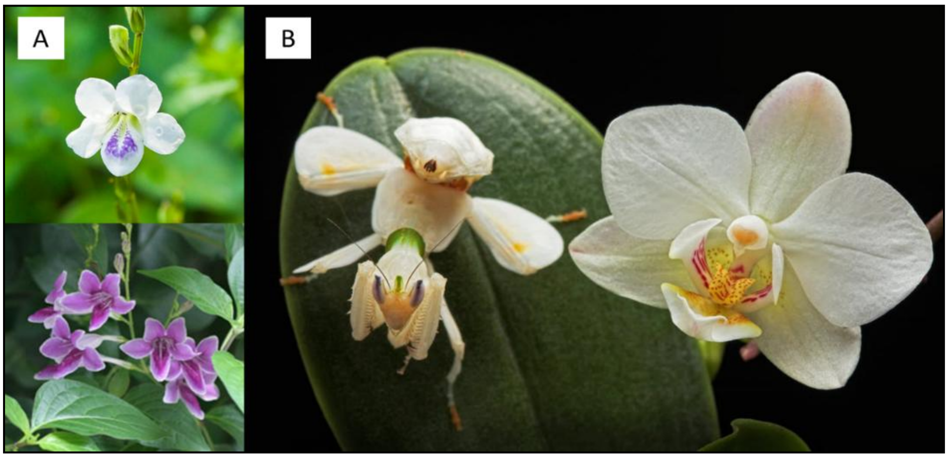

Fig. 2.22. Orchid mantid (*H. coronatus*) compared to (A) *Asystasia* sp. and (B) Moth orchid (*P. amabilis*). Photo by Igor Siwanowicz.

According to O'Hanlon *et al.* (2014), orchid mantids were the first mantid species that used mimicry as a hunting strategy. Mimicry is usually used as a defence mechanism to avoid predation (McMonigle, 2013). Not only do mantids resemble their backgrounds, some species that have elongated bodies, position themselves to imitate the position of flowers, grasses and twigs (O'Hanlon *et al*., 2014; McMonigle, 2013). The wings of mantid species that make use of camouflage usually aids in mimicry and often have bright patterns (McMonigle, 2013). Mantids have the ability to change colour to match their surroundings, however this is not as pronounced as in some reptile species i.e. chameleons (Green, 2014). Mantids can only change to different shades of a colour which enables them to resemble their immediate environment more accurately. However, this does not only indicate that they can change colour but also that mantids are aware of colour (Green, 2014). Observations have even been made of mantids repositioning themselves to increase the level of camouflage which increases the level of disguise that they achieve (Green, 2014).

2.6 Biodiversity of South Africa

South Africa has a very rich biological diversity with regards to fauna and flora and is ranked the third-most biologically diverse country in the world (Cadman *et al*., 2010), even though it only occupies 2 % of earth's surface (CBD, 2018). There are nine recognised biomes in South Africa (i.e. Albany thicket, Desert, Forest, Fynbos, Grassland, Indian Ocean Costal Belt, Nama-Karoo, Savanna and Succulent Karoo) eight centres of endemism and many endemic species (von Maltitz and Scholes, 2006). Within the borders of South Africa, is the Cape Floristic region (known for the Fynbos of the area) which is one of only six of the Floral kingdoms in the world. South Africa also has a rich and diverse arid plant community (Succulent Karoo) (Fig. 2.23) (Rutherford *et al*., 2000; Pryke and Samways, 2009).

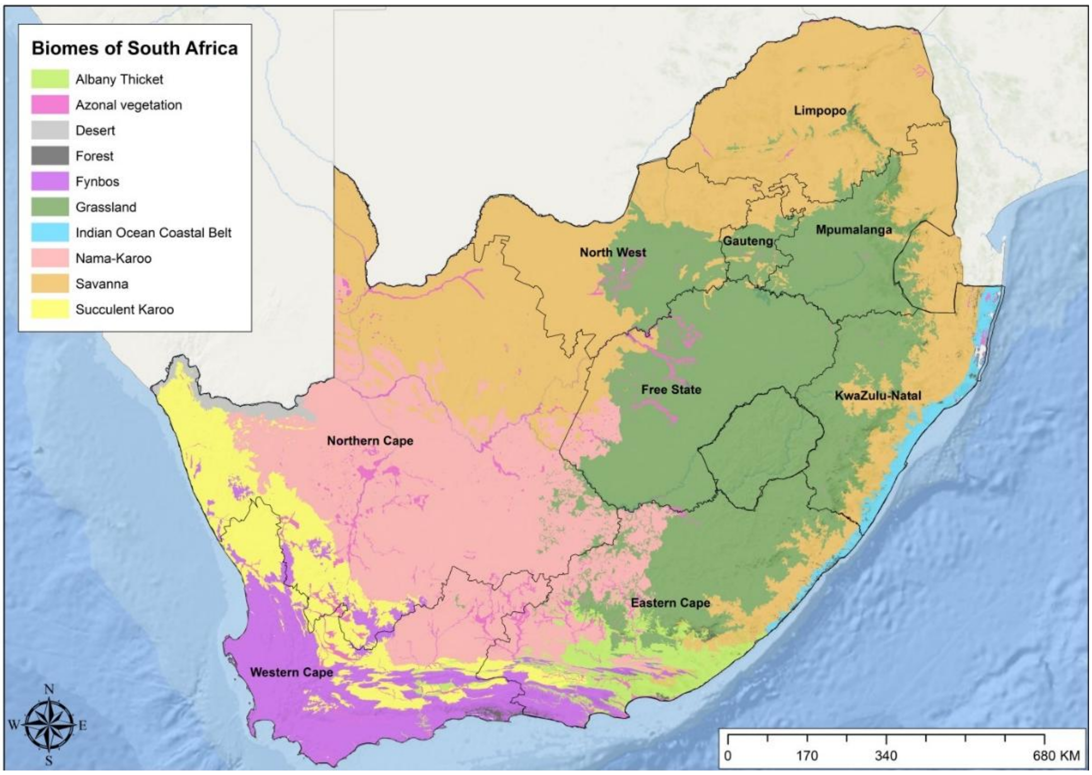

Fig. 2.23. Vegetation and biome map of South Africa, Lesotho and Swaziland (eSwatini) (Mucina *et al*., 2006).

The Convention on Biological Diversity (CBD) estimated that South Africa not only has an endemism rate of 56%, 65% and 70% respectively for amphibians, plants and invertebrates, but that it also hosts 10% of the world’s plant species and 7% of the world’s bird, reptile and mammal species (CBD, 2018). This high level of biodiversity is ascribed to the various differences in climate, geology and topography.

These conditions thus relate to the variety of vegetation biomes in South Africa. Arthropods seem to be positively correlated with plant diversity, thus as the diversity of the vegetation of an area increases so does the diversity of the arthropods (Botha *et al*., 2016, 2018). Distinct arthropod communities have been reported in different biomes in South Africa (i.e. Savanna and Grassland) (Botha *et al*., 2015). This is however not the case for all arthropod taxa. The Fynbos and Succulent Karoo biomes do not have exceptional local ant richness (Braschler *et al*., 2012).

2.7 Threats to Biodiversity in South Africa

Biodiversity can be influenced by a multitude of disturbances, however two of the biggest are considered to be land-cover change or land use change and habitat degradation and loss.

Although all biomes in South Africa have fallen victim to these two biodiversity threats, the KwaZulu-Natal region which hosts several biomes is referred to as example below. KwaZulu-Natal is the province which has the highest mean rainfall in South Africa. This is ascribed to this region being situated adjacent to the warm Agulhas/Mozambique Ocean current. Four different biomes, several centres of endemism, as well as the Maputaland-Pondoland-Albany biodiversity hotspot occurs in this region (Jewitt *et al*., 2015). The biodiversity in this province is threatened by a high human population density (Jewitt *et al*., 2015, Statistics South Africa, 2011).

It was estimated that 7.6% of KwaZulu-Natal natural habitat has been anthropogenically transformed since 2005, indicating a severe threat to the biodiversity of this province. However, land degradation is also prevalent in other areas of South Africa. For example, the dunes of the southern Kalahari became degraded to such an extent that some plant species (graminoids) have become locally extinct (Rutherford and Powrie, 2009). It was estimated that if the current rate at which land use changes (i.e. urbanisation, mining and agriculture) continues, three of the nine provinces (i.e. KwaZulu-Natal, Gauteng and North West) will only have natural landscapes within their protected reserves by 2050 (SANBI, 2013). Forest, Fynbos and Desert biomes, which encompass 35% of protected ecosystems in South Africa are also the best protected biomes in the country (SANBI, 2013). Albany Thicket, Nama-Karoo and Grasslands are the least protected while the Grasslands are considered to be the most threatened biome (SANBI, 2013).

Scholes and Biggs (2005) estimated the Grassland biome to have the highest degradation and land use change rate and that about 74% has been transformed. Within this threatened biome, five centres of endemism exist. These are located in the vicinity of Barberton, Drakensberg Alpine, Lydenburg, Sekhukhune, Soutpansberg and Wolkberg (Schmidt *et al*., 2007). Of the Grassland biome surface area, 10% is categorized as being critically endangered, 12% as endangered and 30% as vulnerable. This indicates a serious need for conservation within this biome, especially with the threats associated with climate change.

Climate change threatens the delicate ecosystems and biomes of South Africa. A prediction by Von Maltitz and Scholes (2006) stated that the Karoo and Savanna biomes will extend into the Grassland and much hotter and drier conditions will prevail at the current rate of climate change. This will most likely result in a high level of species loss, especially those species such as arthropods that are sensitive to temperature changes (Simaika and Samways, 2015). Another prediction for the Grasslands of South Africa estimated that the Grassland biome will only remain at higher altitudes by 2050 (SANBI, 2011).

Studies are required to determine diversity and species richness in threatened biomes of South Africa since climate change could drastically influence and possibly threaten this diversity, and subsequently also the ecology of arthropod species. Knowledge of species developmental biology and distribution is key to mitigating the possible effects that climate change could have on species.

Knowledge of the biology, distribution and behaviour of particularly the smaller groups of arthropods is essential to determine any future effects that climate change and changing land use patterns may have on these species. Kremen *et al.* (1993) indicated that monitoring is key to understanding the way in which climate change alters the environment and different ecosystems. The challenge is however to monitor species such as insects, since they are abundant, their development is influenced by temperature and are quick to respond to a changing environment. However, to monitor changes or disturbances and mitigate the associated effects, a reference point must exist for comparisons to be made (Kremen *et al.*, 1993).

2.8 Mantodea in South Africa

2.8.1 What we know about Mantodea in South Africa

South Africa has approximately 180 different mantid species within the country (Kaltenbach, 1996). The largest families within the Mantodea order in South Africa are Hymenopodidae, Mantidae, Thespidae, Sibyllidae and Empusidae. The Sibyllidae is known as an African family and consists of three genera that contain 16 species (McMonigle, 2013). Despite this, only one species of Sibyllidae has been reported from South Africa (Picker *et al*., 2004). This family resembles the Empusidae, but Wieland (2013) indicated that the resemblance between these two families is superficial since they evolved independently. The Sibyllidae species are mostly found on the bark of trees in tropical regions while Empusidae are grass dwellers (Wieland, 2013) and the Hymenopodidae mimics flowers and have spiral or band markings on their wings (Picker *et al*., 2004).

In 1996 a Mantodea checklist was compiled by Alfred Kaltenbach. The latter publication is a starting point to understanding the diversity of Mantodea in South Africa (Kaltenbach, 1996). However, Kaltenbach only visited the three South African institutions, all situated in Pretoria (Agricultural Research Council, University of Pretoria- Entomology Department and the Transvaal Museum).

The following species of the Tarachodidae and Mantidae family were reported by Kaltenbach to be endemic to South Africa: *Tarachodes lucubrans* Burchell, *Entella natalica* Beier, *Miomantis quadripunctata* Saussure*, Compsothespis cinnabarina* Beier and *Paramantis sacra* Thunberg (Scholtz and Holm, 1985). Kaltenbach (1996) also indicated that there were approximately 90 Mantodea species that could be endemic to southern Africa.

2.8.2 The gap in knowledge regarding Mantodea in South Africa

Despite what is known about the approximately 180 different Mantodea species that are reported to occur in South Africa (Kaltenbach, 1996), large knowledge gaps exist. This was illustrated by results of an internet search on Mantodea in South Africa. According to a Scopus search, 611 scientific articles have been published from 1927 to 2019 on Mantodea in the world, yet only eight of these were done in or referred to South Africa. One study included Mantodea as part of the arthropod surveys conducted in agricultural areas of South Africa (Botha *et al*. 2018). The seven other studies all addressed molecular and genetic aspects and in most of these cases it was mostly Blattodea that were investigated. Other studies throughout the world have investigated various behavioural aspects of mantids such as their cannibalistic mating behaviour and movement which can be used in robotic advances (Arkin *et al*. 2000). However, scientific reports on their biology or distribution are limited throughout the world, and in South Africa, largely absent.

Due to the lack of knowledge regarding Mantodea, it is possible that there could be many more species in South Africa, especially considering that the endemism rate for invertebrates is estimated to be 70% (CBD, 2018). The only surveys of Mantodea in South Africa, were done in 1996 by Kaltenbach (Kaltenbach, 1996, 1998) as well as a limited survey that was done during 2005 which included only three localities (Cape floristic region, Richards bay in Kwa-Zulu Natal and the Kruger National Park in Mpumalanga). The latter survey was done by the Mantodea Project which is in affiliation with the Cleveland Museum of Natural history in Ohio, USA (CMNH, 2015). Currently no research is being done on Mantodea in South Africa and very little is known about the biology or distribution of most of the species.

Mantodea should not only be studied because of their potential to serve as environmental indicators of change but also because they are an important ecological and functional group and could be an important element in conservation planning. By monitoring a group such as this, the changes in their abundance and richness can be used not only to mitigate the threats that they are facing but also contribute towards future conservation planning efforts (Kremen *et al*., 1993). “Although species may appear functionally redundant when one function is considered under one set of environmental conditions, many species are needed to maintain multiple functions at multiple times and places in a changing world” (Isbell *et al.*, 2011).

The dispersal or distribution of an insect species is mostly a response to biological and environmental factors such as temperature, food availability and habitat suitability (Matthews and Matthews, 1978). A common practise is to use visual representation such as maps to indicate the localities at which specimens were observed, and these localities are presumed to fulfil their biotic and abiotic requirements. The patterns observed from these maps can be seen as the likely distribution of a species on a larger scale. According to Chefaoui *et al.* (2005) the potential distribution of *Copris hispanus* L. and *C. lunaris* (Coleoptera: Scarabaeidae) may aid in conservation efforts by identifying possible reintroduction localities and increasing gene flow by establishing corridors or greenbelts that contribute to a species ability to move through the maze of disturbances such as cities or agro-ecosystems.

Large scale surveys could be conducted to address the gap with regards to the lack of distribution and diversity data of Mantodea in South Africa. However, this would be a very expensive and time consuming expedition. Suarez and Tsutsui (2004) indicated that specimen records held in well curated national collections and herbariums are an important tool in conservation as the data residing within the museum records can aid in species distribution patterns, biodiversity patterns, alien species introductions and even provide some ecological insights with regards to a specific species. These records can however be considered as somewhat inconsistent and observationally biased (Ross *et al.*, 2012). Museum records are therefore somewhat consistent in their inconsistency, but they are nonetheless very useful, especially for developing distribution maps based on historic data. Worldwide, museums contain about 2.5 billion animal and plant specimens of which various metadata are available (Krishtalka and Humphrey, 2000).

At the very least, museum records can be considered a large scale starting point to which more data can be added as it is collected. Giberson and Burian (2017) indicated that the study of archived specimens was a cost-effective way to update local biodiversity data such as species lists and distribution maps. Giberson and Burian (2017) re-examined mayfly specimens (Ephemeroptera) which formed part of an environmental assessment project from 1971 to 1973 and found 21 new species records for the locality were data was originally collected. The use of museum data can also be useful in determining a species threat level (McCarthy 1998).

Without knowledge of biology and distribution of species, the effects of climate change, pesticides and agricultural activities on species such as mantids is difficult to monitor and impossible to anticipate and mitigate. The key to understanding the complexities of any ecosystem hinge on the basic biological information of a wide variety of species. Generating data about Mantodea in South Africa should be done as it is critical for future conservation efforts. Lastly, this study will give a glimpse into the biology and distribution of an insect group which has not just fascinated the human race but entertained us so much that myths, legends and superstitions were created in their honour.

2.9 References

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2.11 Appendix 1: Mantodea classification.

Table 1. Classification of the Mantodea with regards to subfamilies and number of genera and species per subfamily.

Family	**Subfamily**	***Genera***	***Species***	***Number of Species per family***
Acanthopidae	-	*7*	*42*	42
Acontistidae	-	*6*	*37*	37
Amorphoscelidae	Amorphoscelinae	5	62	95
	Paraoxypilinae	8	30	
	Perlamantinae	2	3	
Angelidae	-	*7*	*51*	51
Chaeteessidae	Chaeteessinae	6 (5 Extinct)	17 (11 Extinct)	23 (6 Extant)
Coptopterygidae	-	2	24	24
Empusidae	Blepharodinae	2	6	31
	Empusinae	8	25	
Epaphroditidae	-	3	8	8
Eremiaphilidae	Eremiaphilinae	2	68	68
Galinthiadidae	-	4	22	22
Hymenopodidae	Acromantinae	13	87	273
	Hymenopodinae	12	79	
	Oxypilinae	10	72	
	Phyllocraniinae	2	4	
	Phyllothelyinae	2	15	
	Sibyllinae	3	16	
Iridopterygidae	Hapalomantinae	7	39	135
	Iridopteryginae	6	16	
	Nanomantinae	14	32	
	Nilomantinae	5	7	
	Tropidomantinae	13	41	
Liturgusidae	Liturgusinae	20	91	91
Mantidae	Amelinae	27	143	1035
	Angelinae	3	5	
	Antemninae	3	3	
	Choeradodinae	14	74	
	Compsothespinae	1	14	
	Danuriinae	6	24	
	Deroplatyinae	3	17	
	Dystactinae	8	15	
	Heterochaetinae	1	11	
	Mantinae	39	376	
	Mellierinae	2	7	
	Miomantinae	27	177	
	Orthoderinae	2	11	
	Oxyothespinae	8	42	

Mantidae	Schizocephalinae	1	1	1035
	Stagmatopterinae	6	44	
	Stagmomantinae	3	25	
	Vatinae	7	46	
Mantoididae	Mantoidinae	3	13 (1 Extinct)	13 (12 Extant)
Photinaidae	Cardiopterinae	1	6	44
	Macromantinae	1	4	
	Photinainae	8	31	
	Photiomantinae	1	3	
Stenophyllidae	-	1	3	3
Tarachodidae	Caliridinae	6	21	250
	Tarachodinae	24	229	
Thespidae	Haaniinae	2	11	202
	Hoplocoryphinae	3	42	
	Miopteryginae	3	15	
	Oligonicinae	16	67	
	Pseudomiopteriginae	7	27	
	Thespinae	10	40	
Toxoderidae	Toxoderinae	14	61	61

CHAPTER 3: ARTICLE 1

Distribution of *Galepsus* spp. in Southern Africa and Life History of *Galepsus lenticularis* (Mantodea: Tarachodidae)

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Article

Distribution of Galepsus spp. in Southern Africa and Life History of *Galepsus lenticularis* (Mantodea: Tarachodidae)

Bianca Greyvenstein [1,*], Hannalene Du Plessis [1], Nicolas Moulin [2] and Johnnie Van den Berg [1]

[1] Unit for Environmental Sciences and Management, North-West University, Potchefstroom 2520, South Africa; hannalene.duplessis@nwu.ac.za (H.D.P.); johnnie.vandenberg@nwu.ac.za (J.V.d.B.)
[2] Institut Systématique, Evolution, Biodiversité (ISYEB), Muséum national d'Histoire naturelle, 75231 Paris Cedex 05, France; nmentomo@gmail.com
* Correspondence: biagrey90@gmail.com

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Abstract: *Galepsus* Stål is a genus within the Mantodea and has hardly been studied in Africa. The distribution of the *Galepsus* genus in Southern Africa was established, based on insect collection records, and the biology of *Galepsus* (*Lygdamia*) *lenticularis* Saussure, was studied. In Southern Africa, 11 species of *Galepsus* were recorded. The first record of *Galepsus* (*Onychogalepsus*) *centralis* Beier, in South Africa was recorded during this study. The mean number of eggs per ootheca was 49.8 (±21.1) and unfertilized oothecae were significantly shorter and contained fewer eggs than hatched and unhatched oothecae, suggesting that females might invest fewer resources into production of oothecae that will not produce prodigy. No parthenogenesis was observed during this study. Although the mean duration of the male and female nymphal stages were similar, longevity of adult females (91.2 ± 35.0 days) was three times longer than that of males (26.3 ± 15.4 days). This phenomenon as well as the long period (20 ± 14.1 days) between oviposition of different oothecae, and duration of the incubation period (20.25 ± 6.3 days) suggests a survival strategy to reduce competition between siblings. Total longevity of males (166.9 ± 38.8) and females (252.9 ± 54.2) differed significantly. This study provides information on the distribution of *Galepsus* spp. in Southern Africa and describes the biology of *G. lenticularis* under captive breeding conditions, and contributes to the understanding of various biological aspects of *G. lenticularis* which has never been studied before.

Keywords: biology; competition; distribution; mantis; resources

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1. Introduction

The Mantodea is a small arthropod order and, because they are thermophilic, their distribution linked largely to tropic and subtropical regions. Mantid distribution is limited to tropical and subtropical regions between the 45–46 degree latitudes [1]. It is estimated that there are approximately 2600 mantid species globally [2–6]. The Mantidae, with approximately 1000 species, is the largest of the 21 families in the Mantodea [6–9]. The Tarachodidae family has 253 species and is well presented in Southern Africa [5,6,10,11].

South Africa is poorly represented with regard to knowledge of the distribution and species richness of the Mantodea [11]. Africa is one of the continents with the greatest number of Mantodea species, thus South Africa could have a significant number of species [5,12]. However, only approximately 197 species of mantids in 11 families have been recorded in South Africa [11], slightly more than the 180 mantid species reported earlier [10]. The only surveys of Mantodea in South Africa were done by Kaltenbach from 1996 to 1998 [10,13] and a survey in 2005 in three areas (Cape floristic region, Richards

Bay in the Kwa-Zulu Natal province and the Kruger National Park in the Mpumalanga province). The latter survey was done by the Mantodea Project which is an affiliation of the Cleveland Museum of Natural History in Ohio, USA [14]. Due to the lack of knowledge regarding Mantodea, it is possible that there could be significantly more species, especially considering that South Africa's endemism rate for invertebrates is estimated at 70% [15]. Scientific reports on Mantodea biology and distribution are limited throughout the world, and in South Africa, largely absent.

Galepsus is a genus in the Tarachodidae family and there are four subgenera and 67 valid species within this genus [6], some of which have only recently been described, i.e., *G.* (*Syngalepsus*) *dudleyi* Moulin 2018 and *G.* (*Syngalepsus*) *bucheti* Moulin 2018 [16]. *Galepsus* is one of the genera that require global revision, especially those from under-collected regions such as Sub-Saharan Africa [17]. The distribution of *Galepsus* is estimated to be mostly in Sub-Saharan Africa, Fiji and the island of the Comoros [5].

Galepsus spp. seem to be common in the grassland biome of South Africa. A total of 202 *Galepsus* individuals were recorded in one short term biodiversity survey (32,400 m^2) which was done in agricultural rangeland and crop fields in the Highveld Grassland Biome in South Africa [18], while another study recorded 72 *Galepsus* individuals in the same region (2400 m^2) [19]. *Galepsus* spp. was also commonly collected in a study of arthropod diversity in ruderal green space within urban areas in the Grassland biome of South Africa [18]. However, few studies mention *Galepsus* (*Lygdamia*) *lenticularis* Saussure 1872. However, it the distribution of the species was reported to be throughout Southern Africa [5], while [10] listed only 10 distribution records of this species in the region. The lack of knowledge and need for research on *G. lenticularis* was also highlighted on a taxonomic website dedicated to this group, i.e., Mantodea Species file [6]. Basic biological and distribution information regarding *Galepsus* spp. in general and *G. lenticularis* in particular would contribute to information on this arthropod group and species in the Grassland and Savanna biome of Southern Africa. The aim of this study was to compile distribution maps of *Galepsus* spp. in Southern Africa and to study the biology *G. lenticularis*.

2. Materials and Methods

2.1. Species Distribution Database

Distribution records of *Galepsus* spp. were collected during visits to the following institutions that host insect collections in South Africa: Ditsong Museum of Natural History (Pretoria), Agricultural Research Council (Biosystematics Division in Pretoria), National Museum (Bloemfontein), Albany Museum (Grahamstown), Rhodes University (Grahamstown), Durban Natural Science Museum, Iziko South African Museum (Cape Town), and KwaZulu-Natal Museum (Pietermaritzburg). Most specimens in these collections where previously identified by visiting taxonomists while many were sent for identification to the Vienna Museum in Germany, the University of Drexel in Philadelphia, USA, the Muséum national d'Histoire naturelle (MNHN) in Paris, France and the research collection of Nicolas Moulin in Montérolier, France. Southern Africa in the context of this paper includes the following countries: Angola, Botswana Lesotho, Mozambique, Namibia, South Africa, Eswatini, Zimbabwe, and Zambia. This is due to the lack of specimen records from other African countries in the museum collections in South Africa, other African countries were not included. *Galepsus* specimens and distribution labels where photographed (Canon EOS D1300, Canon, Tokyo, Japan), digitized and a database was compiled. This database contains the following information for each specimen record: Genus and species name (to the available level of identification), collector's details and collection date where available, and the geo-referenced locality. A website (http://Mantodea.speciesfile.org) and literature were used to determine the current nomenclature within the genus. All locality data was georeferenced using the principles suggested [20] and all coordinates were converted from degrees, minutes, and seconds (DMS) to decimal degrees (DD) with the use of the website (gps-coordinates.net).

DD were used for developing the distribution maps for *Galepsus* species in Southern Africa by means of GIS software (ArcMaps, Version 10.6.1).

2.2. *Rearing and Biology of Galepsus Lenticularis*

Individuals were collected in the Grassland biome in the North-West and Free State provinces of South Africa during the summer of 2016/2017. These field-collected individuals were in the adult phase and were allowed to mate and lay eggs in order to get sufficient numbers of individuals to use for the captive breeding and biological studies. A sub-sample of the field-collected specimens was identified by Nicolas Moulin, honorary associate to MNHN.

For breeding purposes, pairs of male and females were placed in glass containers. One-liter glass containers were used to ensure that ample space was available for the male to increase the chances of a successful escape after mating. To further limit the likelihood that females would cannibalize the males during or after mating, ample food was provided before the male was introduced into the breeding container. After copulation concluded, the male was removed from the breeding container.

The terrarium (15 cm × 10 cm × 20 cm) in which females were kept after mating were checked daily for the presence of oothecae that was laid overnight. Oothecae were removed and put into small (5 cm diameter and 5 cm high) containers inside a desiccator with potassium hydroxide (KOH) to ensure a humidity level of 68% ± 5% within the closed desiccator [21]. The desiccator was kept in an insect rearing room at a temperature of 27 ± 1 °C until nymphs emerged from the oothecae.

Rearing of emerged nymphs was done under controlled conditions. Each specimen was placed in a plastic honey jar (7 cm diameter and 15 cm high) with three holes (each 2 cm in diameter) covered with gauze to allow air flow, hereafter referred to as terrariums. Thin branches (5 mm × 10 cm) were placed inside each jar for climbing and hanging purposes, especially during molts. Food was provided every second day and a fine water mist was sprayed into each container. Live aphids (10) (*Brevicoryne* spp.) (Hemiptera: Aphididae) were used to feed the first and second instars of *Galepsus* while live crickets (2) (*Acheta* sp. Orthoptera: Gryllidae) of different sizes (nymphal instars, i.e., pinheads) were used to feed the nymphs from the 3rd instar onwards. Instances where previous food was not consumed, no additional food was added to prevent over feeding. After molting to the second instar, nymphs were removed from the communal terrarium and placed in separate terrariums to prevent cannibalism. Nymphs were reared until adulthood after which males and females were identified. Observations continued until all individuals died.

After the final molt, each individual was sexed. This was by means of counting the number of abdominal segments and the presence of wings. *Galepsus lenticularis* females have only reduced wing buds and six abdominal segments while males have eight segments and fully developed wings [7,22,23] (Figure 1a,b).

The following life history parameters were recorded during this study: Size of oothecae, number of egg chambers inside hatched and unhatched oothecae, numbers of days between molts and survival rate to the adult phase. The mean number of days between molts and days to adulthood were calculated separately for males and females. The data recorded and discussed in this paper were recorded for 48 individuals (30 males and 18 females) that completed their life cycles. The mean duration of male and female life cycles was calculated and fertility, hatching, and survival rate determined. A distinction was also made between different types of oothecae, i.e., hatched and unfertilized (field collected as well as from laboratory reared females), and unhatched (field-collected batches laid by females of which the mating status was not known).

The length, width, and height of each ootheca were recorded, based on descriptions (Figure 1c) [23]. The length of the ootheca was measured from the first egg chamber to the last egg chamber and did not include the residual process [23].

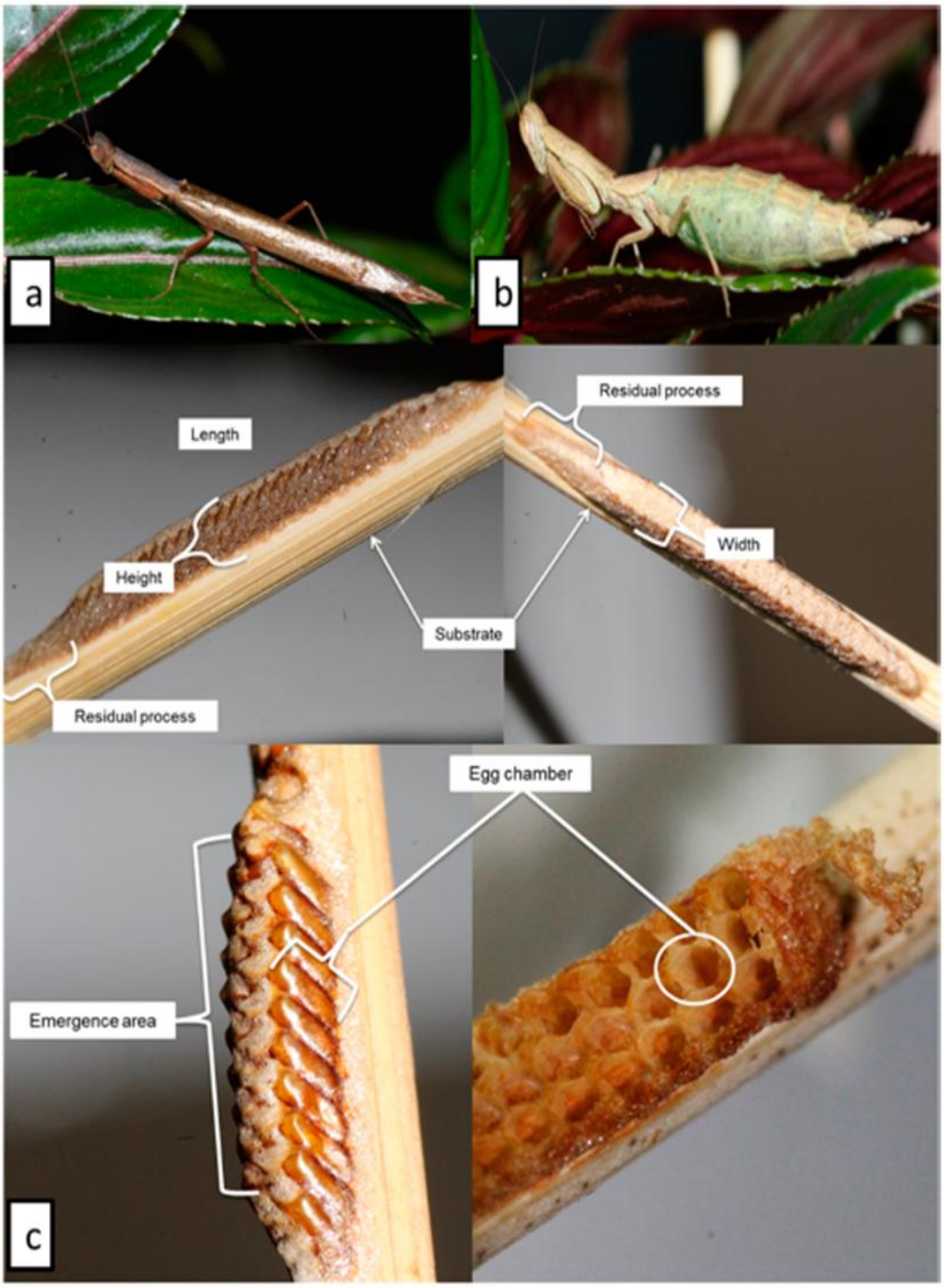


Figure 1. *Galepsus lenticularis* male (**a**) and female (**b**), and general morphology (**c**) of the oothecae, indicating different parameters and areas of interest as suggested by Brannoch [23].

2.3. Data Analysis

The descriptive statistics (Means and Standard Error) and the statistical analyses and of the developmental parameters of *G. lenticularis* were done using Statistica Version 13.3 [24]. Analyses of Variance (ANOVA) were used to determine if differences existed between the size (length, width, and height) and the number of egg chambers contained by each of the three types of oothecae (i.e., hatched, unfertilized, and unhatched). The mean numbers of days between molts, adult longevity and mean number of days to reach adulthood were also analyzed by means of ANOVAs and compared between the sexes. All significant differences were further analyzed using a post hoc Tukey honest significant difference (HSD) test.

3. Results

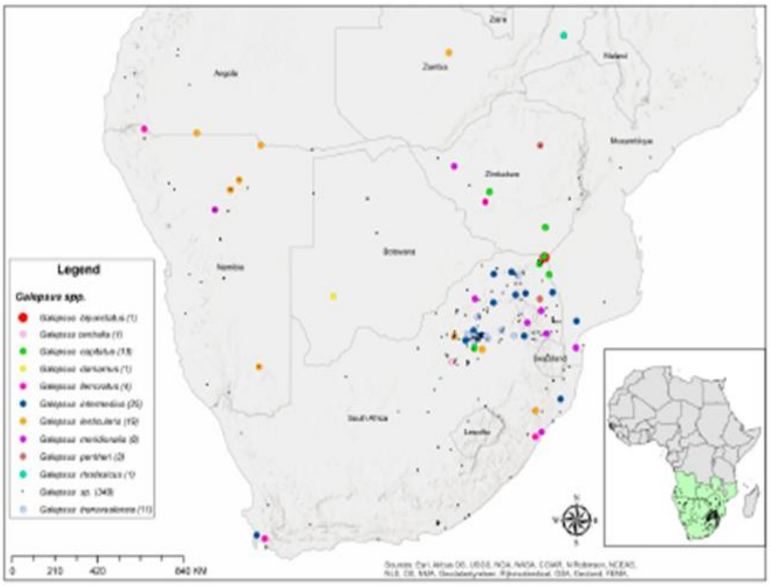
3.1. Distribution of *Galepsus*

Distribution records reported in this paper were compiled from records that are available in seven South African institutions that host curated arthropod collections and were identified by a taxonomist with expertise in Afro-tropical Mantodea and are based in Europe (3rd author of this paper). The results presented in this paper should be viewed in this context, since no specimen records were included beyond those residing in South Africa.

A total of 435 specimens of *Galepsus* spp. collected between 1897 and 2016 were recorded in museum collections in South Africa. Most records (71 of 81 specimens) originating from beyond the borders of South Africa (93.7%) were collected between 1897 and 1974, with the majority (50.6%) of records (36 specimens) being collected between 1963 and 1973. Only 20% (89 specimens) of all specimens in South African museums were identified to species level (Table 1). The distribution records also included several other Southern African countries: Angola, Botswana, Eswatini, Lesotho, Mozambique, Namibia, Zambia, and Zimbabwe (Figure 2).

Table 1. The eleven recorded *Galepsus* species throughout Southern Africa and their associated taxonomic nomenclature.

Family	Subgenus	Species
Tarachodidae	*Syngalepsus* Beier, 1954	*Galepsus bipunctatus* Beier, 1931
Tarachodidae	*Onychogalepsus* Beier, 1954	*Galepsus capitatus* Saussure, 1869
Tarachodidae	*Onychogalepsus* Beier, 1954	*Galepsus centralis* Beier,1957
Tarachodidae	*Onychogalepsus* Beier, 1954	*Galepsus damaranus* Giglio-Tos, 1911
Tarachodidae	*Onychogalepsus* Beier, 1954	*Galepsus femoratus* Giglio-Tos, 1911
Tarachodidae	*Onychogalepsus* Beier, 1954	*Galepsus intermedius* Werner, 1907
Tarachodidae	*Lygdamia* Stäl, 1877	*Galepsus lenticularis* Saussure, 1872
Tarachodidae	*Onychogalepsus* Beier, 1954	*Galepsus meridionalis* Saussure, 1872
Tarachodidae	*Onychogalepsus* Beier, 1954	*Galepsus pentheri* Giglio-Tos, 1911
Tarachodidae	*Onychogalepsus* Beier, 1954	*Galepsus rhodesicus* Beier, 1954
Tarachodidae	*Onychogalepsus* Beier, 1954	*Galepsus transvaalensis* Beier, 1954



Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA,

Figure 2. Distribution records of the eleven *Galepsus* species that occur in Southern Africa. Numbers in brackets indicate the number of individual records per species of *Galepsus*. The smaller map of Africa indicates the geographic region defined as Southern Africa in the context of this paper.

The sites at which *Galepsus* species were collected are scattered throughout South Africa and the neighbouring countries which cumulatively constitute Southern Africa (Figure 2). Eight of the ten *Galepsus* spp. was only collected in South Africa. Only a single specimen each of *Galepsus* (*Onychogalepsus*) *damaranus* Giglio-Tos, 1911 and *G.* (*Onychogalepsus*) *rhodesicus* Beier, 1954, from Botswana and Zambia respectively, exists for these two species (Table 2). A single record of an unidentified *Galepsus* sp. was recorded in Lesotho as well as in Eswatini.

Table 2. Comparison of the number of specimen records for each *Galepsus* species and thus its distribution throughout Southern Africa as recorded throughout the museums of South Africa. It should be noted that 285 specimens that were recorded in the museum collections of South Africa were undefined (labelled as 165 G. sp.).

	Countries in Southern Africa								
Species	**Angola**	**Botswana**	**Lesotho**	**Mozambique**	**Namibia**	**South Africa**	**Eswatini**	**Zimbabwe**	**Zambia**
Galepsus sp.	12	5	1	6	25	285	1	14	-
G. bipunctatus	-	-	-	-	-	1	-	-	-
G. capitatus	-	-	-	-	-	9	-	4	-
G. centralis						1			
G. damarnus	-	1	-	-	-	-	-	-	-
G. femoratus	-	-	-	-	1	2	-	1	-
G. intermedius	-	-	-	1	-	24	-	-	1
G. lenticularis	1	-	-	1	5	10	-	1	-
G. meridionalis	-	-	-	1	1	5	-	1	-
G. pentheri	-	-	-	-	-	2	-	1	-
G. rhodesicus	-	-	-	-	-	-	-	-	1
G. transvaalensis	-	-	-	-	-	11	-	-	-

The oldest collection records of *Galepsus* spp. in Southern Africa dates back to 1897. These specimens are held at the Iziko South African Museum in Cape Town. One specimen was identified as *G.* (*Onychogalepsus*) *femoratus* Giglio-Tos 1911 while the other is yet to be identified to species level. Information on the date of collection of 386 of the available records indicated that most of the *Galepsus* specimens were collected between 1993 and 2004. This number constitutes 20% of the total number of records of this genus in Southern Africa over the past 120 years.

Galepsus (*Onychogalepsus*) *femoratus* Giglio-Tos 1911 and *G.* (*Onychogalepsus*) *intermedius* Werner 1907 were each recorded in three countries, including South Africa, despite *G. intermedius* being the most abundant species with 25 distribution records (Table 2). While *G. lenticularis* however was not the most abundant in the museum collections, it was the most prevalent since it was recorded from Angola, Mozambique, Namibia South Africa, and Zimbabwe. South Africa is thus the only country in Southern Africa where all three *Galepsus* subgenera have been recorded (Table 2).

Galepsus (*Onychogalepsus*) *transvaalensis* Beier 1954 and *G.* (*Syngalepsus*) *bipunctatus* Beier 1931 were recorded only within South Africa's borders, with 11 records of *G. transvaalensis* from the Gauteng province and a single record of *G. bipunctatus* at Pafuri in the Kruger National Park, close to the border of South Africa and Zimbabwe (Figure 2). All recorded species of *Galepsus* belong to the subgenus *Onychogalepsus* except for *G. bipunctatus* which is the only representative of the subgenus *Syngalepsus* and *G. lenticularis* which is the only representative of the subgenus *Lygdamia*. *Galepsus* (*Onychogalepsus*) *capitatus* Saussure 1869 and *G.* (*Onychogalepsus*) *pentheri* Giglio-Tos 1911 were recorded only in South Africa (two records) and Zimbabwe (one record).

During collections of specimens (2016–2018) for the breeding and biology of G. *lenticularis*, one record of *G. centralis* Beier, 1957 in the subgenus *Onychogalepsus* was collected in Potchefstroom in the North West province of South Africa. It should be noted that this is the only record of *G.* (*Onychogalepsus*) *centralis* Beier 1957 in South Africa (Table 1 and Figure 2).

Most of the *Galepsus* specimens were collected outside of the various different protected areas in South Africa (Figure 3). A total of 267 (76%) of the specimens were collected outside protected areas while Provincial nature reserves and National parks respectively contributed 36 (44%) and 31 (38%) specimen records. The distribution based on records of *Galepsus lenticularis* is depicted in Figure 4.

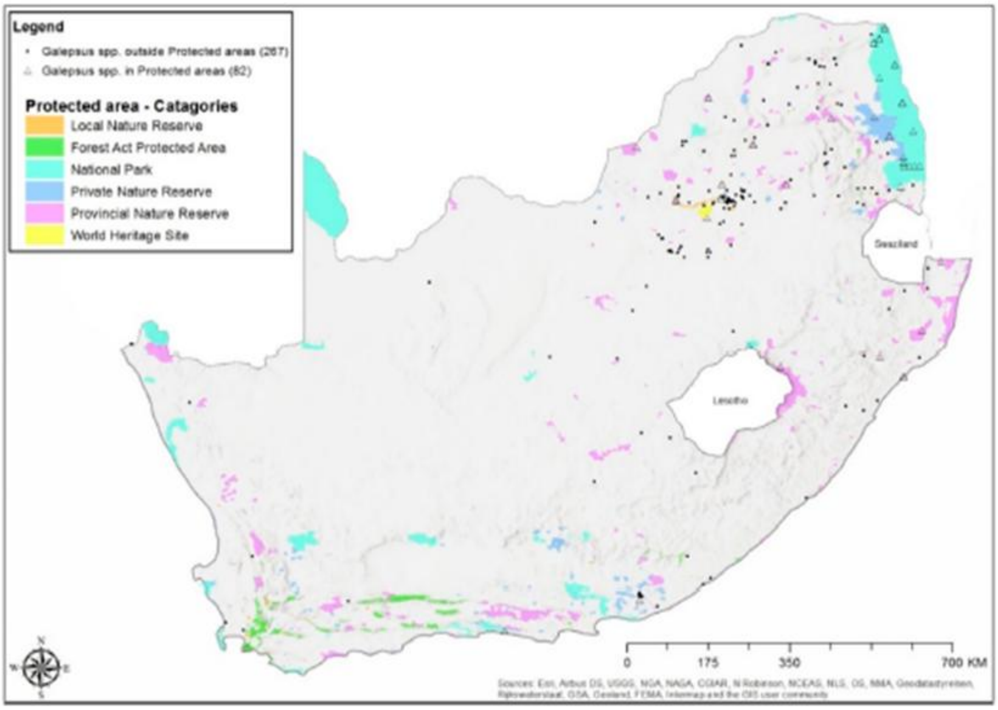


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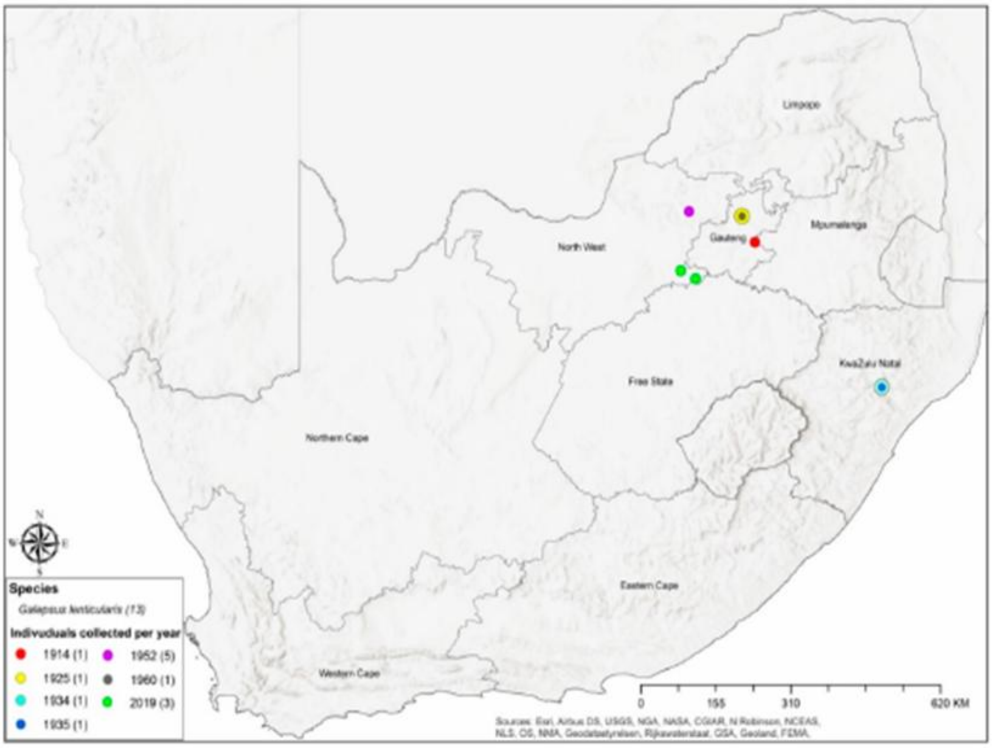
Figure 3. Distribution records of unidentified *Galepsus* spp. collected in protected and non-protected areas of South Africa.



Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA,

Figure 4. Distribution of *Galepsus lenticularis* based on current and historic records. The sizes of points on the map differs to enable distinguishing of overlapping points.

3.2. *Biology of Galepsus lenticularis*

The oothecae of G. *lenticularis* collected in the field were usually attached to flat substrates such as long stemmed grasses or sticks. The oothecae are not oval or covered with the usual foamy sheath as with several other species in the Mantidae family, i.e., *Stagmatoptera supplicaria* Burmeister 1838, as depicted by [23]. *Galepsus lenticularis* oothecae are oblong in form, dorsally flattened and usually light to dark brown in color. Hatched oothecae can be identified by the presence of white eclosion sack-like structures present on the greyish dorsally-flattened area of emergence. Measurements of ootheca parameters were done as indicated in Figure 1c. The ootheca length was measured as the area of emergence and did not include the residual process. To determine the number of eggs per ootheca, oothecae were dorsally dissected along the length and inspected under a microscope. The residual process was also dissected but did not contain any egg chambers. Eggs were arranged in oblong rows of between 2 and 3 eggs each, arranged next to each other (Figure 1c).

A total 42 oothecae were produced by the 18 captive reared and 9 field collected *G. lenticularis* females. Nine of these 42 oothecae were fertilized and hatched and were produced by the 9 field-collected females that were bred with field collected males under captive breeding conditions. The field-collected females produced 19 oothecae which never hatched (unhatched). Fourteen unfertilized oothecae were laid by 18 unmated females in the terrariums and thus no nymphs emerged from these unfertilized oothecae. No breeding with the captive-reared females were done because the possibility of parthenogenesis was also investigated, which has been recorded in other mantid species, i.e., *Coptopteryx viridis* Giglio-Tos 1915 (Coptopterygidea) [25], *Miomantis paykulli* Stäl 1871 [26], and in the Springbok mantis, *Miomantis caffra* Saussure, 1871 (Mantidae) [27]. Only nine of the 18 unmated captive-reared females produced oothecae during their lifecycle. Five of these females each laid two unfertilized oothecae. The pre-oviposition period in the case of unfertilized ootheca was 53 days (mean female age of 214 days). The period between laying of the two unfertilized oothecae was 20 days (mean female age of 235 days). The longest that a female lived after laying a final unfertilized ootheca was 50 days (mean female age of 285 days).

The length of the oothecae ranged between 18.9 and 30.0 mm (Figure 1c). The numbers of eggs per ootheca varied between the different types of oothecae. Unfertilized oothecae contained a mean of 36.6 eggs while the hatched and unhatched oothecae contained 50.2 and 59.2 eggs per ootheca, respectively (Table 3).

Table 3. Mean size and number of internal egg chambers of the various types of oothecae of *Galepsus lenticularis* reared under captive breeding conditions. SD = Standard deviation.

Oothecae (42)	Length (cm) ± SD	Width (cm) ± SD	Height (cm) ± SD	Number of eggs ± SD
Overall (42)	2.47 ± 0.76	0.24 ± 0.059	0.31 ± 0.070	49.79 ± 21.12
Unfertilized (14)	1.89 ± 0.44	0.26 ± 0.063	0.30 ± 0.068	36.64 ± 15.35
Unhatched (19)	2.63 ± 0.76	0.22 ± 0.053	0.30 ± 0.074	59.26 ± 22.52
Hatched (9)	3.00 ± 0.61	0.25 ± 0.050	0.30 ± 0.070	50.20 ± 15.74

No abnormalities or noticeable morphological differences were observed between hatched, unhatched and unfertilized oothecae (Table 3). Unfertilized oothecae were significantly ($p = 0.0033$) shorter (11.10 mm) than those that hatched ($p = 0.0005$) and 7.40 mm shorter than the unhatched ($p = 0.0059$) oothecae. The number of eggs per ootheca was significantly ($p = 0.0068$) higher in unfertilized than unhatched field-collected ootheca ($p = 0.0048$). Despite the significant differences in length between the three oothecae types, no statistical difference in the width or height were recorded (Table 4).

Table 4. Analysis of variance (ANOVA) and associated post hoc Tukey p-values between the three types of ootheca and the various morphological parameters.

Statistical Test	Oothecae	Length	Width	Height	Number of Eggs
ANOVA	Overall	0.0033 *	0.0503	0.8390	0.0068 *
Post Hoc (HSD Tukey)	Unfertilized × Unhatched	0.0059 *	0.0477 *	0.8608	0.0048 *
	Unhatched × Hatched	0.2753	0.2979	0.8926	0.4765
	Hatched × Unfertilized	0.0005 *	0.8227	1.000	0.2304

Significant p-value < 0.05, indicated by *.

3.3. *Developmental Parameters*

The mean overall hatch rate was 40.3%. Of the 192 neonate nymphs that hatched, 76 reached the 2nd instar and 48 (63%) of these completed their entire lifecycle. Eleven (40.0%) of the individuals that hatched reached adulthood (Table 5). The mean duration from hatch to adulthood was 21 weeks (148 days) (Table 5). While nymphs mostly became adults after seven molts some exceptions were recorded. Six individuals required ten molts to reach adulthood (three males and three females) and is therefore included in Table 5. One male became an adult after only four molts.

Table 5. Mean duration (in days) of each of the respective life stages of *Galepsus lenticularis* and differences between male and female development under laboratory conditions.

Life Stage	Mean Duration (days ± SD) Overall	Males	Females	p-Value
Ootheca (incubation period)	20.25 ± 6.3	19.16 ± 4.94	22.06 ± 7.91	0.125
1st Instar	14.39 ± 3.91	14.80 ± 4.60	13.72 ± 2.32	0.361
2nd Instar	15.77 ± 10.57	15.70 ± 11.60	15.88 ± 8.91	0.953
3rd Instar	18.38 ± 11.04	20.33 ± 13.03	15.11 ± 5.43	0.114
4th Instar	23.22 ± 15.05	21.70 ± 13.10	25.77 ± 17.95	0.369
5th Instar	27.97 ± 21.78	24.13 ± 13.10	34.16 ± 29.81	0.126
6th Instar	26.02 ± 12.46	25.03 ± 12.95	27.58 ± 11.85	0.515
7th Instar	23.78 ± 15.95	23.42 ± 16.03	24.30 ± 16.46	0.880
8th Instar	19.22 ± 6.66	17.81 ± 5.25	21.42 ± 8.40	0.275
9th Instar	22.16 ± 13.34	14.33 ± 10.69	30.00± 12.12	0.169
Total nymphal period *	148.85 ± 40.44	141.20 ± 36.06	161.61 ± 45.03	0.091
Adult longevity **	50.66 ± 40.02	26.30 ± 15.44	91.27 ± 35.03	0.000*
Pre-oviposition period	53.00 ± 26.50	N/A	53.00 ± 26.50	N/A
Interval between oothecae	20.00 ± 14.10	N/A	20.00 ± 14.10	N/A
Period from hatch to death	199.16 ± 61.31	166.93 ± 38.79	252.88 ± 54.20	0.000*

* From ootheca hatch to final molt (1st Instar – 8th/9th instar). ** Duration of adult phase.

Although no statistical differences were found between the male and female development times or the duration of an instar per sex, a difference ($p = 0.00001$) was recorded between adult longevity of females and males (Table 5). The mean longevity (first instar to death) of females was 253 days while male longevity was 167 days and females and males lived for 93 and 26 days respectively after reaching adulthood (Table 5). The mean duration per instar was largely similar for males and females (Table 5).

The sex ratios of nymphs differed between individual oothecae but were predominantly male biased. Overall, 57% of the nymphs that survived to adulthood were males and 43% were females (Table 6). However, of the 48 individuals that reached adulthood, 18 (37.5%) were female and 30 (62.5%) males.

Table 6. The mean hatch rate, survival rate and gender dynamics throughout the study that resulted from each individual field-collected female kept in the laboratory and each produced a single fertile ootheca.

Ootheca No.	No. of Days from Oviposition to Nymph Emergence	No. of Eggs per ootheca	Fertility (%)	Survival (%)	Male(%)	Female (%)	Sex Ratio (♂:♀)
Ootheca 1	41	76	67.11	05.88	33.33	66.67	1:2
Ootheca 2	11	34	08.82	33.33	100.0	00.00	1:0
Ootheca 3	17	66	13.64	11.11	00.00	100.0	0:1
Ootheca 4	16	49	32.65	18.75	66.67	33.33	2:1
Ootheca 5	18	45	68.89	80.65	68.00	32.00	2:1
Ootheca 6	20	64	54.69	08.57	33.33	66.67	2:1
Ootheca 7	21	49	30.61	06.67	100.0	00.00	1:0
Ootheca 8	19	41	60.98	32.00	75.00	25.00	3:1
Ootheca 9	14	28	25.00	42.86	33.33	66.67	1:2
Mean ± (SD)	19.7 ± 8.6	50.2 ± 15.7	40.3 ± 23.1	25.6 ± 24.3	56.6 ± 33.9	43.4 ± 33.9	1.6:1

4. Discussion

4.1. Distribution Patterns of Galepsus spp. in Southern Africa

The distribution records of Mantodea in general are widely dispersed with various records also in the MNHN (France), United States National Museum, The Natural History museum (London) and various German institutes [28–31]. The lack of taxonomic expertise concerning Mantodea which exists within Africa requires that specimens collected in the region be identified by experts outside the continent.

Only six records of male *Galepsus* specimens were collected in Africa [31], one record of *G. capitatus* and five of *G.* (*Onychogalepsus*) *meridionalis* (Saussure, 1872) var. *montana* males from Kenya. These two species as well as the eight other species were recorded throughout South Africa [10,13]. However, four *Galepsus* species, i.e., *G.* (*Onychogalepsus*) *focki* Werner 1923, *G.* (*Lygdamia*) *brincki* Beier 1955, *G.* (*Onychogalepsus*) *ulricae* Kaltenbach 1996, and *G.* (*Onychogalepsus*) *letabaensis* Kaltenbach 1996, were listed to occur in Southern Africa [10,13]; however, no records of these species were found in any of the insect collections visited during this study. No specimen records of *G. centralis* occurs in the collections in South Africa, which includes the list compiled by Kaltenbach [10]. However, only two specimens of *G. centralis* were previously collected, one in Tanzania and another in the Democratic Republic of the Congo [2,5]. These two records were also those used for the original species description of *G. centralis* by Beier in 1957 [32].

It should be noted however that no consistency with regards to sampling methods exist for museum records. The distribution map (Figure 2) indicates that the distribution of *Galepsus* in Southern Africa is associated with the grassland and savanna biomes. This could explain the lack of records from the Cape Floristic region which is one of the most biological diverse areas in South Africa [33,34].

The subgenus *Onychogalepsus* seems to occur predominantly in grassland and savannah in South Africa while the *Lygdamia* subgenus seems to be widely distributed throughout Southern Africa (Table 1 and Figure 2).

Interestingly, the single record of *G. bipunctatus* and only representative of the subgenus *Syngalepsus* was collected at Pafuri, in the Limpopo province of South Africa. It was noted that the only specimen (*G. bucheti*) collected during their expedition in Central African Republic which belongs to the subgenus *Syngalepsus* was collected by means of a light trap on the banks of the Sangha river with "Arboreal stratum" [16]. The habitat depicted by means of photographs in Moulin [16] is similar to that of Pafuri with a similarly large river (Limpopo River) and tree-dominated vegetation. This could be an indication of the habitat preferred by the subgenus *Syngalepsus*. Further investigation is required to shed light on the habitat of this species.

Galepsus records in South Africa indicated that more specimens where collected outside of protected areas. This may suggest that *Galepsus* exists in areas that are subject to disturbances, which could indicate that *Galepsus* is either a common species, or that it is highly adaptable. Protected areas are ideal study sites to generate baseline biodiversity data since they are often rich in biodiversity and are important for a wide range of species, due to these areas being viewed as "natural and pristine" without major disturbances [35–39]. A possible explanation for the collection bias is the higher population density and collection activities associated with these areas. The higher numbers of records outside of protected areas is most likely due to the ease of collecting in these areas, compared to in protected areas, especially for amateur collectors. The red tape associated with acquiring of permits for collection in protected areas makes the practice of collecting of specimens by citizen-scientists virtually impossible.

Old records or museum data can contribute to establishing baseline data regarding biodiversity within a region [40]. Historical data are also a source of distribution records and potential biodiversity and ecological information [41]. Battiston et al. [28] indicated that old records and descriptions were important with regards to the ecology of mantids in the Mediterranean area, and since little was known about mantids in this region, old records were used in highlighting conservation issues for Moroccan mantids. For example, mantid specimens in museum collections in Morocco was collected 78 years prior to the investigation [28], and when the locality description information of *Tenodera rungsi* Uvarov 1935 was revisited in 2011, a population of *T. rungsi* was still present at the described locality [28]. The occurrences and distribution of the genus *Galepsus* in this study is based on museum collection records and is another example of the validity and importance of museum collection records.

4.2. *Biology of Galepsus Lenticularis*

There is a lack of literature about not only the biology of *Galepsus* spp., but the entire Tarachodidae family. A study by Ene [42] on *Tarachodes (Barbachodes) afzelii* Stäl 1871, which occurs in west Africa, is the only other study with which the data of this study on the biology of *G. lenticularis* can be compared to. The recent rearrangement of the systematics of the entire Mantodea order [9] also now places *Galepsus* and *Tarachodes* in the same subfamily (Tarachodinae), thus validating comparisons to results obtained by Ene [42]. The oothecae of this other species in the Tarachodidae family, *T. afzelii*, is constructed in a simplistic and unordinary manner, which differs from the majority of Mantodea oothecae [42]. The latter description of the oothecae is quite similar to that of *G. lenticularis*. The construction of more "primitive" oothecae by *G. lenticularis* and *T. afzelii* closely resembles that of Blattodea oothecae [42,43]. This is in accordance with the phylogenetic position of *Galepsus* [44]. It was suggested that the lack of the characteristic protective air-filled and foamy sheath coating of the oothecae might be the reason that females of *T. afzelii* exhibit a degree of parental care and guard oothecae during the incubation period and up to 48 hours after nymphs hatched [42]. However, no such behaviour was noted during this study on *G. lenticularis*.

The size of the oothecae of *Galepsus* and *Tarachodes* was similar (24.7 mm in length for *G. lenticularis* and 30.0 mm for *T. afzelii*). However, the mean number of eggs per ootheca was 50 and 129 for *G. lenticularis* and *T. afzelii* respectively. Despite this difference in number of eggs per oothecae, it was indicated that field-collected oothecae and oothecae obtained from laboratory studies of *Orthodera ministralis* Fabricius 1775 (Mantodea: Mantidae) did not differ significantly in structure [45].

Various aspects such as temperature, food, water limitations and rainfall have been shown to influence ootheca structure [42,45–47]. However, the difference observed in *G. lenticularis* oothecae (unhatched and hatched and unfertilized) with regard to the number of eggs and length of the oothecae could indicate that these females would rather conserve valuable resources, instead of producing unfertilized oothecae which do not produce offspring. In contrast to this, a recent study [48] indicated that the length of the ootheca of a cockroach species (*Periplaneta americana*) Linnaeus 1758 (Blattodea: Blattidae), was not influenced by the fertility of the oothecae. Although *P. americana* can also reproduce through parthenogenesis, it is highly likely that females would not invest valuable resources into formation of oothecae if it produces no genetically diverse offspring. No parthenogenesis was recorded for *G. lenticularis* in this study, despite it being recorded for some other mantid species [26,49,50].

The mean incubation period of *G. lenticularis* oothecae was 20 days (Table 5). Similar incubation periods were recorded for *T. afzelii*, with incubation periods ranging between 18 and 21 days under field conditions and 25 days under laboratory conditions [42]. The duration of the incubation period of eggs of *Tenodera aridifolia aridifolia* Stoll 1813 (Mantodea: Mantidae) was between 14 and 21 days at 30 °C [51]. Higher temperatures have been indicted to result in shorter incubation periods [42,45]. Recently, it was documented that the incubation period of *Ephestiasula rogenhoferi rogenhoferi* Saussure 1872 (Hymenopodidae) (previously known as *Ephestiasula pictipes* Wood-Mason 1879) is between 15.2 and 16.9 days during various seasons i.e., late winter–summer, monsoon and post monsoon–early winter (2013–2014) [52]. The interval between laying of the two unfertilized oothecae by *G. lenticularis* were laid at an interval of was 20 days, while this interval was 36 days for *T. afzelii* [42].

4.3. Developmental Parameters

No significant differences ($p = 0.09$) (Tables 5 and 6) in male and female nymphal developmental periods were recorded. Similarly, no significant differences were reported to exist between the nymphal development periods of *E. rogenhoferi* [52] and *T. afzelii* [42]. The adult females of *G. lenticularis* lived nearly three times as long (91 days) as the males (26 days). Similarly, it was found that female *T. afzelii* lived twice as long as males, irrespective of whether the female was mated or not [42]. Although food limitations may influence adult longevity, a case was recorded where an adult female lived for 44 days without food [42]. Female longevity was also significantly longer than that of males under both laboratory and field conditions for *Iris oratoria* (Linnaeus 1758) (Mantodea: Tarachodidae) [53]. *Ephestiasula rogenhoferi* female adult longevity was 20 to 25 days longer than that of males [52].

It has been suggested that the longevity of adult females of *I. oratoria* was the reason that the sex ratio of this species changed over time after spring commences [52]. While the sex ratio during the 1st-instar is 1:1, it changed due to comparatively higher mortalities amongst male individuals over time, resulting in the sex ratio becoming female-biased later in the season. However, in this study, under captive breeding and laboratory conditions, the sex ratio for *G. lenticularis* was male dominated. Some variation did exist but in seven of nine of the ootheca that hatched, the sex ratio favored males. A similar change in sex ratio over time was reported for a *Tenodera sinensis* Saussure 1871 (Mantidae) population in the USA, where the population was male dominated during one year, but not the following year [54]. This could indicate that fluctuations in sex ratios of mantid species can occur between years.

Since female *G. lenticularis* cannot fly, a male dominated population is required as males need to find females to mate. Males, due to their flight capability, are more likely to be subject to predation by bats and birds [42,55,56]. Although cannibalism was not recorded for *G. lenticularis* during this study, cannibalism might occur in nature if females are not as well fed as they were during this study. Another hindrance to male mantids are that they tend to be more attracted to light which is a factor which could increase the likelihood of them becoming prey [57,58]. Males of *T. sinensis* have a larger home range size (55.05 m^2) in comparison to the females (23.78 m^2) [54], which increases the opportunity for multiple matings to occur.

The variance in number of nymphal instars, duration of the stages, as well as female adult longevity and reproductive capability of *G. lenticularis* could be strategy to reduce competition between siblings for limited resource. First instar nymphs require approximately 14 days to develop to the second instar. Similarly, the period between production of the 1st and 2nd ootheca by *G. lenticularis* females was approximately 20 days, which is also the incubation period of an ootheca. This would allow first instar nymphs to become second instars before the younger ootheca hatches, which would then decrease the likelihood of a particular female's genetic progeny to compete for resources. Although no female was recorded producing more than two oothecae in this study, *T. afzelii* were recorded to produce up to five oothecae per female [42].

Phenological differences in oothecae have been observed for *Tenodera sinensis* Saussure 1871 and *Tenodera angustipennis* Saussure 1869 [59,60] and also between *T. angustipennis* and *Tenodera aridifolia* [61].

Hurd and Eisenberg [59] suggested that the differences in the periods to hatching of oothecae were an evolutionary adaptation to mitigate inter-guild competition between nymphs of different species. The nymphs occur in the same habitat and stratum and therefore compete for limited food resources [59]. The long period between oothecae production by *G. lenticularis* females could therefore also be a strategy to reduce resource competition between siblings, or inter-guild competition with other grassland mantid species. It was suggested that temporal differences in oviposition could be an evolutionary advantage for certain species [62]. For example, oothecae of *T. angustipennis*, which is a small species, are laid much later in the season, compared to that of the bigger *T. sinensis*, which feed on later-hatching and smaller individuals of *T. angustipennis*.

Christensen and Brown [54] reported that the abundance of *T. sinensis*, a mantid species that occurs in the State of New York (USA), ranged between 10 and 39 mantids per 1000 m^2 and that females with larger abdomens (presumably ready to lay an ootheca), would travel greater distances than non-gravid females. Female activity and movement could therefore also be influenced by the availability of suitable substrates and micro-habitats on which to attach oothecae. This possible increase in movement, along with the above-mentioned synchronicity of incubation periods of oothecae as well as nymphal developmental stages, could further increase the survival rate of the progeny of a particular *G. lenticularis* female by decreasing sibling resource rivalry or competition. Further investigation into movement patterns and density of field populations of *G. lenticularis* could shed some light on this proposed survival strategy. The hatch and survival rate of 40% and 25% respectively, recorded for *G. lenticularis* in this study would most likely be much lower under field conditions, which may lead to further decreases in competition among siblings.

There were large variations in developmental parameters of nymphs that emerged from a single ootheca, similar to what was reported for *Stagmomantis limbata* Hahn 1835 (Mantidae) [63]. Under field conditions this could be as a result of multiple paternities [51]. However, in this study, females were limited to breeding with one male to prevent multiple paternities, but field collected females could have been inseminated by more than one male before their oothecae were collected.

Multiple paternities have been indicated to be possible in *T. aridifolia* [51], and it was suggested that multiple sperm storage organs could be a strategy use by female arthropods to control their paternity [64]. A study reported the differences in the number of male parents per ootheca in two mantid species of the Liturgusidae family, i.e., *Ciulfina rentzi* Holwell, Ginn and Herberstein 2007 and *Ciulfina klassi* Holwell, Ginn, and Herberstein 2007 [65]. In the latter example, between four and six male parents contributed to a single ootheca of *C. klassi*, while only one male parent was responsible for a single ootheca of *C. rentzi* [66]. The production of oothecae with multiple paternities could theoretically be possible and could increase genetic diversity within a localized population, which could also increase survival of a species such as *G. lenticularis*. However, further research regarding the possibility of multiple paternities in the *G. lenticularis* should be investigated to determine this theoretical possibility.

5. Conclusions

Galepsus is widespread in Southern Africa and it seems more prevalent in grassland and savanna areas. The presence of only single specimens of *G. bipunctatus* Beier 1931 and *G.* (*Onychogalepsus*) *centralis* Beier 1957 in the museum collections in South Africa could indicate that it is possibly rare and that conservation thereof is required. This may however also be a by-product of the lack of sampling and taxonomic expertise. This study is the first to describe the biology of *G. lenticularis* and distribution *Galepsus* in Southern Africa and highlights the importance of museum collections. Museum collections have large numbers of records that contain distribution data, which will become more important because it enables the identification of possible habitable and favorable areas for species of which little is known, for example *Galepsus* in Southern Africa.

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CHAPTER 4: ARTICLE 2

The charismatic praying mantid: A gateway for insect conservation

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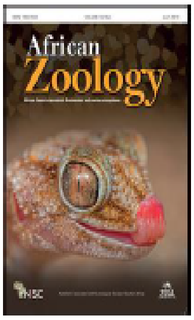

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Bianca Greyvenstein, Hannalene du Plessis & Johnnie van den Berg

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Perspective

The charismatic praying mantid: A gateway for insect conservation

Bianca Greyvenstein*, Hannalene du Plessis and Johnnie van den Berg

Unit for Environmental Sciences and Management, North-West University, Potchefstroom, South Africa
**Correspondence: biagrey90@gmail.com*

Praying mantids (Mantodea) are not only apex predators with a 'mystical' status, but are also regarded as a kind of oracle and, in some cultures, as omens associated with good or bad. In the future, the cultural, mystical and religious values allocated to mantids over millennia can contribute not only to their own conservation, but also to conservation of arthropods in general. Historically, Mantodea influenced African, Greek, Egyptian, Japanese and Chinese cultures and they affected human culture in a variety of ways. Some of these are coin designs, hairstyles, swords, death rituals, war strategies, advertisements, children's books and even modern music. Despite human fascination with mantids, this group of arthropods is unfortunately overlooked in terms of conservation and research. Conservation as a mitigation strategy to protect threatened and endangered species is influenced by philosophical and psychological aspects and requires more than a purely scientific approach. This paper highlights the role of praying mantids in human culture and the historical relationships between humans and other arthropods. Acknowledgement of these cultural aspects of the mantids may contribute to a positive change in people's perceptions of arthropods and eventually in insect conservation. It is suggested that mantids could be used as a flagship or gateway species to advance awareness of insect conservation. We can generate much needed insect appreciation by building on the existing 'global' cultural values, fascination and intrigue of the charismatic mantid, therefore increasing wonderment of the small things that dominate the world we live in.

Keywords: biodiversity, cultural value, ethno-entomology

Introduction

There is more to conservation than ecosystem services. The cultural importance of biodiversity, the ecosystem and the values thereof are not often discussed. A shift has been made in conservation from the core issues of intrinsic vs. instrumental value. The consensus is that although conservation is a multifaceted endeavour with a variety of complex environmental, psychological and philosophical issues, it is the relational value (i.e. all aspects of interrelatedness or the human relationship with nature, including inclinations, qualities and principles) of nature that remains important (Chan et al. 2016; Samways 2017, 2018).

Relational values should be the focus to increase awareness and generate appreciation that in turn will aid in conservation efforts (Chan et al. 2016; Samways 2017, 2018). Insect conservation is complicated by the fact that most insects have caused unpleasant experiences, lack aesthetic appeal, or are associated with certain superstitions. Beyond this, insects are not only small, but are to a large extent ignored/unnoticed in everyday life. This has led to the perception and categorisation of most insects being stereotypically referred to as 'gross', 'nuisance' and 'dangerous', whereas only a few insects can truly be described as being dangerous (Barua et al. 2012; Samways 2018). This was termed as the perception challenge by Samways (2015). Cultural value can, however, aid in changing the perceptions and bad associations regarding insects.

Cultural value concerning the environment refers to the historic value associated with a particular landscape or species within human culture. Sagoff (1974) indicated that this is as important as a citizen's right to vote. Cultural values influence conservation because different cultures value different qualities within nature (Holland and Rawles 1994) and therefore form part of the relational value regarding nature (Chan et al. 2016). A vital aspect of cultural values is that it is based on the belief system of different people. A variety of beliefs exist that consider some animals or habitats to have magical or spiritual properties. These beliefs and cultures differ from that of modern civilisation, and have an undeniable influence on conservation efforts, regardless of their positive or negative associations (Holmes et al. 2017).

Examples of spiritual beliefs or cultural values that influence conservation is, for example, the value assigned to hyenas in Kombolcha in Ethiopia. These hyenas are protected despite the fact that they attack people. The reason for their protection is that it is believed that their howls bring messages from ancestors. It is also believed that the hyenas eat evil spirits and, through this, they

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protect the people in this community. These magical or supernatural actions of the hyenas can be seen as a variation of the typical ecosystem services that scavengers, such as hyenas, usually fulfil (Holmes et al. 2017). A similar belief has been reported from Nigeria regarding the Sclater's Monkey, which is classified on the IUCN red data list as vulnerable (Baker 2013). Even though these monkeys are responsible for damage to crops and homes of the Igbo communities, they are seen as 'belonging to the gods' and are therefore under the protective order of their mythical 'no threat' status (Baker 2013).

Sclater's Monkey and the hyenas of Kombolcha are not the only examples of creatures that are associated with various cultural and spiritual beliefs. Mantodea, a small and less diverse order than most other arthropod orders with an estimated 2 500 species worldwide (Wieland and Schütte 2012; Green 2014; Otte et al. 2020), are associated with a wide array of spiritual beliefs and cultural values from various parts of the world.

Cultural value of the charismatic Mantodea

In southern Africa, the Khoi or African Bushmen believe that the mantid is the 'manifestation of God come to Earth' as it is said that the first San member was a mantid (Lauck 1998). The folk story of the birth of the first of the San happened as follows: The 'mantid' appeared in the beginning of time when the earth was covered by water (Fourie 1993). Mantid was then sent to find the purpose of life and asked Bee to assist him. Bee carried Mantid until he became too weak to continue, but luckily found an open flower floating in the water where Bee left Mantid (Fourie 1993). It is said that Bee planted a seed within Mantid and then died. When the sun rose, it warmed Mantid and from the seed within him the first member of the San was born (Fourie 1993).

The mantid is seen as an oracle, and in some cases as a good or bad omen, because of the above mentioned ideology of the mantid in the Khoisan and various other southern African cultures (i.e. Xam, Nama, Damara and Maloti Bushmen) (Schmidt 2018). Various rituals that include dancing or sitting on one's knees are linked to the physical presence of a mantid. In the Khoisan culture, people address questions to mantids to ask for advice, to indicate where lost cattle are or whether it will rain, and lastly to bring a message from an ancestor (Schmit 2018). These questions were then answered by the mantid by a change in posture, such as raising its front legs or looking in a specific direction. Interestingly, these beliefs and the folklore about mantids in African cultures are similar to that of the ancient Greeks.

Mantis is derived from the Greek word 'μάντις' meaning prophet or soothsayer (Scholtz and Holm 1985; McMonigle 2013; Green 2014). As indicated by the first Khoi San in southern Africa, many legends exist about mantids. Additionally, many of these myths originate from observations of the characteristic posture that mantids have that resembles the act of praying in many human cultures. In contrast, scientists refer to the praying mantid as 'preying' mantid, referring to their predatory ecological role in nature. However, sometimes even a scientist will prey victim to use names inspired by cryptids, deities and monsters (Jozwaik et al. 2015) to name new species. For example, the mantid family Empusidae under which the mantid *Empusa* (Figure 1) is classified, was inspired by the ancient Greek demon who would suck the blood from her victims (Smith 1849), the inspiration of most modern vampire myths.

Figure 1: A representative mantid species from the Empusidae family of which the name that was inspired by an ancient blood sucking demon (Photo by B Greyvenstein)

The ancient Greeks believed that mantids had supernatural powers. Female mantids were featured on a series of the ancient drachma, which was used as currency in Metapontum in Sicily during the fifth century BC (Campbell 2014). These silver coins (Figure 2) are now considered as collector's items of high monetary value (Paraskevaides and Sverdloff 1998).

According to Chinese mythology, recorded in the ancient Chinese dictionary 'Erya', the praying mantid, is seen as fearless and courageous. Mantids therefore inspired approaches to warfare, for example to 'strike fast without hesitation' (Lauck 1998). Two ancient Chinese martial art forms are based on mantid behaviour and posture: the Northern Praying Mantis (Figure 3a) and the Southern Praying Mantis (Figure 3b). These two fighting styles are unrelated regarding the techniques and origin, but share the name of the revered praying mantid (Lee 2003).

The mantid is seen as a symbol of power and cunning in Japanese culture as they attack their prey that are unaware of approaching danger. A Japanese legend tells of a mantid that was so confident in its strength that the mantid's spirit was not the only thing broken when it was crushed by a bullock cart (Prete and Wolfe 1992). The latter resulted in the saying: 'like a mantid raising its arms to stop the wheel of a passing cart' (Sax 2001). This legend inspired a multitude of Japanese sword designs, such as the L6/Bainite Shobu Zukuri Blade known as the 'praying mantis Samurai sword', which also features an image of a mantid on the sword itself (Figure 4) (Hanwei and Chen 1998).

Figure 2: Mantid figure on the ancient Drachma that was minted in fifth century BC by the city of Metapontum, Italy (Vcoins 2019)

Despite the admiration that mantids receive in Japanese culture, the mantid is also known as *kamikiri-ma* ('hair-cutting demon') or *kamikiri-mushi* ('hair-cutting insect') (Foster 2015) (Figure 5). Kamikiri was to blame for the phenomenon of sudden hair cutting and was said to have targeted young women at dusk, especially in the city of Matsusaka (Foster 2015). Women with long hair and men with a 'chonmage' (topknot) during the Edo period (1603–1867) were considered to have a 'status' in the community. Thus, the cutting of one's hair was seen as a drastic change in religious conviction. Kamikiri, with its haircutting ability became a threat to the people in this community (Foster 2015). Women were known to write prayers on pieces of paper and place them in hairpins to discourage Kamikiri's unsolicited barber events.

Despite the lack of reference to mantids in ancient Egyptian literature or art, a small coffin was discovered that contained a mantid wrapped in linen during an excavation at Deir el Madeina in Bruyère, as well as a drawing of a mantid that was made on papyrus (Figure 6). Additionally, Kritsky and Cherry (2000) also described a wall drawing of a mantid in the tomb of Seti I (a Pharoah) who reigned during the 19th Dynasty of Egypt (1279–1290 BC). In the latter drawing, the mantid was associated with the opening of the Mouth ceremony, a ritual that was believed to allow the dead to eat and drink in the afterlife (Keimer 1938). The ancient Egyptians referred to mantids as '*Abyt*' or Abyt-bird, which is translated to dancer or praying mantids. In the "Book of the dead" (Egyptian funeral text used from 1550 BC to 50 BC), which was used to assist the dead through 'Duat' or the underworld, mantids were responsible for fetching people and leading them to where they had to go

Figure 3: Comparison between the (a) Northern and (b) Southern praying mantis Kung Fu styles (Kord 2018)

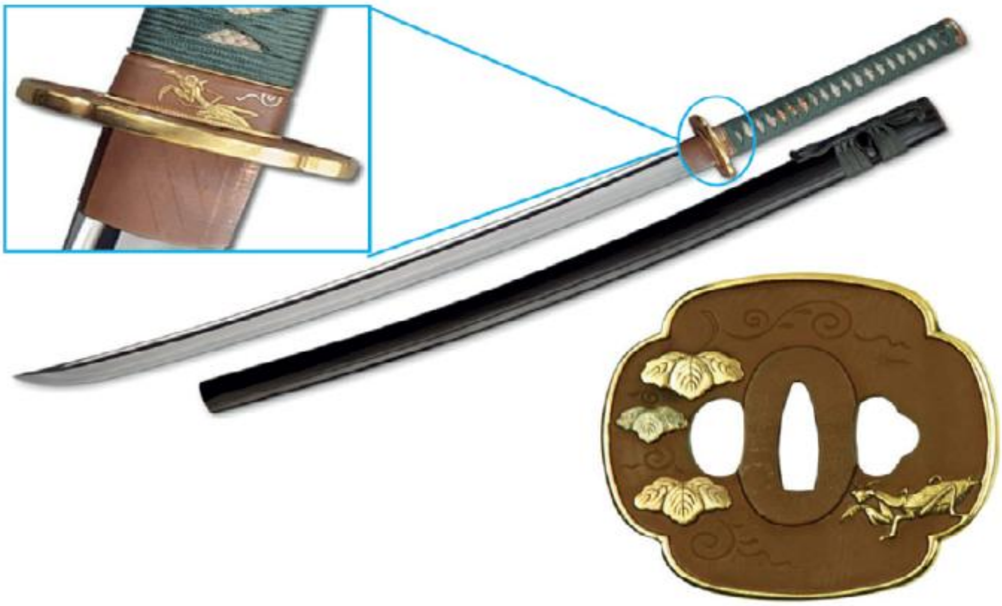

Figure 4: Japanese praying mantid Katan (Hanwei and Chen 1998)

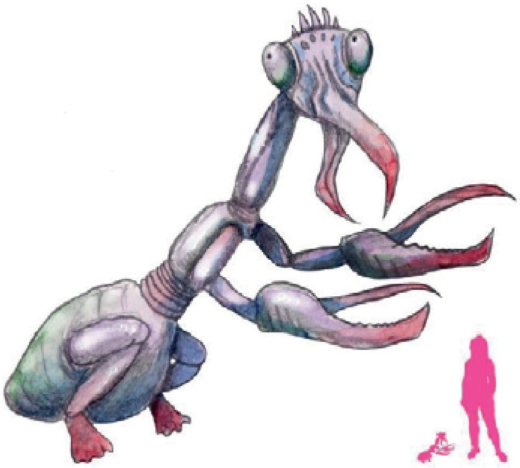

Figure 5: Illustration of Kamikiri as was envisioned by the Japanese (Foster 2015; Picture: A Book of Creatures 2019)

in the afterlife. This gave birth to the origin of the myth of the necromancer (praying mantid) not only accompanying souls to the other side, but also playing a role in the magical practice of necromancy that enables the living to communicate with the dead (Prete et al. 1999).

The fascination of humans with mantids was not only limited to prehistory. More recently, mantids have been the inspiration of several creative works, such as the 1935 wood engraving known as Dream (https://mcescher.com/lw-272/), by the famous Dutch graphic designer and mathematician Maurits Escher (Emmer and Schattschneider 2003). Several films with mantids as inspiration for the characters were also released. For example, 'The Deadly Mantis', was an American based monster film (Figure 7a) produced during 1957 (Fandom 2015), whereas the 1978 movie 'Chinese Kung Fu' (Figure 7b) was inspired by mantids' fighting strategy and posture (Cityonfire 2014).

Mantis, a fictional female superhero (Figure 8), first appeared in the Avengers during 1973, a product of Marvel Comics. The abilities and talents of this female hero figure included martial arts, plant manipulation, extreme empathy and the accelerated ability to heal (Marvel 2018).

There are also modern warfare examples with reference to mantids, although often less heroic than those described above. For example, the US navy had a mission in 1988 titled 'Operation Praying Mantis' that was described as a retaliation action to the Iranian sea-mine that almost sank a US Navy destroyer, the USS Samuel B. Roberts (FFG 58), on 14 April 1988. On 18 April 1988, the US was ready to employ Operation Praying Mantis and 'strike back' (Peniston 2015).

More recently, an English rock band named 'Praying Mantis' featured the image of a mantid head as their band logo album cover. Their song 'Children of the Earth' has reached more than 200 000 views on YouTube and they have more than 15 000 followers on Facebook (Praying Mantis 2020). This is not the only example of mantids being used as band or product logos. Even in the advertising industry, the image of a mantid (Figure 9c) is used for a bug tracker called MantisBT and is described as 'an open source issue tracker that provides a delicate balance between simplicity and power' (http://mantisbt.org/).

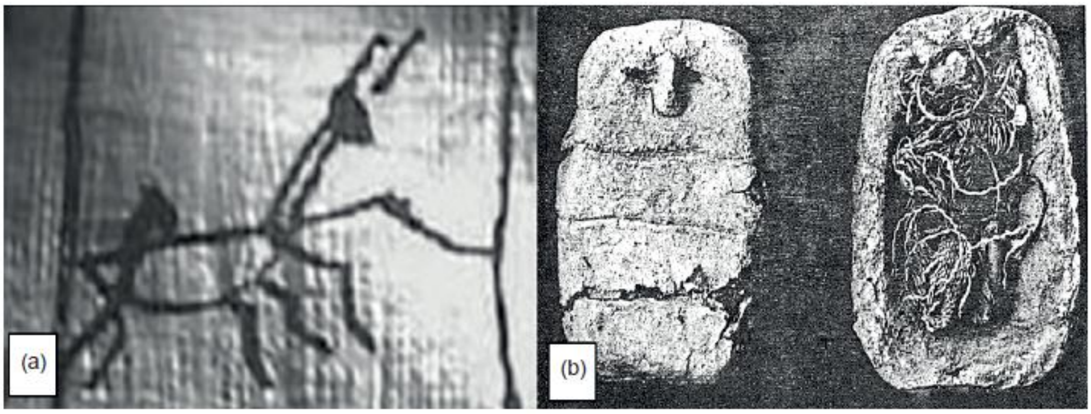

Figure 6: (a) An ink drawing of a mantid on papyrus (Kenawy and Abdel-Hamid 2015). (b) A mantid mummy with original coffin found in Egypt (Keimer 1938)

Figure 7: Mantids featuring in (a) American (Fandom 2015) and (b) Chinese films (Cityonfire 2014)

Mantids also feature in a variety of books that range from pet guides to poetry. 'Lanky Legs: Praying mantis' and 'Manuelo the playing mantis' are examples of children's books featuring mantids (Freeman 2004; Macheske 2016). In the latter, Manuelo is a praying mantid that longs to join in outdoor concerts, but cannot play an instrument. Through perseverance, he is able to form new friendships and overcome his challenges and starts playing the cello (Freeman 2004).

Despite all the beliefs and fascination with mantids over the past millennia, not much is known about their behavioural, ecological or biological attributes, and thus little has been done regarding their conservation. This tends to be the case for a magnitude of insects. The importance of aesthetic, cultural and religious values that we assign to mantids, and diversity in general, should be the focus to increase awareness, appreciation and empathy that in turn increases the overall relatedness and thus relational value of nature. This is of critical importance when conservation of insects, such as mantids, is being investigated. History has indicated that a pure ecosystem services approach does not increase the relational value (Bekessy et al. 2018).

Arthropod-human relationships

The perceptions people have of arthropods are either good or bad, depending on their previous experiences with these creatures (Shipley and Bixler 2017). Sadly, despite the good experiences people have had with insects, all insects are categorically associated with the few non-appreciated bugs that adversely influence the perceptions of the entire insect group. Mantids are, however, not the only insects with cultural values dating back hundreds of years.

Several stories regarding human-arthropod relationships have been recorded during ancient (Pharaonic) Egyptian times; for example, stories from the Bible indicate how people were plagued by insects, such as locusts (Kenawy and Abdel-Hamid 2015). In contrast to the bad associations with locusts in the Christian Bible, a well-known Islamic folklore story paints spiders, which are usually frightening to people, in a more positive light. It is said that the spider aided in the refuge of Prophet Muhammed (Firdaus 2017). Prophet Muhammed was seeking refuge from the Quraysh, in a cave in Mecca, and he could not be found. This was, because Allah sent a spider and two doves to conceal the entrance of the cave. The spider spun its web across the entrance of the cave, whereas the doves appeared to be nesting at the entrance of the cave. This deceived the Quraysh, because it indicated to them that no one had entered the cave. Thus the spider and doves kept the Prophet from being found by the Quraysh as they passed the cave in which he was hiding (Firdaus 2017).

Figure 8: Mantis: The Marvel Comics created female superhero (Raney 2019)

Locusts were not the only arthropods that contributed to the human-arthropod interaction described by the ancient Egyptians. The Egyptian civilisation was known for the fact that they deemed some insects exceptionally special and even worshipped them, for example dung beetles (Coleoptera: Scarabaeidae), jewel beetles (Coleoptera: Buprestidae) and click beetles (Coleoptera: Elateridae). Coleoptera were known to Egyptians as 'Atem', the creator god of Heliopolis (one of the oldest cities in ancient Egypt and was known as the City of the Sun) (Kenawy and Abdel-Hamid 2015). Not all of the human-arthropod interactions are from ancient Egypt. In Barbados, for example, stick insects are believed to be the horses of the gods; responsible for transporting the gods. It is also believed that when a stick insect is seen near a house that someone in the house will die (Carrington et al. 2004; Vargas 2006).

Arthropods have also featured in cave paintings that date back to 8000 BC (see Pager 1976 and Mguni 2015). These paintings mainly depict the activity of indigenous people collecting honey and termite alates, and they were found inside caves in Spain, India, Australia, South Africa and Zimbabwe (Pager 1976; Crane 2005; Mguni 2015).

In the culture of the Daudai of New Guinea, centipedes are tattooed on women as an ornamental 'insecticide', thus protecting them from the bites of real centipedes (Hambley 1927). Pearson (1996) reported that tattoos of all insects, not just of the beautiful bugs, but also mantids and beetles

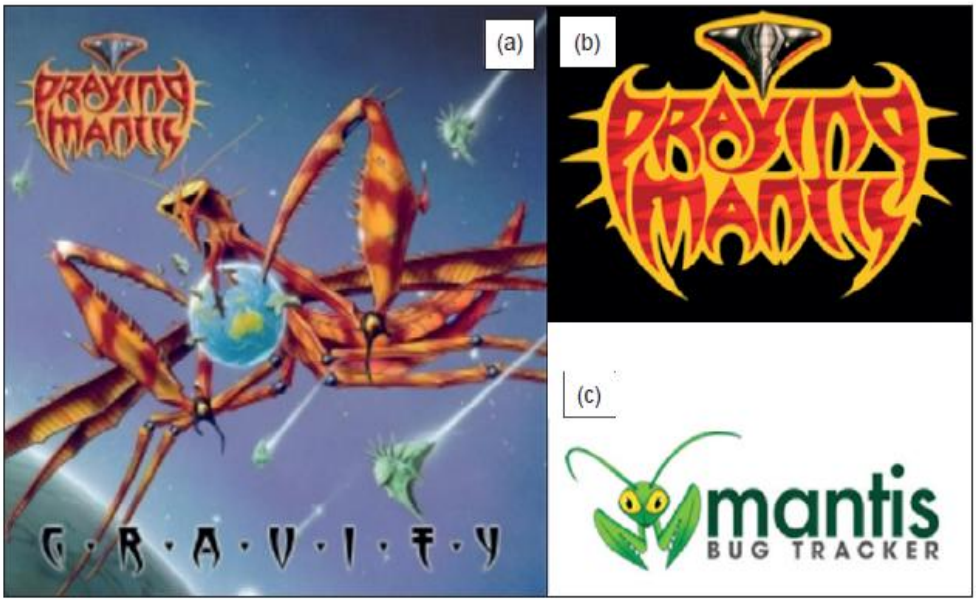

Figure 9: Images of mantids used in modern sectors of (a) and (b) music (Praying Mantis 2019) and (c) advertisement (www.mantisbt.org)

are becoming more common, which signifies that arthropods are gaining a positive perception amongst people.

Beyond the various magical or supernatural beliefs that arthropods encompass, they are also believed to be medicinally relevant. Insects are used in various folk-medicinal treatments, for example, *Brahmaea japonica* (Lepidoptera: Brahmaeidae) larva is believed to mitigate anaemia, whereas some mantid species i.e. *Mantis religiosa* (Mantodea: Mantidae), *Hierodula patellifera* (Mantodea: Mantidae) and *Tenodera aridifolia* (Mantodea: Mantidae) are used to treat fever, toothache and respiratory problems (Meyer-Rochow 2017). Spiders are boiled in oil on a fire and this oil can then be used to alleviate earache (Lloyd 1921). The same results are believed to be attained if the ootheca of a mantid is consumed (Thomas 2003).

Beyond all the old world stories, folklore, myths and remedies passed on from generation to generation, the need for arthropod conservation still requires much convincing. The reason being that most people tend to dislike most insect species. Insects, such as dragonflies, butterflies and ladybirds tend to be more easily associated with positive human perceptions, because they are associated with positive experiences from childhood (Samways 2018). The arthropod-human relationship remains complicated. Yet, if the psychology behind these interactions and the 'perception challenge' are better understood, it may contribute to development of citizen science programs and education strategies. This could in turn increase awareness that can be used to expose people to the diverse and beautiful multitude of insect species, aiding in conservation efforts in the future (Roy et al. 2015; Samways 2015; Simaika and Samways 2018). Before all arthropods can or will be fully appreciated and valued, some convincing is required, and mantids can aid in this endeavour.

Mantids: a gateway insect for conservation

Mantids and jumping spiders have prominent eyes (Figure 10), which are associated with the aesthetic appeal of these arthropods. These prominent eyes might be the reason that people have a more positive attitude towards specific arthropods, such as mantids (Tam et al. 2013). Tam et al. (2013) indicated that assigning facial structures to nature (anthropomorphism of nature) (Figure 11) increases the connection sensed by people towards nature, therefore increasing the likelihood of participating/supporting conservation efforts. Manesi et al. (2015) revealed that not even an entire facial structure is required as the eye spots found on some butterfly species can positively and significantly increase the aesthetic appeal of that butterfly species and therefore change the conservation attitude towards the species. This may be because direct eye contact among humans influence their emotions and perceptions and often creates a feeling of connectedness (Rychlowska et al. 2012; Myllyneva and Hietanen 2015; Schilbach 2015). Mantids and dragonflies are the only insects with pseudopupils, creating the optical illusion of direct eye contact (González-Martín-Moro et al. 2014). Contact between humans and these insects could therefore influence people's perceptions and their 'sense of connectedness'. Shipley and Bixler (2017) indicated that people perceive insects in three main categories i.e. beautiful, bothersome and fun. The most beautiful or liked insects were, butterflies, ladybirds and fireflies, whereas cockroaches, wasps, spiders and mosquitos were considered the most disliked or bothersome bugs. This study classified 'fun bugs' as insects that were not well-known and that intrigued the participants. Mantids were one of these 'fun bugs' and were referred to as a 'gateway bug' (Shipley and Bixler 2017). Two groups of people were identified in this study, i.e. a group that assigned high scores to beautiful bugs and who exhibited a higher aversion or disgust for the bothersome bugs, and another group who were more intrigued by the 'fun bugs'. The scores assigned to mantids by both groups were similar, which meant that mantids could be used as a way to engage or intrigue both clusters of people (Shipley and Bixler 2017). Despite the intrigue and fascination mantids have caused, they are not part of conservation plans and their ecological importance remains unknown.

Figure 10: These two arthropods, (a) mantid and (b) jumping spider, are examples of gateway bugs (Photos by Paul Janse van Rensburg)

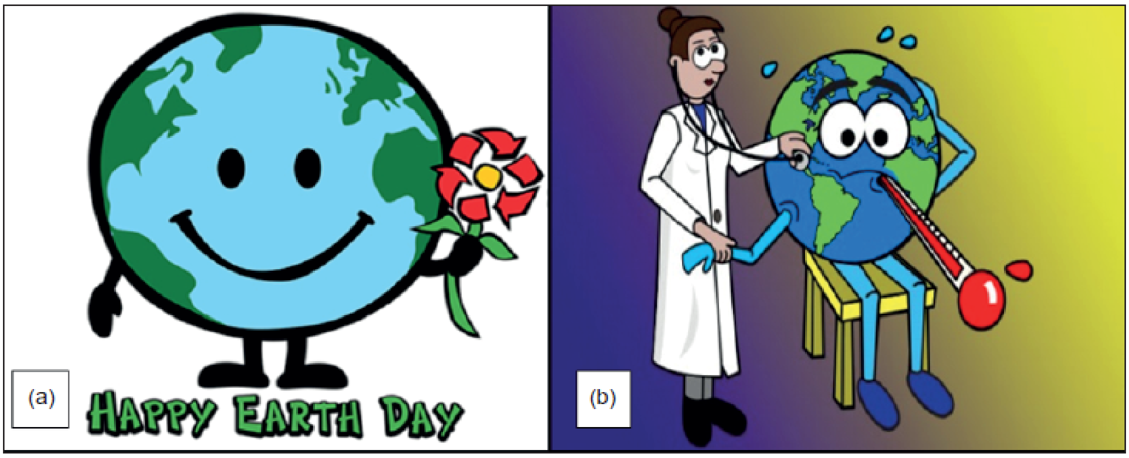

Figure 11: Examples of the anthropomorphism of nature (earth), which personalises: (a) recycling (Clipart Library 2020) and (b) climate change issues (TSSS 2016)

Previous research on mantids largely addressed their taxonomy, hunting behaviour, vision and possible use in robotics. Mantids should be studied not only for their potential to serve as environmental indicators, or because of their functional and ecological roles, but also because studying mantids can indicate the threats to their survival that can be mitigated (Kremen et al. 1993). 'Although species may appear functionally redundant when one function is considered under one set of environmental conditions, many species are needed to maintain multiple ecosystem services at multiple times and places in a changing world' (Isbell et al. 2011).

In this rapidly changing world, rapid conservation actions are required to save not only a species, but as much biodiversity as possible, because the interconnectedness of the environment has relational value beyond measure. Insects play a vital role in this regard and using cultural aspects are crucial in identifying a flagship species, especially in the insect world (Barua et al. 2012).

Barua et al. (2012) stated that creating awareness of invertebrate conservation is increased by using flagship species. These species can also act as umbrella species i.e. by conserving the habitat of one species, other species that share the habitat will also benefit (Lambeck 1997; Foit et al. 2016). Invertebrate flagship species were described by Barua et al. (2012) as follows: 'it should be part of a diverse group, easily identifiable and non-cryptic, and should resonate with specific and diverse audiences and the importance of cultural knowledge of the audience'. Barua et al. (2012) stated that the aesthetics of the particular invertebrate were also important, for example the wing shape and colour of a butterfly. This supports the findings of Shipley and Bixler (2017) who described these insects as the 'beautiful group'.

The Mantodea is a small but somewhat cryptic order. Despite this, they have an almost global array of cultural value, such as increased relational value, aesthetic appeal (variety of colours and shapes) and they are easy to identify, because of their signature pose. The most recognisable characteristic is their anthropomorphic attributes (prominent eyes) and the possible feeling of connectedness as a result of their pseudopupils. Thus, mantids have almost all the required attributes of a flagship species.

The charismatic and culturally valued mantids could potentially be the gateway- and flagship species for insect conservation, and, as stated by Simaika and Samways (2018), be insect 'conservation ambassadors'. Mantids will therefore also act as an umbrella species that could lead not only to their conservation, but also the conservation of various other insect species that, as EO Wilson described, are 'the tiny things that run the world' (Wilson 1987).

Conclusion

Conservation has a unique task of trying to incorporate humanity (with all the various aspects of human behaviour) into actions that will relate to the protection of species that are declining as a result of humanity (Paquet and Darimont 2010; Biggs et al. 2011). This task requires a very diverse group of people, all with different beliefs and values, to collaborate. This collaboration is essential to increase successful conservation efforts. By incorporating psychological, philosophical and cultural values instead of only the ecological significance and associated services of a species, the effectiveness and possibilities of conservation strategies might be simpler to attain. Mantids could be an ideal potential flagship species for complex and critically important insect conservation efforts because they have a wide variety of associated cultural values, prominent anthropomorphic characteristics and are easy to identify owing to their signature pose. These factors may increase not only the appreciation for this charismatic insect but may intrigue people enough to investigate and learn more about the other tiny creatures that are essential to our life on this earth.

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ORCIDs

Bianca Greyvenstein http://orcid.org/0000-0003-2033-7113
Hannalene du Plessis http://orcid.org/0000-0003-1163-1468
Johnnie van den Berg http://orcid.org/0000-0002-6831-3180

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CHAPTER 5: ARTICLE 3

Updated checklist of Mantodea and notes on species from southern Africa

(Submitted for review to ***Check list***)

Updated checklist of Mantodea and notes on species from southern Africa

Bianca Greyvenstein, Hannalene du Plessis & Johnnie van den Berg
Unit for Environmental Sciences and Management, North-West University, Potchefstroom, South Africa

Corresponding author: biagrey90@gmail.com

5.1 Abstract

An updated checklist of the praying mantid (Insecta: Mantodea) species of southern Africa is presented in this paper. While 120 species were previously reported to occur in South Africa, this paper reports 198 species, 60 genera and 11 families. This species list was generated from the approximately 4000 specimen records found in national insect collections in South Africa. These collections date back to 1849 and summarizes 150 years of Mantodea records from the region. This species list primarily provides specimen data and highlights the lack of knowledge about southern Africa's mantid fauna. New distribution records of one genus and 20 species are also included in this checklist.

Keywords: diversity, mantids, museum

5.2 Introduction

The Mantodea order consists of 24 families and approximately 2400 species worldwide (Green 2014; Wieland and Schütte 2012; McMonigle 2013; Wieland 2013). The largest of these families is the Mantidae which consists of approximately 1200 species. The following Mantodea families are listed in descending order of species richness (McMonigle 2013): Hymenopodidae, Tarachodidae, Thespidae, Iridopterygidae, Acanthopidae, Amorphoscelidae, Ememiaphilidae, Liturgusidae, Toxoderidae, Empusidae, Sibyllidae, Mantoididae, Chaeteessidae and Metallyticidae. The latter family consists of only five species, all belonging to one genus which occurs only in South-east Asia (McMonigle 2013).

Despite the approximately 120 species of Mantodea reported to occur in South Africa (Schoeman 1985a; Schoeman 1985b), very little is known of their biology and ecology. A 2018 Scopus (www.scopus.com) internet search of published scientific papers indicated that between 1927 and 2018, 559 papers were published on Mantodea worldwide. However, only nine of these publications were from institutions in South Africa. These studies all addressed molecular and genetic aspects and in most of these cases it was actually Blattodea that were investigated. Other studies throughout the world have investigated various behavioral aspects of mantids such as their cannibalistic mating behavior and movement which can be used in robotic advances (Arkin et al. 2000). Scientific reports on their biology and distribution are limited in the world, and in South Africa, largely absent.

Due to the lack of knowledge regarding Mantodea, it is possible that there are many more species in the southern African region than those currently documented. The only surveys of Mantodea in South Africa were by Kaltenbach (Kaltenbach 1996; 1998) and the Mantodea Project which is in affiliation with the Cleveland Museum of Natural history in Ohio, USA (Svenson et al. 2013). The latter survey in South Africa was done during 2005 and only included three regions (Cape floristic region, Richards Bay in KwaZulu-Natal and the Kruger National Park in Mpumalanga). This compilation of museum records and updates to the original checklist contributes to establishment of an information base and identifies knowledge gaps with regards to mantids in South Africa and some neighboring countries.

5.3 Materials and Methods

All of the National insect collections and museums throughout South Africa were visited during this study. The following seven institutions constitutes all the national insect collections in South Africa: Ditsong Museum of Natural History (Pretoria), Agricultural Research Council (Biosystematics Division, Pretoria), National Museum (Bloemfontein), Albany Museum (Grahamstown), Rhodes University (Grahamstown), Durban Natural Science Museum, Iziko South African Museum (Cape Town) and the KwaZulu-Natal Museum (Pietermaritzburg). Specimens in these collections where mostly identified by various taxonomists during previous visits to these institutions. Many of the museum specimens were previously identified by taxonomists at the departments of Dr. Max Beier at the Vienna museum in Germany, Dr. James Rehn at University of Drexel in Philadelphia, USA, and Dr. Roger Roy at the Muséum National d'Histoire Naturelle (MNHN) in France.

Unidentified specimens that were encountered in the abovementioned museums were identified by means of the literature and through assistance from a taxonomist that specializes in African Mantodea. These ignota specimens were not included in this check list and were only identified to genus level in the database itself (http://natural-sciences.nwu.ac.za/unit-environmental-sciences-and-management/praying-mantid-mantodea-records-southern-africa). In order to compile this database, all of the Mantodea specimens and distribution labels where photographed and the label information digitized. This database contains the following information for each specimen record: genus and species name (to the level of identification), collector's details, collection date if available, and locality. The website (Mantodeaspeciesfile.org) (Otte et al. 2020) was used to determine the current nomenclature. The species list compiled from the South African museum collections described above was compared to that provided in publications by Kaltenbach (Kaltenbach, 1996; Kaltenbach, 1998) after which similarities and differences were highlighted. To our knowledge this paper provides the most comprehensive list of Mantodea in South African national collections. The complete southern Africa Mantodea database is also available at (http://natural-sciences.nwu.ac.za/unit-environmental-sciences-and-management/praying-mantid-mantodea-records-southern-africa).

The taxonomic identifier is indicated for each species, as well as the various collections at which the specimens are located. The following list indicates the abbreviations for each institutional collection: Ditsong National Museum of Natural History (Pretoria) - (DNMNH), Agricultural Research Council (Biosystematics Division in Pretoria) - (ARC), National Museum (Bloemfontein) - (NMB), Albany Museum (Grahamstown) - (AMG), Rhodes University (Grahamstown) - (RUG), Durban Natural Science Museum - (DNSM), Iziko South African Museum - (Cape Town) (ISAM) and the KwaZulu-Natal Museum (Pietermaritzburg) - (KNM).

The geographical distribution is indicated below for each species in brackets [ ] and the following abbreviations where used for the different southern African countries: South Africa [SA], Zimbabwe [ZIM], Zambia [ZAM], Botswana [BOT], Mozambique [MOZ], Democratic Republic of the Congo [DRC], Angola [AG], Lesotho [LS], Swaziland (eSwatini) [SW], Kenya [KN], Namibia [NAM], Ethiopia [ET], Mauritius [MT], Central Africa [CA], Tropical Africa [TA], Malawi [MAL], Cameroon [CAM], Gabon [GB] and Tanzania [TZ]. If available, the name of the person which identified the specimen is also provided (Id).

5.4 Results

This updated checklist includes the information on all the Mantodea specimens in institutional collections in South Africa as well as those listed by Kaltenbach (1996, 1998). The known species richness has increased from approximately 120 species in 1998 to 199 species (this report). This includes first reports of two subfamilies, one tribe, nine genera and 21 species which were not previously reported from the southern African region. However, some anomalies did occur as the species list was updated. These anomalies are indicated in the species list below.

5.4.1 The updated checklist of Mantodea species in southern Africa

FAMILY THESPIDAE Saussure, 1869

SUBFAMILY HOPLOCORYPHINAE Giglio-Tos, 1916

1. *Hoplocorypha fumosa* Giglio-Tos, 1916 [SA, MOZ, ZIM]
Id by Albert John Hesse (ISAM).
2. *Hoplocorypha macra* Stäl, 1856 [SA & NAM]
Id by Rehn 1925 & Max Beier 1952 (DNMNH), Id by Kaltenbach 1985 (ARC) & Id by Albert John Hesse (ISAM).

3. *Hoplocorypha nana* Sjostedt, 1909 [SA]
Id by Max Beier 1952 & Kaltenbach 1991 (DNMNH) & Id by Kaltenbach 1985 (ARC).

4. *Hoplocorypha saussurii* Giglio-Tos, 1916 [SA & NAM]
Id by Max Beier 1952, Roger Roy 1977 (DNMNH).

5. *Hoplocorypha striata* Beier, 1930 [SA]
Id by Kaltenbach 1991 (DNMNH).

6. *Hoplocoryphella grandis* Brancsik, 1895 [SA & BOT]
Id by Rehn 1925, Roger Roy 1977 & Kaltenbach 1989 (DNMNH).

FAMILY ANGELIDAE Beier, 1935

7. *Agrionopsis distanti* Kirby, 1899 [SA, ZIM & ZAM]
Id by Rehn 1923, Beier & Kaltenbach 1991(DNMNH), Id by H.D. Brown (ARC) & Id by Albert John Hesse (ISAM).

8. *Leptocola stanleyana* Westwood, 1889 [GB, MOZ & NAM]
Id by Beier (DNMNH) & Id by Albert John Hesse (ISAM). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is thus a new record of this species in southern Africa.

FAMILY LITURGUSIDAE Giglio-Tos, 1915

SUBFAMILY LITURGUSINAE Giglio-Tos, 1915

Tribe Liturgusini Giglio-Tos, 1915

9. *Theopompella aurivillii* Sjostedt, 1900 [DRC, TZ]
Id by Max Beier 1952 (DNMNH).

10. *Theopompella fusca* Giglio-Tos, 1917 [DRC]
Id by Max Beier 1952 (DNMNH).

11. *Theopompella westwoodi* Kirby, 1904 [SA]
Id by Rehn 1925 (DNSM).

This Genus was not mentioned in the species list compiled by Kaltenbach in 1996 and is thus a new record of this Genus in southern Africa.

12. *Zouza radiosa* Giglio-Tos, 1907 [SA]
Id by Kaltenbach 1988 (DNMNH).

FAMILY MANTIDAE Latreille, 1802

SUBFAMILY AMELINAE Westwood, 1889

Tribe Amelini Westwood, 1889

13. *Ameles* sp. Burmeister, 1838 [SA]
Id by F.W. Gess (AMG) & Id by G. Cock (NMB). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is thus a new record of this species in southern Africa.

14. *Bolbella punctigera* Stäl, 1871 [SA]
Id by Rehn 1925 & Kaltenbach 1982 (DNMNH) & Id by Albert John Hesse (ISAM).

15. *Bolbella rhodesiaca* Beier, 1930 [SA & ZIM]
Id by H.D Brown 1963 (ARC) & Id by Max Beier 1952 (DNMNH).

16. *Dystactula grisea* Giglio-Tos, 1915 [SA, NAM, MOZ & ZIM]
Id by Albert John Hesse (ISAM) & Id by Moulin (RUG).

17. *Gonypetella deletrix* Rehn, 1927 [SA, BOT & NAM]
Id by Kaltenbach 1988 (DNMNH) & Id by Albert John Hesse (ISAM).

18. *Gonypetella kilimandjarica* Sjostedt, 1909 [SA & ZIM]
Id by Kaltenbach 1988 (DNMNH) & Id by Albert John Hesse (ISAM).

SUBFAMILY CHROICOPTERINAE Giglio-Tos, 1915

Tribe Chroicopterni Giglio-Tos, 1915

19. *Chroicoptera saussurei* Giglio-Tos, 1915 [SA & LS]
Id by Kaltenbach 1988 (DNMNH) & Id by Albert John Hesse (ISAM).

20. *Chroicoptera vidua* Stäl, 1856 [SA]
Id by Rehn 1925 (DNMNH).

Subgenus *Entella* Stäl, 1877

21. ***Entella congica*** **Giglio-Tos, 1915 [SA]**
Id by Albert John Hesse (ISAM). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is thus a new record of this species in southern Africa.

22. ***Entella delalandi*** **Saussure, 1870 [SA]**
Id by Max Beier 1952 & Kaltenbach 1988 (DNMNH).

23. ***Entella nebulosa*** **Serville, 1839 [SA]**
Id by Albert John Hesse (ISAM).

24. ***Entella pusilla*** **Beier, 1953 [SA & ZIM]**
Id by Max Beier 1952 (DNMNH) & Id by Albert John Hesse (ISAM).

25. ***Entella taborana*** **Giglio-Tos, 1915 [SA]**
Id by Max Beier 1952 (DNMNH). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is thus a new record of this species in southern Africa.

26. ***Entella transvaalica*** **Beier, 1955 [SA]**
Id by Kaltenbach 1985 (DNMNH).

27. ***Entelloptera rogenhoferi*** **Saussure, 1872 [SA, NAM, ZIM]**
Id by Kaltenbach 1984 (ARC), Id by Max Beier 1952 & Kaltenbach 1991 (DNMNH).

28. ***Ligaria brevicollis*** **Stäl, 1877 [SA & ZIM]**
Id by Max Beier 1952 & Kaltenbach 1985 (DNMNH).

29. ***Ligaria chopardi*** **Giglio-Tos, 1915 [SA, NAM & ZIM]**
Id by Albert John Hesse (ISAM). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is a new record of this species in southern Africa.

30. ***Ligaria dentata*** **Giglio-Tos, 1915 [AG & NAM]**
Id by Albert John Hesse (ISAM).

31. ***Ligaria quadripunctata*** **Stäl, 1877 [SA, NAM & ZIM]**
Id by H.D Brown 1963 (ARC). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is a new record of this species in southern Africa.

32. ***Ligaria quadrinotata*** **Chopard, 1914 [SA & ZIM]**
Id by Max Beier 1952 & Dept. Kaltenbach 1992 (DNMNH).

33. ***Ligariella trigonalis*** **Saussure, 1899 [SA & NAM]**
Id by Max Beier 1952 & Kaltenbach 1985 (DNMNH) & Id by Albert John Hesse (ISAM).

SUBFAMILY COMPSOTHESPINAE Giglio-Tos, 1913

34. *Compsothespis anomala* Saussure, 1872 [SA]
Id by H.D Brown 1963 (ARC), Id by Max Beier 1952 (DNMNH) & Id by Albert John Hesse (ISAM)

35. *Compsothespis natalica* Westwood, 1889 [SA]
Id by H.D Brown 1963 (ARC) & Id by Rehn 1925 (DNMNH).

SUBFAMILY DANURIINAE BRUNNER DE WATTENWYL, 1893

36. *Neodanuria bolauana* Saussure, 1869 [SA]
Id by Albert John Hesse (ISAM). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is thus a new record of this species in southern Africa.

37. *Popa spurca* Stäl, 1856 [SA, ZIM & NAM]
Id by F.W. Gess (AMG), Id by Rehn 1925, D.W. Rorke 1954 & Roger Roy 1977 (DNMNH), Id by Uvarov (KNM) & Id by Albert John Hesse (ISAM). Please refer to the comment section of this paper for this species.

Subgenus *Danuriodes* Giglio-Tos, 1907

38. *Danuria kilimandjarica* Sjostedt, 1909 [NAM & ZIM]
Id by Albert John Hesse (ISAM).

Subgenus *Danuria* Stäl, 1856

39. *Danuria thunbergi* Stäl, 1856 [SA, MOZ, NAM, ZAM & ZIM]
Id by F.W. Gess (AMG), Id by Guy Anstruther Knox Marshall, Rehn 1925 & Kaltenbach 1992 (DNMNH), Id by Uvarov (KNM) & Id by Albert John Hesse (ISAM).

SUBFAMILY DYSTACTINAE Giglio-Tos, 1915

Tribe Dystactini Giglio-Tos, 1915

40. *Dystacta alticeps* Schaum, 1852 [SA, MOZ, NAM & ZIM]
Id by Kaltenbach 1984 (ARC), Id by Rehn 1925, Max Beier 1952 & Roger Roy 1977 (DNMNH) & Id by George Arnold (ISAM).

41. *Pseudodystacta braueri* Karny, 1908 [SA]
Identifier not specified (ISAM).

SUBFAMILY HETEROCHAETINAE Brunner de Wattenwyl, 1893

42. *Heterochaeta occidentalis* Beier, 1963 [SA & NAM]
Id by Kaltenbach & Roger Roy (DNMNH), Id by J.A.G. Gain (NMB) & Id by Albert John Hesse (ISAM).

SUBFAMILY MANTINAE Latreille, 1802

Tribe Mantini Beier, 1964

43. *Mantis religiosa* Linne, 1758 [SA, NAM, MOZ, SW & ZIM]
Id by Moulin (ARC & RUG), Id by Rehn 1925 & Kaltenbach 1985 (DNMNH) & Id by Albert John Hesse (ISAM).

44. *Omomantis zebrata* Charpentier, 1843 [SA, BOT, NAM, MOZ & ZIM]
Id by H.D. Brown (ARC), Id by Rehn 1925 & Kaltenbach 1985 (DNMNH), Id by Uvarov (KNM) & Id by Albert John Hesse & Stiewe (ISAM).

Tribe Paramantini Roy, 1973

45. *Bisanthe pulchripennis* Stäl, 1876 [SA, BOT, NAM & ZIM]
Id by Rehn 1925, Max Beier 1952 & Kaltenbach 1989 (DNMNH) & Id by Albert John Hesse (ISAM).

46. *Hierodula* sp. Burmeister, 1838 [SA]
Id by J.A.G Gain (NMB). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is thus a new record of this species in southern Africa.

47. *Paramantis natalensis* Stäl, 1856 [SA]
Id by Roger Roy & Kaltenbach 1984 (DNMNH).

48. *Paramantis sacra* Thunberg, 1815 [SA & BOT]
Id by Kaltenbach 1991 (DNMNH) & Id by Albert John Hesse (ISAM).

49. *Rhomboderella scutata* Bolivar, 1889 [SA & ZIM]
Id by Moulin (ARC & NMB) & Id by Albert John Hesse (ISAM).

50. *Sphodromantis gastrica* Stäl, 1858 [SA, BOT, NAM, SW & ZIM]
Id by Kaltenbach 1988 (DNMNH), Id by Kaltenbach 1984 & Moulin (ARC), Id by Uvarov (KNM) & Id by Albert John Hesse (ISAM).

51. *Sphodromantis viridis* Forskal, 1775 [ZIM]
Identifier not specified (ARC).

Tribe Polyspilotini Giglio-Tos, 1917

52. *Polyspilota aeruginosa* Goeze, 1778 [SA, MOZ, NAM, TZ & ZIM]
Id by Rehn 1925, Max Beier 1952 & Roger Roy 1977 (DNMNH), Id by Kaltenbach 1984 (ARC), Id by Uvarov (KNM) & Id by Albert John Hesse & Stiewe (ISAM).

53. *Polyspilota caffra* Westwood, 1889 [SA & ZIM]
Id by Max Beier 1952 & Roger Roy 1977 (DNMNH) & Id by Guillarmod (AMG).

54. *Tenodera capitata* Saussure, 1869 [SA, MOZ, MAL & ZIM]
Id by Kaltenbach 1992 (DNMNH).

55. *Tenodera iringana* Giglio-Tos, 1912 [SA]
Id by Max Beier 1952 (DNMNH). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is thus a new record of this species in southern Africa.

56. *Tenodera sinensis* Saussure, 1871 [SA]
Identifier not specified (ISAM). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is thus a new record of this species in southern Africa.

57. *Tenodera superstitiosa* Fabricius, 1781 [SA, MOZ, TZ, ZAM & ZIM]
Id by Rehn 1925, Max Beier 1952 & Kaltenbach 1985 (DNMNH).

SUBFAMILY MIOMANTINAE Westwood, 1889

Tribe Miomantini Westwood, 1889

58. *Cilnia chopardi* Werner, 1927 [SA]
Id by Max Beier 1952 (DNMNH).

59. *Cilnia humeralis* Saussure, 1871 [SA, NAM & ZIM]
Id by Rehn 1925 & Kaltenbach 1985 (DNMNH), Id by Kaltenbach 1984 (ARC), Id by Uvarov (KNM) Id by J.A.G Gain (NMB) & Id by Albert John Hesse & Stiewe (ISAM).

60. *Neocilnia gracilis* Beier, 1930 [SA]

61. *Miomantis aequalis* Rehn, 1904 [SA]
Id by Rehn 1925 (DNMNH).

62. *Miomantis caffra* Saussure, 1871 [SA]
Id by Rehn 1925, Roger Roy & Kaltenbach 1992 (DNMNH).

63. *Miomantis coxalis* Saussure, 1898 [SA]
Id by Rehn 1925, Max Beier 1952 & Kaltenbach 1988 (DNMNH) & Id by Albert John Hesse (ISAM).

64. *Miomantis exilis* Giglio-Tos, 1911 [SA, BOT & NAM]
Id by Rehn 1925, Max Beier 1952 & Kaltenbach 1988 (DNMNH) & Id by Albert John Hesse (ISAM).

65. *Miomantis fenestrata* Fabricius, 1781 [SA]
Id by Rehn 1925 & Kaltenbach 1988 (DNMNH), Id by Uvarov (KNM) & Id by Albert John Hesse (ISAM).

66. *Miomantis helenae* Giglio-Tos, 1914 [SA & ZIM]
Id by Max Beier 1952 & Dept. Kaltenbach 1988 (DNMNH).

67. *Miomantis monacha* Fabricius, 1787 [MOZ]
Id by Albert John Hesse (ISAM).

68. *Miomantis natalica* Beier, 1930 [SA, NAM & ZIM]
Id by Kaltenbach 1988/1992 (DNMNH) & Id by C.S. Cummings (AMG).

69. *Miomantis prasina* Burmeister, 1838 [SA]
Id by Kaltenbach 1981 (DNMNH).

70. *Miomantis quadripunctata* Saussure, 1898 [SA & MOZ]
Id by Kaltenbach 1988/1992 (DNMNH), Id by Erhmann 1991 (ARC) & Id by Albert John Hesse (ISAM).

71. *Miomantis saussurei* Schulthess-Rechberg, 1899 [SA, MOZ & ZIM]
Id by Rehn 1925 (DNMNH) & Id by Albert John Hesse (ISAM).

72. *Miomantis semialata* Saussure, 1872 [SA & ZIM]
Id by Max Beier 1952 & Kaltenbach 1985 (DNMNH) & Id by Albert John Hesse (ISAM).

73. *Taumantis globiceps* Beier, 1969 [SA]
Id by Dept. Erhmann 1991 (ARC).

Tribe Rivetinini Ehrmann & Roy, 2002

74. *Carvilia saussurii* Stäl, 1876 [NAM]
Id by Albert John Hesse (ISAM).

75. *Ischnomantis fatiloqua* Stäl, 1856 [SA, NAM & ZIM]
Id by Rehn 1925, Roger Roy 1976 & Moulin (DNMNH), Id by F.W. Gess (AMG), Id by Erhmann 1991 (ARC) & Id by Albert John Hesse (ISAM).

76. *Ischnomantis grandis* Saussure, 1869 [SA]
Identifier not specified (ARC).

77. *Solygia sulcatifrons* Serville, 1839 [SA]
Id by Uvarov (KNM).

SUBFAMILY SCHIZOCEPHALINAE Saussure, 1869

78. *Schizocephala bicornis* Linne, 1758 [SA]
Id by J.A.G Gain (NMB). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is thus a new record of this species in southern Africa.

FAMILY IRIDOPTERYGIDAE Giglio-Tos, 1915

SUBFAMILY HAPALOMANTINAE Beier, 1964

Tribe Hapalomantini Beier, 1964

Subgenus *Bolbena* Giglio-Tos, 1915

79. *Bolbena hottentotta* Karny, 1908 [AG & NAM]
Id by Albert John Hesse (ISAM).

Subgenus *Bolboda* Giglio-Tos, 1915

80. *Bolbena minutissima* Karny, 1908 [SA]
Id by Max Beier 1952 (DNMNH).

81. *Hapalogymnes gymnes* Rehn, 1927 [SA]
Id by Rehn 1925 (DNMNH).

Subgenus *Hapalomantis* Saussure, 1871

82. *Hapalomantis orba* Stäl, 1856 [SA]
Id by Max Beier 1952 (DNMNH) & Id by Albert John Hesse (ISAM).

83. *Tarachina schultzei* Karny, 1908 [SA, NAM & ZIM]
Id by Rehn 1925 (DNMNH) & Id by Albert John Hesse (ISAM).

84. *Tarachina transvaalensis* Beier, 1953 [SA & NAM]
Id by Kaltenbach 1989 (DNMNH) & Id by Erhmann 1991 (ARC).

SUBFAMILY TROPIDOMANTINAE Giglio-Tos, 1915

Tribe Tropidomantini Giglio-Tos, 1915

85. *Negromantis gracillima* Kaltenbach, 1996 [SA]
Id by Kaltenbach (ISAM).
FAMILY AMORPHOSCELIDAE Stäl, 1877

SUBFAMILY AMORPHOSCELINAE Stäl, 1877

Tribe Amorphoscelini

86. *Amorphoscelis austrogermanica* Werner, 1923 [SA]
Id by Roger Roy 1962. (DNMNH).

87. *Amorphoscelis tuberculata* Roy, 1963 [SA, NAM & ZIM]
Id by Roger Roy 1976. (DNMNH).

FAMILY EMPUSIDAE Burmeister, 1838

SUBFAMILY BLEPHARODINAE Giglio-Tos, 1919

88. *Idolomantis diabolica* Saussure, 1869 [SA]
Id by Moulin (DNSM)**.** This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is thus a new record in southern Africa.

SUBFAMILY EMPUSINAE Burmeister, 1838

89. *Idolomorpha dentifrons* Saussure & Zehntner, 1895 [SA, MOZ & NAM]
Id by Albert John Hesse (ISAM).

Tribe Empusini Burmeister, 1838

90. *Empusa guttula* Thunberg, 1815 [SA, BOT & NAM]
Id by Albert John Hesse & Stiewe (ISAM) & Id by Roger Roy 1977 (DNMNH).

91. *Empusa spinosa* Krauss, 1902 [SA, AG & NAM]
Id by H.D Brown (ARC), Id by Kaltenbach 1998 (DNMNH), Id by J.A.G Gain (NMB) & Id by Stiewe (ISAM).

Tribe Idolomorphini Ehrmann & Roy, 2002

92. *Hemiempusa capensis* Burmeister, 1838 [SA, NAM, ZAM & ZIM]
Id by Roger Roy 1977 & Rehn 1916 (DNMNH), Id by F.W. Gess (AMG), Id by Albert John Hesse (ISAM) & Id by Uvarov (KNM).

FAMILY GALINTHIADIDAE Giglio-Tos 1919

93. *Galinthias amoena* Saussure, 1871 [SA]
Id by Roger Roy 1976 (DNMNH) & Id by Albert John Hesse (ISAM).

94. *Harpagomantis tricolor* Linne, 1758. [SA, BOT, LS, NAM & ZIM]
Id by Roger Roy 1977 & Max Beier 1952, (DNMNH), Id by F.W. Gess (AMG), Id by Max Beier 1953, Kaltenbach 1984 & Erhmann 1991 (ARC), Id by S. Louw (NMB), Id by Albert John Hesse & Stiewe (ISAM) & Id by Uvarov (KNM).

95. *Harpagomantis discolor* Stäl, 1877 [SA, ZIM & MOZ]
Id by Roger Roy 1977 & Rehn 1925 (DNMNH) & Id by Uvarov (ARC). Please refer to the comment section of this paper for this species.

96. *Pseudoharpax ugandanus* Giglio-Tos, 1915 [ZIM]
Id by Albert John Hesse (ISAM).

FAMILY HYMENOPODIDAE Giglio-Tos, 1915

SUBFAMILY OXYPILINAE Saussure, 1871

Tribe Oxypilini Saussure, 1871

97. *Junodia strigipennis* Westwood, 1889 [SA, SW, ZAM & ZIM]
Id by Roger Roy 1977 & Rehn 1925 (DNMNH) & Id by Albert John Hesse (ISAM).

SUBFAMILY ACROMANTINAE Brunner de Wattenwyl, 1893

Tribe Otomantini Giglio-Tos, 1915

98. *Otomantis scutigera* Bolivar, 1890 [SA & MOZ]
Id by Albert John Hesse (ISAM).

99. *Oxypiloidea tridens* Saussure, 1872 [SA & MOZ]
Id by Roger Roy 1988 (DNMNH) & Id by Albert John Hesse (ISAM).

Tribe Oxypilini Saussure, 1871

Subgenus *Anoxypilus* Giglio-Tos, 1915

100. *Oxypilus capensis* Saussure, 1871 [SA, NAM & ZAM]
Id by Roger Roy 1976/1977 & Max Beier 1952 (DNMNH), Id by Kaltenbach 1984 (ARC), Id by Albert John Hesse (ISAM) & Id by Uvarov (KNM).

101. *Oxypilus inscriptus* Beier, 1955 [SA]
Id by Roger Roy 1966 (DNMNH). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and are thus a new record of these species in southern Africa.

102. *Oxypilus transvalensis* Giglio-Tos, 1915 [SA & NAM]
Id by Kaltenbach 1984 (ARC).

SUBFAMILY PHYLLOCRANIINAE Brunner de Wattenwyl, 1893

103. *Phyllocrania paradoxa* Burmeister, 1838 [SA, AG, DRC, NAM & ZIM]
Id by Rehn 1925, Roger Roy 1977, Max Beier 1952 & Kaltenbach 1998 (DNMNH), Id by Kaltenbach 1985 (ARC), Id by Albert John Hesse (ISAM) & Id by Uvarov (KNM).

104. *Phyllocrania insignis* Westwood, 1843 [SA]
Id by H.D. Brown (ARC). Please refer to the comment section of this paper for this species.

SUBFAMILY HYMENOPODINAE Giglio-Tos, 1915

Tribe Hymenopodini Giglio-Tos, 1915

105. *Pseudocreobotra ocellata* Beauvois, 1805 [SA]
Id by Max Beier 1952 (DNMNH).

106. *Pseudocreobotra wahlbergi* Stäl, 1871 [SA, MAL, MOZ, TZ & ZIM]
Id by Rehn 1925 & Dept. Kaltenbach 1998 (DNMNH), Id by H.D. Brown (ARC), Id by Albert John Hesse (ISAM) & Id by Kaink (AMG).

SUBFAMILY SIBYLLINAE Giglio-Tos, 1915

Subgenus *Sibylla* Stäl, 1856

107. *Sibylla pretiosa* Stäl, 1856 [SA, SW, NAM & ZIM]
Id by Erhmann 1991 & H.D. Brown (ARC), Id by Rehn 1925, Max Beier 1952 & Roger Roy 1977 (DNMNH), Id by Albert John Hesse & Stiewe (ISAM) & Id by Uvarov (KNM).

FAMILY TARACHODIDAE Handlirsch, 1930

SUBFAMILY TARACHODINAE Giglio-Tos, 1917

Tribe Tarachodini Giglio-Tos, 1917

108. *Ariusia conspersa* Stäl, 1877 [SA]
Id by Moulin (NMB).

109. *Antistia maculipennis* Stäl, 1876 [SA, SW & NAM]
Id by Max Beier 1952 & Kaltenbach 1984/1989 (DNMNH) & Id by Albert John Hesse (ISAM).

110. *Antistia parva* Beier, 1953 [SA & NAM]
Id by Kaltenbach 1989 (DNMNH) & Id by Kaltenbach 1984 (ARC).

Subgenus *Syngalepsus* Beier, 1954

111. *Galepsus bipunctatus* Beier, 1931 [SA]
Id by Kaltenbach 1991 (DNMNH).

Subgenus *Onychogalepsus* Beier, 1954

112. *Galepsus capitatus* Saussure, 1869 [SA & ZIM]
Id by Kaltenbach 1991 (DNMNH) & Id by Kaltenbach 1984 (ARC).

113. *Galepsus centralis* Beier,1957
Id by Nicolas Moulin 2019

114. *Galepsus damaranus* Giglio-Tos, 1911 [BOT]
Id by Roger Roy 1977 (DNMNH).

115. *Galepsus femoratus* Giglio-Tos, 1911 [SA, NAM & ZIM]
Id by Albert John Hesse (ISAM).

116. *Galepsus intermedius* Werner, 1907 [SA & MOZ]
Id by Rehn 1925 & Kaltenbach 1991 (DNMNH) & Id by Erhmann 1991 & H.D. Brown (ARC).

117. *Galepsus meridionalis* Saussure, 1872 [SA, MOZ, NAM & ZIM]
Id by Kaltenbach 1991 (DNMNH), Id by Uvarov (KNM) & Id by Albert John Hesse (ISAM).

118. *Galepsus pentheri* Giglio-Tos, 1911 [SA & ZIM]
Id by Kaltenbach 1991 (DNMNH) & Id by Kaltenbach 1984 (ARC).

119. *Galepsus rhodesicus* Beier, 1954 [ZAM]
Id by Kaltenbach 1989 (DNMNH).

120. *Galepsus transvaalensis* Beier, 1954 [SA]
Id by Kaltenbach 1989 (DNMNH) & Id by Kaltenbach 1984 (ARC).

Subgenus *Lygdamia* Stäl, 1877

121. *Galepsus lenticularis* Saussure, 1872 [SA, AG, MOZ, NAM, ZIM & ZAM]
Id by Max Beier 1952 & Kaltenbach 1991 (DNMNH) & Id by Albert John Hesse (ISAM).

122. *Episcopomantis chalybea* Burmeister, 1838 [SA, BOT, KN, ZIM & NAM]
Id by Roger Roy 1977 (DNMNH), Id by Kaltenbach 1984 (ARC) & Id by Albert John Hesse & Stiewe 2003 (ISAM).

123. *Oxyelaea elegans* Giglio-Tos, 1917 [SA]
Id by Stiewe (KNM & NMB). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is thus a new record of this species in southern Africa.

124. *Nothogalepsus planivertex* Beier, 1953 [SA & NAM]
Id by Kaltenbach 1992 (DNMNH).

125. *Pyrgomantis fasciata* Giglio-Tos 1917 [MOZ]
Identifier not specified (DNSM). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is thus a new record of this species in southern Africa.

126. *Pyrgomantis nasuta* Thunberg, 1784 [SA, BOT, MOZ, NAM & ZIM]
Id by Rehn 1925 (DNMNH), Id by Erhmann 1991 (ARC) & Id by Albert John Hesse (ISAM).

127. *Pyrgomantis rhodesica* Giglio-Tos, 1917 [SA & BOT]
Id by Max Beier 1952 & Kaltenbach 1992 (DNMNH) & Id by Kaltenbach 1984 (ARC).

128. *Pyrgomantis simillima* Beier, 1954 [SA]
Id by Kaltenbach 1992 (DNMNH).

129. *Pyrgomantis singularis* Gerstaecker, 1869 [SA]
Identifier not specified (DNMNH). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is thus a new record of this species in southern Africa.

Subgenus *Chiropus* Saussure, 1869

130. *Tarachodes dives* Saussure, 1869 [SA, AG, NAM & ZIM]
Id by Kaltenbach 1992 (DNMNH) & Id by Albert John Hesse (ISAM).

Subgenus *Tarachodes* Burmeister, 1838

131. *Tarachodes bicornis* Giglio-Tos, 1911 [ZIM]
Id by Albert John Hesse (ISAM).

132. *Tarachodes insidiator* Wood-Mason, 1882 [SA, MOZ, NAM & SW]
Id by Rehn 1925 & Kaltenbach 1989 (DNMNH), Id by Uvarov (KNM) & Id by Albert John Hesse (ISAM).

133. *Tarachodes lucubrans* Burchell, 1822 [SA, NAM & ZIM]
Id by Max Beier 1952, Roger Roy 1977 & Kaltenbach 1989 (DNMNH) & Id by Albert John Hesse (ISAM).

134. *Tarachodes maurus* Stäl, 1856 [SA, NAM, ZAM & ZIM]
Id by Max Beier 1952 (DNMNH) & Id by Albert John Hesse (ISAM).

135. *Tarachodes perloides* Burmeister, 1838 [SA]
Identifier not specified (ARC).

136. *Tarachodes sanctus* Saussure, 1871 [SA, MOZ, NAM, ZAM & ZIM]
Id by Max Beier 1952 & Kaltenbach 1992 (DNMNH) & Id by Albert John Hesse (ISAM).

FAMILY TOXODERIDAE Saussure, 1869

SUBFAMILY TOXODERINAE Saussure, 1869

Tribe Toxoderini Saussure, 1869

137. *Toxodera* sp. Serville, 1837 [SA, AG & ZAM]
Id by H.D. Brown (ARC) & Id by G. Cock (NMB). This species was not mentioned in the species list compiled by Kaltenbach in 1996 and is thus a new record of this species in southern Africa.

5.4.2 List of species from literature not in South Africa collections

The 43 species listed below were recorded by Kaltenbach (1996; 1998), however, no record of these species were found in any of the South African insect collections or museums.

FAMILY THESPIDAE Saussure, 1869

SUBFAMILY HOPLOCORYPHINAE Giglio-Tos, 1916

1. ***Hoplocorypha boromensis* Brancsik, 1895 [MOZ]**
2. ***Hoplocorypha brevicollis* Beier, 1931 [SA]**
3. ***Hoplocorypha garuana* Giglio-Tos, 1916 [AG & NAM]**
4. ***Hoplocorypha perplexa* Rehn, 1912 [NAM]**
5. ***Hoplocorypha turneri* Beier, 1930 [NAM]**

FAMILY MANTIDAE Latreille, 1802

SUBFAMILY AMELINAE Westwood, 1889

Tribe Amelini Westwood, 1889

6. ***Bolbella brevis* Beier, 1953 [SA]**

SUBFAMILY CHROICOPTERINAE Giglio-Tos, 1915

Tribe Chroicopterini Giglio-Tos, 1915

7. ***Chroicoptera longa* Giglio-Tos, 1915 [SA]**
8. ***Ligaria aberrans* Karny, 1908 [NAM, ZIM & BOT]**

Subgenus *Entella* Stäl, 1877

9. ***Entella exilis* Giglio-Tos, 1915 [SA]**
10. ***Entella natalica* Beier, 1955 [SA]**
11. ***Entella orientalis* Giglio-Tos, 1915 [SA, TZ & MOZ]**
12. ***Entella rudebecki* Beier, 1955 [LS]**

SUBFAMILY COMPSOTHESPINAE Giglio-Tos, 1913

13. ***Compsothespis cinnabarina* Beier, 1955 [SA]**
14. ***Compsothespis kilwana* Giglio-Tos, 1913 [SA]**
15. ***Compsothespis michaelseni* Werner, 1923 [NAM]**

SUBFAMILY HETEROCHAETINAE Brunner de Wattenwyl, 1893

16. *Heterochaeta reticulata* Roy, 1976 [TZ & ZIM]

SUBFAMILY MANTINAE Latreille, 1802

Tribe Paramantini Roy, 1973

17. *Paramantis prasina* Serville, 1839 [SA, MT & CAM]

18. *Bisanthe modesta* Giglio-Tos, 1917 [MOZ & ZAM]

Subspecies *Menyharthi* Brancsik, 1895

19. *Bisanthe menyharthi* Brancsik, 1895 [MOZ & ZAM]

Tribe Polyspilotini Giglio-Tos, 1917

20. *Polyspilota caffra* Westwood, 1889 [SA & ZIM]

21. *Polyspilota magna* Giglio-Tos, 1911 [SA]

SUBFAMILY MIOMANTINAE Westwood 1889

Tribe Miomantini Westwood 1889

22. *Miomantis acuticeps* Beier, 1969 [ZIM & MAL]

23. *Miomantis australis* Beier, 1930 [NAM]

24. *Miomantis binotata* Giglio-Tos, 1911 [TA]

25. *Miomantis brevipennis* Saussure, 1872 [SA]

26. *Miomantis lacualis* Giglio-Tos, 1911 [MOZ]

27. *Miomantis minuta* Giglio-Tos, 1911 [SA]

28. *Miomantis moerana* Giglio-Tos, 1917 [CA]

29. *Miomantis paykulli* Stäl, 1871 [SA & MT]

30. *Parasphendale costalis* Kirby, 1904 [ET]

31. *Parasphendale gracilicollis* Beier, 1930 [ZIM]

Tribe Rivetinini Ehrmann & Roy, 2002

32. *Geothespis australis* Giglio-Tos, 1916 [SA & NAM]

FAMILY IRIDOPTERYGIDAE Giglio-Tos, 1915

SUBFAMILY HAPALOMANTINAE Beier, 1964

Tribe Hapalomantini Beier, 1964

33. *Tarachina constricta* Werner, 1923 [NAM]

34. *Bolbena minor* Giglio-Tos, 1915 [NAM]

Subgenus Bolbira Giglio-Tos,1915

35. *Hapalomantis minima* Werner, 1906 [SA, ZIM & AG]

FAMILY HYMENOPODIDAE Giglio-Tos, 1915

SUBFAMILY ACROMANTINAE Brunner de Wattenwyl, 1893

Tribe Otomantini Giglio-Tos, 1915

36. *Otomantis rendalli* Kirby, 1899 [SA]

SUBFAMILY OXYPILINAE Saussure, 1871

Tribe Oxypilini Saussure, 1871

37. *Junodia amoena* Schulthess-Rechberg, 1899 [MOZ & TZ]

38. *Oxypilus meruensis* Sjostedt, 1909 [AG, ZIM, ZAM & MOZ]

FAMILY TARACHODIDAE Handlirsch, 1930

SUBFAMILY TARACHODINAE Giglio-Tos, 1917

Tribe Tarachodini Giglio-Tos, 1917

Subgenus *Lydamia* Stäl,1877

39. *Galepsus brincki* Beier, 1955 [NAM]

Subgenus *Onychogalepsus* Beier, 1954

40. *Galepsus focki* Werner, 1923 [NAM]

Subgenus Tarachodes Burmeister, 1838

41. *Tarachodes okahandyanus* Giglio-Tos, 1911 [NAM]

FAMILY TOXODERIDAE Saussure, 1869

SUBFAMILY TOXODERINAE Saussure, 1869

Tribe Calamothespini Giglio-Tos, 1914

42. *Calamothespis lineatipennis* Werner, 1923 [NAM]

43. *Calamothespis oxyops* Rehn, 1927 [SA]

5.4.3 Described specimens without Holotypes in South Africa.

The following Genera (3), Subgenus (1) and species (18) where described by Kaltenbach (1996), however the only records of these specimen records exist in Kaltenbach (1996) as the Holotype specimen are no longer located in any of the South African insect collections and museums.

FAMILY MANTIDAE Latreille, 1802

SUBFAMILY AMELINAE Westwood, 1889

Tribe Amelini Westwood, 1889

1. *Bolbella affinis* Kaltenbach, 1996 [SA]

2. *Dystactula natalensis* Kaltenbach, 1996 [SA]

SUBFAMILY CHROICOPTERINAE Giglio-Tos, 1915

Tribe Chroicopterini Giglio-Tos, 1915

3. *Ligentella beieri* Kaltenbach, 1996 [NAM]

4. *Namamantis nigropunctata* Kaltenbach, 1996 [SA]

5. *Ligaria inexpectata* Kaltenbach, 1996 [ZIM]

Subgenus *Euentella* Kaltenbach, 1996

6. *Entella gaerdesi* Kaltenbach, 1996 [AG & NAM]

SUBFAMILY MANTINAE Latreille, 1802

Tribe Paramantini Roy, 1973

7. *Bisanthe lagrecai* Kaltenbach, 1996 [SA]

SUBFAMILY MIOMANTINAE WESTWOOD, 1889

Tribe Rivetinini Ehrmann & Roy, 2002

8. *Carvilia gracilis* Kaltenbach, 1996 [SA]

SUBFAMILY OXYOTHESPINAE Giglio-Tos, 1916

Tribe Oxyothespini Giglio-Tos, 1916

9. *Oxyothespis meridionalis* Kaltenbach, 1996 [AG, BOT]

FAMILY IRIDOPTERYGIDAE Giglio-Tos, 1915

SUBFAMILY HAPALOMANTINAE Beier, 1964

Tribe Hapalomantini Beier, 1964

Subgenus Bolbena Giglio-Tos, 1915

10. *Bolbena assimilis* Kaltenbach, 1996 [NAM]

11. *Bolbena maraisi* Kaltenbach, 1996 [NAM]

SUBFAMILY TROPIDOMANTINAE Giglio-Tos, 1915

Tribe Tropidomantini Giglio-Tos, 1915

12. *Chloromantis rhombica* Giglio-Tos, 1915 [MOZ & ZIM]

FAMILY TARACHODIDAE Handlirsch, 1930

SUBFAMILY TARACHODINAE Giglio-Tos, 1917

Tribe Tarachodini Giglio-Tos, 1917

13. *Antistia robusta* Kaltenbach, 1996 [SA]

14. *Antistia vicina* Kaltenbach, 1996 [SA]

Subgenus *Onychogalepsus* Beier, 1954

15. *Galepsus ulricae* Kaltenbach, 1996 [NAM]

16. *Galepsus letabaensis* Kaltenbach, 1996 [SA]

Subgenus *Tarachodes* Burmeister, 1838

17. *Tarachodes beieri* Kaltenbach, 1996 [SA, ZIM]

18. *Tarachodes namibiensis* Kaltenbach, 1996 [NAM]

Subgenus *Tarachodina* Kirby, 1904

19. *Tarachodes natalensis* Kaltenbach, 1996 [SA]

5.5 Comments

This species list provides a review encompassing all the known records of Mantodea species in museum collections in South Africa.
It should be noted that three of the species i.e. *Tenodera sinensis* (Saussure), *Pyrgomantis fasciata* (Giglio-Tos) and *Pyrgomantis singularis* (Gerstaecker), which are newly listed to occur in southern Africa, should be taken under advisement as their taxonomic identifier was not specified by the collection that hosted the specimens. Similarly, the following four

species, i.e. *Pseudodystacta braueri* (Karny), *Sphodromantis viridis* (Forskal), *Ischnomantis grandis* (Saussure) and *Tarachodes perloides* (Burmeister) were also identified by unspecified taxonomists. Beyond the above mentioned unspecific identifiers however, as indicated, only three other anomalies where detected.

First, *Phyllocrania insignis* (Westwood, 1843) was indicated by Kaltenbach (1996) to be a synonym of *Phyllocrania paradoxa* (Burmeister, 1838) as he noted that this was deduced by Giglio-Tos in 1927. However, both these species are present in the South African collections and are also listed in the data base of the Mantodea species file (2005) website. Giglio-Tos (1927) mentioned that these two species are very similar but that *P. insignis* differs from *P. paradoxa* with regard to differences in wing venation towards the edges of the forewings. It was also suggested that Westwood (author of *P. insignis*) might have mistaken a female *P. insignis* as a male specimen. In the 1871 paper by Saussure, *P. insignis* was indicated to differ in terms of the shape of the process of the vertex ("top of the head capsule"). However, since no record of the original species description by Westwood in 1843 could be found, and the classification of this species list was updated with the use of the Mantodea species file website (2005–2018), this species is included in this updated version of the southern Africa Mantodea species list. *Phyllocrania insignis* is therefore not regarded as a synonym of *Phyllocrania insignis* as suggested by Kaltenbach (1996). However, as indicated in the Mantodea species file (2005), further investigation is required into this matter.

A similar situation was recorded in Kaltenbach (1996) regarding the species *Popa spurca* (Stäl, 1856). According to Kaltenbach (1996) *P. spurca* was a biotype of *Popa undata* (Fabricius, 1793). However, the Mantodea species file (2005) lists *P. undata* as a synonym of *P. spurca* in the subgenus *spurca.* This was the case for most publications that provide information on this species (Lombardo 1995; Prete et al*.* 2013; Svenson et al. 2015). For this reason, the identification of all *P. undata* specimens found in museum collections during this study was updated to reflect the more appropriate name, *P. spurca*.

Last, an anomaly was uncovered regarding *Harpagomantis discolor* (Stäl, 1877). Specimen records exist for both *Harpagomantis tricolor* (L., 1758) and *H. discolor* as was the case with the above mentioned *P. paradoxa* and *P. insignis*. Kaltenbach (1996) stated that the taxonomic status of *H. discolor* was unclear. According to Giglio-Tos (1927), *H. discolor* males do not have a brown spot on the hindwings and this species is generally larger than *H. tricolor*. Rehn (1927) stated that *H. tricolor* is a much smaller species with limited distribution (mostly in the Western Cape region of South Africa) while *H. discolor* occurs throughout South Africa. The latter species is also larger and have elongated processes on eyes (non-visual elongations that do not contain ommatidia).

However, Karny (1908) suggested that *H. discolor* could be a variety *of H. tricolor*. This view was shared by Beier (1955) which stated that *H. discolor* was a "pigment-poor" variety of *H. tricolor*. A similar conclusion was drawn by Kaltenbach (1996) and this species was therefore regarded as a variety by Kaltenbach (1966). Ehrmann (2002) agreed with Beier (1935; 1955) and Kaltenbach (1996) and noted that *H. discolor* was a synonym for *H. tricolor*. Since the Mantodea species file (2020) recognizes both of these species of *Harpagomantis*, and also highlighted that further investigation into this unique genus is needed.

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CHAPTER 6: ARTICLE 4

Distribution of *Popa* spp. in southern Africa and life history of the African twig mantid, *Popa spurca* (Mantodea: Mantidae)

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Bianca Greyvenstein[a], Hannalene du Plessis[b] and Johnnie van den Berg[c]

a-c: Unit for Environmental Sciences and Management, North-West University, Potchefstroom, 2520, South Africa

a: Correspondence: biagrey90@gmail.com

6.1 ABSTRACT

Popa spurca (Stäl) (Mantidae) is a well-known species within the African Mantodea. Because this species is often kept as pets, several citizen-based platforms provide information on rearing of this species. There is however no scientific information available on the distribution and biology of this species. The aim of this study was to use museum records to establish the distribution of *P. spurca* in southern Africa and specifically South Africa, and to investigate its biology under captive breeding and rearing conditions. A total of 212 specimen records of *P. spurca* were recorded during a survey of all Mantodea in the national museum collections in South Africa. Although very few distribution records (15) of *P. spurca* were from beyond the borders of South Africa, records indicate that it is distributed throughout southern Africa. Inside South Africa, the distribution of this genus seems to be largely associated with the Savanna biome. Rearing was done in an insect rearing room under controlled conditions and live crickets (*Acheta* sp.) were provided as food. Some of the life-history parameters of *P. spurca* differed between males and females, for example, nymphal developmental duration (from the 5th to the 8th instar) and adult longevity were significantly longer in females. The average lifespan of a *P. spurca* individual was 332 ± 62 days. The mean length and width of the oothecae were 18 mm and 11 mm respectively. Oothecae contained an average of 84 ± 30 eggs and the mean incubation period was 35 ± 4 days. This study contributes to the understanding of the biology of *P. spurca* which has never been studied before in southern Africa.

KEYWORDS arthropod biodiversity, biology, IUCN, praying mantis, threatened species

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6.2 Introduction

Mantodea is a relatively small order comprising of approximately 2400 species in 21 families (Otte et al. 2020; McMonigle 2013). The Mantidae is the largest family in this order and has approximately 16 subfamilies and more than 1000 species (Otte et al. 2020).

The *Popa* genus is within the Danuriinae subfamily which also includes six other genera. In total, the Danuriinae subfamily consists of 29 species (Otte et al. 2020; Patel and Singh 2016). Two of these 29 species are *Popa* spp. and it is assumed that this genus is distributed throughout sub-Sahara Africa (Lomardo 1995). The two species within the *Popa* genus is *Popa gracilis* (Schulthess-Schindler) and *Popa spurca* (Stäl). The latter species does however have three subspecies, i.e. *Popa spurca spurca* (Stäl), *Popa spurca crassa* (Giglio-Tos) and *Popa spurca pallida* (Saussure & Zehntner) (Otte et al. 2020).

Recently, Schwarz and Roy (2019) redefined the taxonomic system of Mantodea, placing the *Popa* genus in the tribe Popini, subfamily Popinae, in the family Deroplatyidae. However, the above mentioned species and subspecies were not addressed in the study by

Schwarz and Roy (2019) and to our knowledge the taxonomic status of *Popa* spp. and its three subspecies remains the same as recently indicated by Otte et al. (2020). *Popa spurca spurca* will hereafter be referred to as *P. spurca.*

Popa spurca is known as the twig-mimicking African mantis and it has a relatively thick, stocky and elongated body (Schwarz 2004; McMonigle 2013; Prete et al. 2013). According to Paulian (1957), McMonigle (2013) and Green (2014), *P. spurca* is native to sub-Saharan Africa and Madagascar. Except for the study by Schwarz (2004) and the revision of the *Popa* genus by Lomardo (1995), little scientific information regarding this species is available. Various internet sources do however provide instructions on how to rear this mantid species and also to keep it as a pet (Mantidforum 2020; Mantiszoo 2020).

Little information on the distribution of the Mantodea is available and virtually no information exists on their ecology and life history strategies. Data on biodiversity, distribution and biology of arthropod groups, particularly the Mantodea, is required in order to identify potential threats and to develop conservation strategies if needed. For example, the only information available on potential diseases and threats to this group is that provided by Schmidt-Rhaesa and Ehrmann (2001) who indicated that horsehair worms (Nematomorpha) (Figure 6.1) are parasites of praying mantids throughout the world. Horsehair worms have previously been identified from *P. spurca crassa* in Kenya, Sierra Leone and South Africa. Aquatic larvae serve as the intermediate hosts of these parasites and are thus the vectors transmitting this parasite from its free living aquatic environment to the terrestrial environment (Schmidt-Rhaesa and Ehrmann 2001).

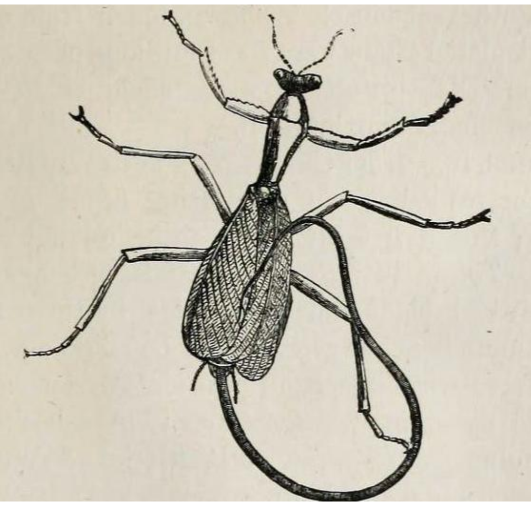

Figure 6.1. A line drawing of a mantis that is parasitized by a horsehair worm. (Smith et al. 1901).

Parasites are not the only threats to mantids, climate change also poses an imminent threat. Recently, Hurd et al. (2019) reported that climate change could potentially disrupt developmental aspects of *Tenodera aridifolia sinensis* Saussure (Mantidae: Mantinae). For example, population growth of *T. aridifolia sinensis* under field conditions in Virginia (USA), was reported to be affected by increased temperatures and extended plant growth seasons experienced from 1995 to 2018. Females of *T. aridifolia sinensis* matured quicker and laid their oothecae earlier in the season. This may result in oothecae not going into diapause and subsequent premature hatching of eggs, followed by killing of first-instar nymphs by frost during winter (Hurd et al. 2019).

Mantid species have been reared under captive conditions to establish their efficacy as possible biological control agents of agricultural pests. *Ephestiasula rogenhoferi* Saussure (Hymenopodidae: Oxypilinae) (syn. *Ephestiasula pictipes* Wood-Mason) was found to be a potential biological control agent for pests in cashew orchards (Vanitha et al. 2016). The high fecundity and ease of mass rearing were factors which contributed to this conclusion made by Vanitha et al. (2016). This indicates that mantids are not only charismatic intriguing predators (Greyvenstein et al. in press) but that some species have important ecosystem services which can be utilized if these services are known. Karlsson et al. (2020) indicated that a desperate need exists for baseline data to be generated in order to evaluate phenomena such as insect declines and climate change. This is particularly important for a small insect order such as the Mantodea.

The aim of this investigation was to use museum records to estimate the distribution range of the *Popa* genus in southern Africa, and to study the biology of *P. spurca* in a captive breeding environment.

6.3 Materials and methods

6.3.1 *Species distribution data base*

Distribution records of *Popa* spp. were collected during visits to the following institutions that host curated insect collections in South Africa: Ditsong Museum of Natural History (Pretoria), Agricultural Research Council (Biosystematics Division, Pretoria), National Museum (Bloemfontein), Albany Museum (Grahamstown), Rhodes University (Grahamstown), Durban Natural Science Museum, Iziko South African Museum (Cape Town) and KwaZulu-Natal Museum (Pietermaritzburg). Most specimens in these collections were previously identified by foreign visiting taxonomists while many were sent for identification to the Vienna Museum in Germany, the University of Drexel in Philadelphia, USA, the Muséum National d'Histoire Naturelle (MNHN) in Paris, France and the research collection of Nicolas Moulin in Montérolier, France.

After *Popa* specimens and distribution labels where photographed (Canon D1300) and digitized, data were used to compile a distribution database of the species. This database contains the following information for each specimen record: genus and species name (to the available level of identification), collector's details and collection date where available, and the geo-referenced locality. A website (http://Mantodea.speciesfile.org) and scientific literature were used to determine the current nomenclature within the genus. All locality data were georeferenced using the principles suggested by Wieczorek (2004). Subsequently, all coordinates were converted from degrees, minutes, and seconds (DMS) to decimal degrees (DD) with the use of the website (gps-coordinates.net). Decimal degrees were used for developing the distribution maps for *P. spurca* in southern Africa by means of GIS software (ArcMaps, Version 10.6.1). The collection dates recorded for each specimen was used to generate intervals of 11 years (i.e. 1856-1867, 1868-1879) to compile graphs indicating the number of specimens collected during an interval.

6.3.2 *Rearing and biology of Popa spurca spurca*

Specimens were collected in the Grassland biome in the North-West and Free State provinces of South Africa during the summer of 2016/2017 with the use of sweepnets. Adults of these field-collected individuals were mated and nymphs that emerged from oothecae were used to rear a sufficient number of individuals to observe under captive rearing conditions. A sub-sample of the field-collected specimens was identified by Nicolas Moulin (honorary associate to MNHN), to confirm the species.

For breeding purposes, pairs of males and females were placed in glass containers. One-litre glass containers were used to ensure that ample space was available for the male to avoid sexual cannibalism before, during or after mating. To further limit the likelihood that females would cannibalize the males, ample food was provided before the male was introduced into the breeding container. After copulation concluded, the male was removed from the breeding container. The terrariums (150 mm x 100 mm x 200 mm) in which females were kept after mating was checked daily for the presence of oothecae that were laid. Oothecae were removed and put into small aerated containers (50 mm diameter and 50 mm high) inside a desiccator. A humidity level of 68 ± 5% was maintained inside the closed desiccator, following the method described by Solomon (1951). The desiccator was kept in an insect rearing room at 27 ± 1°C with a 14L: 10D photoperiod cycle until nymphs emerged from the oothecae.

Rearing of nymphs was done in the same insect rearing room where the oothecae were kept. Each specimen was placed in a terrarium (70 mm diameter and 150 mm high) with three holes (each 2 cm in diameter) covered with gauze to allow air flow. Thin twigs (5 mm x 100 mm) were placed inside each jar. It was used for climbing and hanging, especially during moults. Food was provided every second day when fine water mist was also sprayed into each container. Live crickets (*Acheta* sp., Orthoptera: Gryllidae) of different sizes (nymphal instars, i.e. pinheads) were provided as food. After moulting to the second instar, nymphs were removed from the communal terrariums and placed in separate terrariums to prevent cannibalism. Nymphs were reared until adulthood after which males and females were identified. This was done by counting the number of abdominal segments and the appearance of the wings. *Popa spurca* females have reduced wings and six abdominal segments while males have eight segments and elongated fully developed wings (McMonigle 2013; Fatimah et al. 2016; Brannoch et al. 2017) (Figures 6.2a and b).

The following life history parameters were recorded during this study: size of oothecae, number of egg chambers inside fertilized and unfertilized oothecae, numbers of days between moults and survival rate (based on nymphs reaching the adult phase). The mean number of days between moults and days to adulthood were calculated separately for males and females. Results were recorded for 174 individuals (76 males and 98 females) which completed their life cycles. The mean duration of male and female life cycles as well as the hatch and survival rates were determined. A distinction was also made between different types of oothecae, i.e. fertilized and unfertilized (from both field-collected and laboratory-reared females). The length, width and height of each ootheca was recorded, based on descriptions by Brannoch et al. (2017), as indicated in Figure 6.2c. The ootheca length was measured along the area of emergence and did not include the residual process. To determine the number of eggs per ootheca, oothecae were dissected by making a dorsal cut in the middle of the ootheca along its length. Egg chambers could then be distinguished under a microscope. The residual process was also dissected but did not contain any egg chambers.

6.3.3 *Data analysis*

Mean size and number of eggs per *P. spurca* oothecae were analysed by means of descriptive statistics. Shapiro-Wilk normality was used to determine if the data was normally distributed, subsequently data that was not normally distributed was Log-transformed. T-tests were used to compare the length, width and height and the number of eggs in fertilized and unfertilized oothecae. The duration of each instar, adult longevity and total development time (egg to adult) were analysed by means of T-tests. All analyses were done using Statistica Version 13.3 (TIBCO Software Inc., 2017).

6.4 Results

6.4.1 *Distribution of Popa spurca*

Distribution records reported in this paper were compiled from records that are available in the seven South African institutions mentioned above. The results presented in this paper should be viewed in this context, since no museum records were included beyond those residing in South Africa. A total of 212 *Popa* specimens were recorded and distribution records included records of *Popa* spp. from the following southern African counties: Swaziland (Eswatini) (1), Namibia (7), Malawi (1), Zambia (1) and Zimbabwe (2) (Figure 6.3).

The specimens from Namibia were collected in the central parts of the country between 1919 and 1974. The oldest record collected beyond the borders of South Africa was a specimen from Malawi (1918) while the most recent record was from Zambia (1992). The three specimens collected in Zimbabwe were collected in 1919, 1932 and 1946.

Of the 212 specimen records, 197 were collected within the borders of South Africa, between 1855 and 2016. The distribution records of *Popa* spp. are concentrated towards the North eastern region of South Africa, with a few records scattered along the eastern coastal region. Only six records were from the Western Cape region (Figure 6.3). The first *P. spurca* specimen collected in South Africa was collected during 1855 in Durban in the KwaZulu Natal province (Figure 6.4). The largest number of specimens from South Africa was collected between 1916 and 1923, and between 1957 and 1969. Only eight *P. spurca* specimens were added to the mentioned collections between 2008 and 2016 (Figure 6.4).

Popa spp. specimens were collected in both protected and unprotected areas in South Africa (Figure 6.5). Of the 197 *Popa* specimens, 82% (162) were collected outside of protected areas (Figure 6.5). The 35 specimens that were collected in protected areas represent three different categories of protected areas, i.e. National Parks (17 records), Private- and Provincial nature reserves (9 records each). One specimen was collected in the Richtersveld National Park while 16 were from the Kruger National Park. Furthermore, the nine records collected in Private nature reserves were only from Ezemvelo nature reserve in KwaZulu Natal, while three Provincial nature reserves from three different South African provinces yielded nine records. These were from Dwesa Cwebe Wildlife and Marine Sanctuary in the Eastern Cape, iSimangaliso Wetland Park in KwaZulu Natal, and the Wolkberg Wilderness Area in Limpopo.

6.5.2 *Biology of Popa spurca*

The oothecae of *P. spurca* have a barrel-like shape and is minimalistically dorsally flattened (Figure 6.2). The dorsal side of the oothecae encircled the oviposition substrate (twigs) that were provided in the terrarium. The outer wall of the ootheca usually has a brown-greyish colour with no extended residual process (Figure 6.2e). Oothecae that hatched were identified by means of the presence of white eclosion sack-like structures present on the brown-greyish area of emergence. Egg chambers were arranged in a circular pattern, with rows containing between five and 11 eggs each, arranged next to each other (Figure 6.2e).

In this study, 31 oothecae were collected of which nine were fertilized and hatched. These nine oothecae were produced by three field-collected females that were kept under laboratory conditions. Twenty-two oothecae were laid by unfertilized females reared in captivity and were also collected during this study. These were from 15 laboratory-reared captive females. No breeding with females reared in captivity was done since observations on the occurrence of parthenogenesis were also made during this study. Overall, no differences were detected between the morphology of fertilized and unfertilized oothecae (Table 6.1). Each ootheca contained an average of 83.65 ± 29.99 eggs (Table 6.1). The fertilized oothecae contained more egg chambers than unfertilized oothecae.

6.4.3 *Developmental parameters*

In total, 325 nymphs were reared during this study, but only 174 completed their lifecycle (76 males and 98 females). The mean incubation period of oothecae was 35 ± 4.10 days and 43.51% (Table 6.2). The percentage eggs that hatched from the nine oothecae varied greatly (1.3 – 76%) (Table 6.2). The ootheca with the lowest hatch rate had the longest incubation period (45 days), compared to the 32 days till hatching of the ootheca with the highest hatch rate. The shortest incubation period was 28 days. The mean survival rate was 57% with only three oothecae that had survival rates of less than 50 %. The sex ratio was slightly skewed towards females (1:1.29), however in one ootheca a female-biased sex ratio was recorded (1:4). Since only a single male and female from each of two oothecae survived to adulthood, the sex ratios in these oothecae were 1:0 and 0:1.

The majority (54) of the individuals in this study required eight instars to reach adulthood. However, 36 individuals required a ninth instar and three females required 10 instars before reaching adulthood. Male nymphs develop significantly slower (260.58 ± 32.10 days) than females (243.03 ± 27.67 days). The number of days spent in an instar, increased in later instars. For example, the duration of the first instar was 13 ± 4.11 days, that of the third instar was 21.25 ± 11.90 days and the seventh instar was 54.70 ± 30.85 days (Table 6.3). Significant differences were recorded between duration of male and female development periods from the fifth- to the eighth instar (Table 6.3). Males developed significantly slower ($p<0.0004$) and male adult longevity was significantly shorter ($p<0.0001$) than that of the females (Table 6.3).

Fifteen of the laboratory reared (unmated) females produced unfertilized oothecae, six of these females produced two oothecae each and only three females produced three oothecae. The mean pre-oviposition period was 101.27 ± 29.11 days (Table 6.3). The mean duration of the period between production of the first and second oothecae, was 32.33 ± 15.11 days and between the second and third oothecae, 13.67 ± 3.51 days (Table 6.3).

6.5 Discussion

6.5.1 *Distribution patterns of Popa* spp. *in southern Africa*

Lomardo (1993) reported that *P. spurca crassa* only occurs in east Africa, predominantly in Ethiopia and Tanzania, while *P. spurca spurca* occurs throughout sub-Sahara Africa. According to McMonigle (2013) and Green (2014), *P. spurca spurca* is native to sub-Sahara Africa and Madagascar. Specimens of *P. spurca crassa* was recently collected in Madagascar (Kristin et al. 2019), and Kenya (Schmidt-Rhaesa and Ehrmann, 2001).

Although several of the museum records of *Popa* used in this study were only identified to genus level (75 specimens) it is highly likely that all the specimens are of *P. spurca spurca.* No specimens of the genus *Popa* were previously collected from either Ethiopia or Tanzania which is the 'known' distribution of *Popa spurca crassa* (Lombardo, 1995). This is further evidence that *P. spurca spurca* may be the only *Popa* species in southern Africa. The results of this paper are therefore discussed in this context and refer only to *P. spurca spurca.*

However, according to Otte et al. (2020), *P. gracilis* specimens have been recorded in Malawi. Only one of the museum specimens used in this study was collected in Malawi and was not identified to species level. It is therefore possible that this specimen is *P. gracilis*. Although no specimen records from the Democratic Republic of the Congo were recorded during this study, Otte et al. (2020) indicated that *P. spurca pallida* occurred there. All Namibian specimens referred to in this study were identified as *P. spurca* by visiting taxonomists. However, according to Patel and Singh (2016) these specimens could either be the subspecies *crassa* or *pallida* since they report both to appear in this region. Lomardo (1995) indicated that the characteristics used to distinguish between the species and subspecies of *Popa* are difficult to use since large intra-species variation exists.

Popa spurca is known to be a savanna-dwelling mantid (Prete et al. 2013) and its preferred habitat is Savanna which is dominated by "bushes and trees" (Schwarz 2004). The Savanna biome in South Africa is found throughout the north eastern regions which is similar to the distribution of *P. spurca* recorded in this study. Hurd et al. (2019) suggested that the presence of an herbaceous layer is of great importance to certain mantid species, for example, *Tenodera aridifolia sinensis* Saussure (Mantidae: Mantinae). This is most likely also the case with *P. spurca* which evolved characteristics that enables it to camouflage itself among shrubs and bushes, from where its name, twig-mimicking mantids. Although various patches of forest exist along the east coast of South Africa (Rutherford et al. 2000), many of these, and to an extent also the Albany thicket biome, degraded over recent decades to resemble the Savanna/Grassland biomes (Masubelele et al. 2015). The distribution of *P. spurca* in these areas could therefore possibly be explained by the habitat that provides an herbaceous layer that consists of trees and bushes, similar to the Savanna biome. Due to *P. spurca* mimicking twigs, it is assumed they live in trees, where their camouflage is beneficial in terms of catching prey and also avoiding predation.

The majority of the *P. spurca* specimens were collected outside of protected areas. This could be due to the red tape associated with issuing of collection permits for these areas, or a collection bias exists in the areas that are more densely populated (Greyvenstein et al. 2020). Protected areas are also represented by a smaller surface area than unprotected areas which could have an influence on the specimen collected. Very little information regarding the natural habitat and ecology of *P. spurca* is known, making it even more likely that specimens collected in protected areas were bycatches of other studies, or they were collected near camp sites within protected areas and were therefore not the focus of the collection activities. Grytnes and Romdal (2008) provided explanations for some areas being sampled more than others, and indicated that accessibility remained one of the most common explanations. Although the distribution of *P. spurca* in southern Africa was based on museum data, this information identifies various regions of importance for future studies on this species. This is especially important with regards to identification of possible threats such as climate change that could affect not only the distribution of this species but also their biology, population dynamics and ecology.

6.5.2 *Biology of Popa spurca spurca*

Various studies on Mantidae biology have been done (Iwasaki 1996; Hurd et al. 2004; Maxwell 2014a; 2014b). However, none of these were on *P. spurca*, nor was any literature found about the biology of a mantid species in the Danuriinae subfamily. Results of this study will therefore be compared to those of studies that were done on mantids within the Mantidae family.

No nymphs emerged from any of the unfertilized oothecae, indicating that no parthenogenesis occurred in this study. Parthenogenesis has been recorded in other mantid species, i.e., *Coptopteryx viridis* Giglio-Tos (Coptopterygidae) (Cukier et al. 1979), *Miomantis paykulli* Stäl (Mantidae: Miomantinae) (Adair 1924), and in the Springbok mantis, *Miomantis caffra* (Mantidae: Miomantinae) (Walker et al. 2016).

Although Breland and Dobson (1947) noted that the unique characteristics of mantid oothecae could be used to distinguish between oothecae of different families, he also indicated that the morphology of oothecae of some species did not vary enough to be used for species identification. The oothecae of *P. spurca* are similar in appearance to that of *Hierodula ventralis* Giglio-Tos (Mantidae: Mantinae), but is somewhat longer and not as broad or as high as that of *H. ventralis*. Raut et al. (2014) indicated that oothecae produced under captive breeding conditions were larger than field collected oothecae. Despite the differences in size of oothecae noted by Raut et al. (2014), no differences were recorded between size of fertile and unfertile oothecae of *P. spurca*.

The mean number of eggs (83.65) per *P. spurca* ootheca recorded in this study was more than twice that of a similar-sized species, *Orthodera ministralis* Fabricius (Mantidae: Orthoderinae), which, according to Suckling (1984), produced an average of 34 eggs per ootheca under captive breeding conditions. The size, colour and shape of oothecae are influenced by various factors such as food availability, humidity, temperature, genetics and male presence (Roberts 1937; Breland, 1947; Hurd et al. 1995; McMonigle, 2013). The oothecae of mantids are also consumed by certain beetles (*Orphinus* spp.) (Coleoptera: Dermestidae) and parasitized by wasps (*Podagrion* spp.) (Hymenoptera: Torymidae) (Kershaw 1910; Hawkeswood 2003; Bolu and Ozaslan 2015). These are aspects which can influence not only the structure of oothecae but also the hatch and survival rates, and ultimately the population dynamics of mantids in the wild.

No studies have been conducted on the population dynamics of *P. spurca* under natural conditions and it is not known if this species has any potential threats or even if it is endangered. The IUCN Red data list contains information on only 13 of the 2400 estimated Mantodea species (IUCN, 2020; Ehrmann 2002). One species has been classified by the IUCN as critically endangered and another as endangered. Three species are considered as vulnerable. The threat level of several of the species listed on the IUCN Red data list were not classified since there was too little information about the species distribution, population dynamics and biology. These species were classified as data deficient, which may in future also apply to *Popa* species.

6.5.3 *Developmental parameters*

The incubation period for *P. spurca* oothecae was 35 ± 4.1 days which is within the range recorded for other species within the Mantidae family. For example, the oothecae of *H. ventralis* has an incubation period of 25 days (Raut et al. 2014), while *O. ministralis* oothecae required an average of 30.9 days to hatch (Suckling 1984). In contrast, *E. pictipes* was reported by Vanitha et al. (2016) to have an incubation period of approximately 16 days. Robert (1937) indicated that the incubation period of *Stagmomantis limbata* Hahn (Mantidae: Stagmomantinae) oothecae was between 142 and 209 days, and that a female produced 3 to 6 oothecae. The maximum number of oothecae produced by *P. spurca* in this study was three, however, the possibility exists that females could produce more oothecae if males were present and if they mated more than once. The number of oothecae per female is also influenced by temperature and food abundance. According to Hurd et al. (1995), lower temperatures in some seasons may lead to increased development times for females, followed by a reduction in numbers of oothecae produced before the onset of winter.

The rate of survival of *P. spurca* nymphs to adulthood varied between oothecae but the overall survival rate was 56.8% at 27 ± 1°C with a 14L: 10D photoperiod and 68 ± 5% humity level. It can be assumed that survival rate will be much lower under field conditions. Hurd et al. (2004) reported survival rates of 5% and 6-9% for *T. aridifolia sinensis* under field conditions at different localities in the eastern USA. In Japan, *T. aridifolia* and *T. angustipennis* survival rates under field conditions were 2.9% and 2.1% respectively (Iwasaki, 1996). Maxwell (2014a) reported a very low survival rate of the latter species under laboratory conditions. Further field investigations are required to determine the survival success of this species under natural conditions.

The total developmental period of *P. spurca,* from hatch to adulthood was 250.87 ± 30.81 days, and female nymphs developed faster in the latter stages of development. Similar results were recorded for *S. limbata* (Maxwell 2014a). The mean nymphal development time of *P. spurca* males in this study was 17 days longer than for females, but in some cases, it differed by more than a month. This study indicates that although females of this species have a significantly shorter nymphal period and reach adulthood sooner, their adult longevity is twice as long as that of *P. spurca* males.

The sex ratio of *P. spurca* adult individuals was slightly female-biased which was determined by the end of the study (1:1.29). In contrast, Hurd et al. (2004), reported that most mantid species have a sex ratio of 1:1 at hatching. Towards the end of the season, the sex ratio of *P. spurca* became female-biased, most likely because of the longer life span of females. Sexual cannibalism by females is one of the possible explanations for female-biased sex ratios towards the end of the summer season (Hurd et al. 2004). Although the sex ratio of *P. spurca* was female-biased in eight of the nine fertile oothecae in this study, they have a pre-oviposition period of nearly three months. Females of *P. spurca* had a significantly shorter nymphal development than males. The period between production of the first and second, and second and third oothecae decreased with approximately 16 days, possibly due to the end of season approaching. The long adult longevity of female *P. spurca* is not uncommon and was recorded for several other species (Roberts 1937; Maxwell 2014b; Raut et al. 2014; Vanitha et al. 2016; Greyvenstein et al. 2020). The development of female *T. aridifolia sinensis* was reported to be influenced by increasing temperatures associated with climate change, causing females to mature earlier in the fall season and oviposit earlier and subsequently the newly hatched nymphs die at the onset of winter (Hurd et. al 2019). This could be a potential threat to mantid species such as *P. spurca*, especially since it has an extended pre-oviposition period and generally long nymphal development period.

The majority of *P. spurca* adults had eight instars before reaching adulthood and very few required only four or five instars before reaching adulthood. Such a variation in number of instars was also recorded by Maxwell (2014a) with captive reared *S. limbata*. Maxwell (2014a) recorded 64% of nymphs to go through six instars while 36% required seven instars. Vanitha et al. (2016) reported that 96% of *E. rogenhoferi* required only six instars. In this study however, *P. spurca* individuals reached adulthood from as early as the fourth instar to as late as tenth instar. This variation in number of instars has been suggested as a "bet-hedging" strategy used by females to produce variation in development among siblings (Maxwell 2014a) and could also reflect the survival strategy of mantid species. However, various factors have been indicated to influence the number of instars in the Arthropoda, i.e. temperature, resource availability and quality, humidity, genetics, sex and photoperiod (Esperk et al. 2007).

Another reason for the varying number of instars and different developmental times could be to reduce sibling rivalry for similar resources (Greyvenstein et al. 2020). Watanabe et al. (2013) indicated that *T. aridifolia* changed their perching site selection (vegetation height, perching height and vegetation type) as they matured. First-instar nymphs preferred low or near to the ground positions while older nymphs preferred positions toward the maximum growth height of the vegetation. This behaviour was ascribed to optimal foraging positions and a lower predation risk higher up on vegetation (Watanabe et al. 2013). This height segregation in combination with the variation in development period and numbers of instars could be a strategy to maximize the utilization of the limited resources amongst siblings or between species.

6.6 Conclusions

The areas where museum specimens were sampled indicated that the *Popa* genus has *a* widespread distribution in southern Africa and its preferred habitat seems to be the Savanna biome. The widespread distribution could indicate that this species is of least concern with regards to the IUCN Red data list of species, however further assessment is required. This may however also be a by-product of the lack of sampling, under represented areas and/or taxonomic expertise. This study indicates a variation in the numbers of instars and varying developmental periods, especially between *P. spurca* males and females, which could be a survival strategy. The variation in numbers of instars is suggested to be part of the survival strategy of decreasing sibling rivalry and thus maximizing limited food resources. This study is the first to describe the life history of *P. spurca* and the southern African distribution of this twig mimicking genus.

6.7 Acknowledgements

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ORCID

Bianca Greyvenstein http://orcid.org/0000-0003-2033-7113

Hannalene du Plessis http://orcid.org/0000-0003-1163-1468

Johnnie Van den Berg http://orcid.org/0000-0002-6831-3180

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6.9 Tables

Table 6.1. Statistical T-test values between size-parameters and the mean number of egg chambers inside the different types of oothecae of *Popa spurca* reared under captive conditions. SD = Standard deviation.

Oothecae (n)		Length (mm) ± SD	Width (mm) ± SD	Height (mm) ± SD	Number of eggs/ootheca ± SD
T-test	t-value	-0.24	-1.05	0.69	1.89
	p-value	0.81	0.29	0.49	0.07
Overall (31)		18.00 ± 4.78	11.24 ± 2.63	7.44 ± 1.67	83.65 ± 29.99
Unfertilized (22)		18.12 ± 4.95	11.52 ± 2.35	7.32 ± 1.44	78. 04 ± 27.37
Fertilized (9)		17.67 ± 4.53	10.44 ± 3.32	7.78 ± 2.78	99.22 ± 33.03

Table 6.2. The mean hatch rate, survival rate and gender dynamics throughout the study of three field-collected females (three individuals) and their fertile oothecae (9). SD = Standard deviation.

Ootheca number	**Incubation duration**	**No. of eggs per ootheca**	**Hatch rate (%)**	**Survival (%)**	**Male (%)**	**Female (%)**	**Sex Ratio (♂:♀)**
Ootheca 1	45	74	1.35	100.00	0.00	100.00	0:1
Ootheca 2	28	81	71.60	51.72	50.00	50.00	1:1
Ootheca 3	32	66	75.76	54.00	55.56	44.44	1:0.8
Ootheca 4	40	81	11.11	55.56	60.00	40.00	1:0.7
Ootheca 5	40	150	54.00	40.74	33.33	66.67	1:2
Ootheca 6	35	100	50.00	58.00	37.93	62.07	1:1.6
Ootheca 7	37	144	70.83	44.12	44.44	55.56	1:1.3
Ootheca 8	34	128	55.47	7.04	20.00	80.00	1:4
Ootheca 9	39	69	1.45	100.00	100.00	0.00	1:0
Mean ± (SD)	35.00 ± 4.10	99.22 ± 33.03	43.51 ± 30.55	56.80 ± 28.86	44.58 ± 27.89	55.42 ± 27.89	1:1.3

Table 6.3. Mean duration (in days) of each of the life stages of *Popa spurca* and differences between male and female development under laboratory conditions (68 ± 5% humity; 27 ± 1°C and 14L: 10D photoperiod). Three of the females developed to the 10th instar and were not included in the table below. SD = Standard deviation.

	Number of nymphs moulted to adults per instar	**Mean duration (days ± SD)**			**T-tests**	
Life stage		Overall	Males	Females	t-value	p-value
Egg development period	N/A	35.00 ± 4.10	34.50 ± 4.08±	35.39 ± 4.09	-1.386	0.167
1st Instar	N/A	13. 04 ± 4.11	13.47 ± 4.70	13.35 ± 3.61	-0.044	0.964
2nd Instar	0	17.34 ±11.57	18.49 ± 14.23	16.45 ± 8.96	0.755	0.451
3rd Instar	0	21.25 ± 11.90	20.99 ± 10.13	21.46 ± 13.16	-0.305	0.760
4th Instar	3	30.25 ± 23.45	33.61 ± 30.43	27.65 ±15.78	1.714	0.088
5th Instar	3	37. 20 ± 24.32	42.80 ± 26.60	32.93 ± 21.61	3.503	0.008**
6th Instar	23	47.63 ± 29.53	55.92 ± 32.61	41.41 ± 25.43	3.583	0.000***
7th Instar	52	54.70 ± 30.85	65.17 ± 35.48	47.64 ± 25.13	3.742	0.000***
8th Instar	54	53.41 ± 21.82	61.24 ± 23.45	49.10 ± 19.71	2.947	0.004
9th Instar	36	49. 07 ± 12.99	46.40 ± 14.11	49.46 ± 13.01	-0.492	0.625
Total nymphal period#	N/A	250.87 ± 30.81	260.58 ± 32.10	243.03 ± 27.67	3.612	0.000***
Adult longevity##	N/A	81.48 ± 61. 92	47.78 ± 43.02	107.63 ± 61.85	-5.371	0.000***
Pre-oviposition period	N/A	101.27 ± 29.11	N/A	101.27 ± 29.11	N/A	N/A
Interval between 1st & 2nd oothecae	N/A	32. 33 ± 15.11	N/A	32. 33 ± 15.11	N/A	N/A
Interval between 2nd & 3rd oothecae	N/A	13.67 ± 3.51	N/A	13.67 ± 3.51	N/A	N/A
Post-oviposition period###	N/A	47.20 ± 38.79	N/A	47.20 ± 38.79	N/A	N/A
Period from hatch to death	N/A	331.66 ± 62.09	308.36 ± 46.09	349.72 ± 66.92	-4.262	0.000***

#from egg hatch to final moult (1st Instar – 8th /9th instar).

##duration of adult phase

###duration between the last ootheca laid (2nd or 3rd) and death.

Significant differences were indicated as follows: * p=0.05, ** p>0.001 and *** p<0.0001.

6.10 Figures

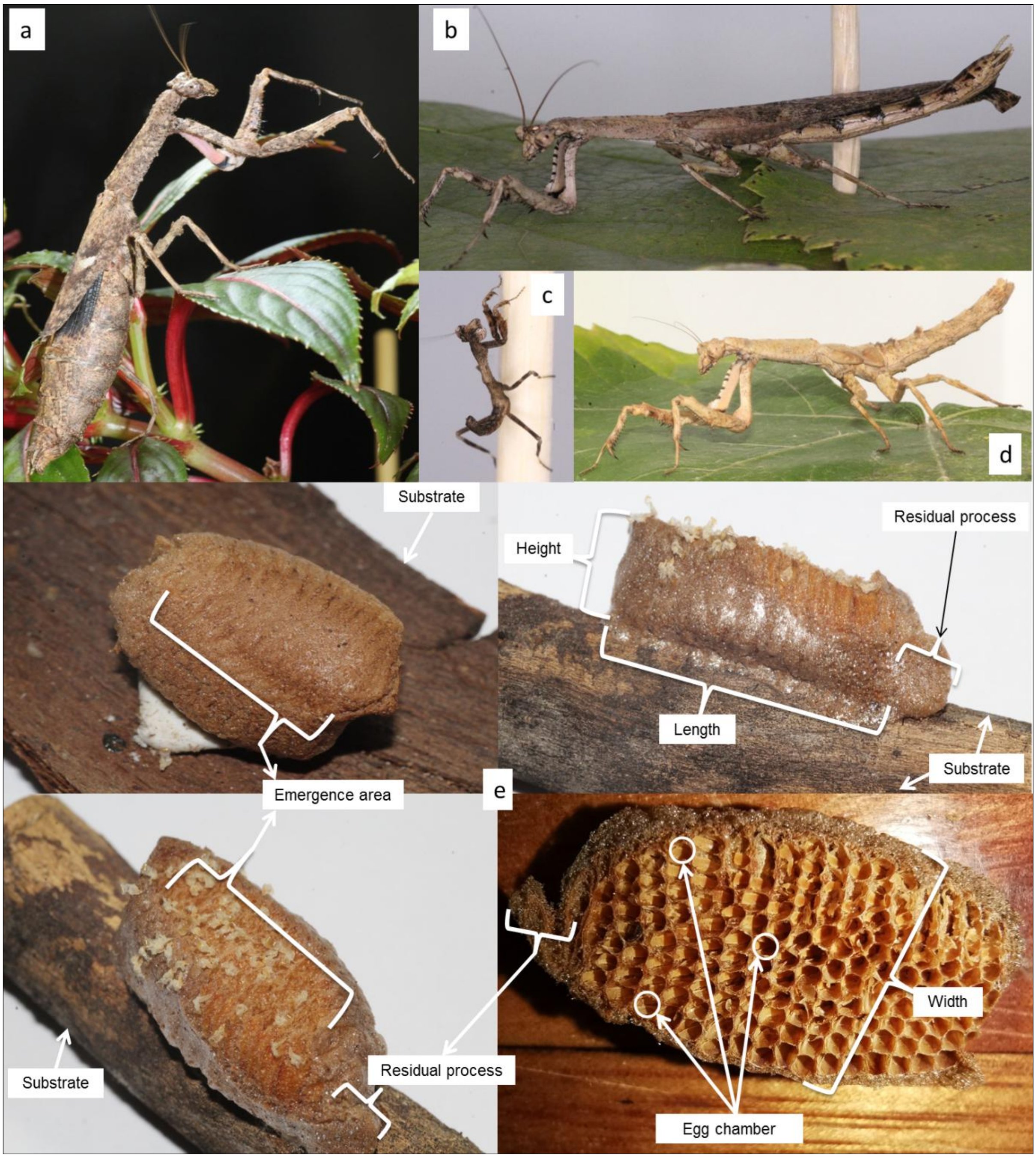


Figure 6.2. *Popa spurca* female (a), male (b), 1st instar nymph (c), 8th instar nymph (d) and general morphology (e) of the oothecae, indicating different parameters and areas of interest as suggested by Brannoch et al. (2017).

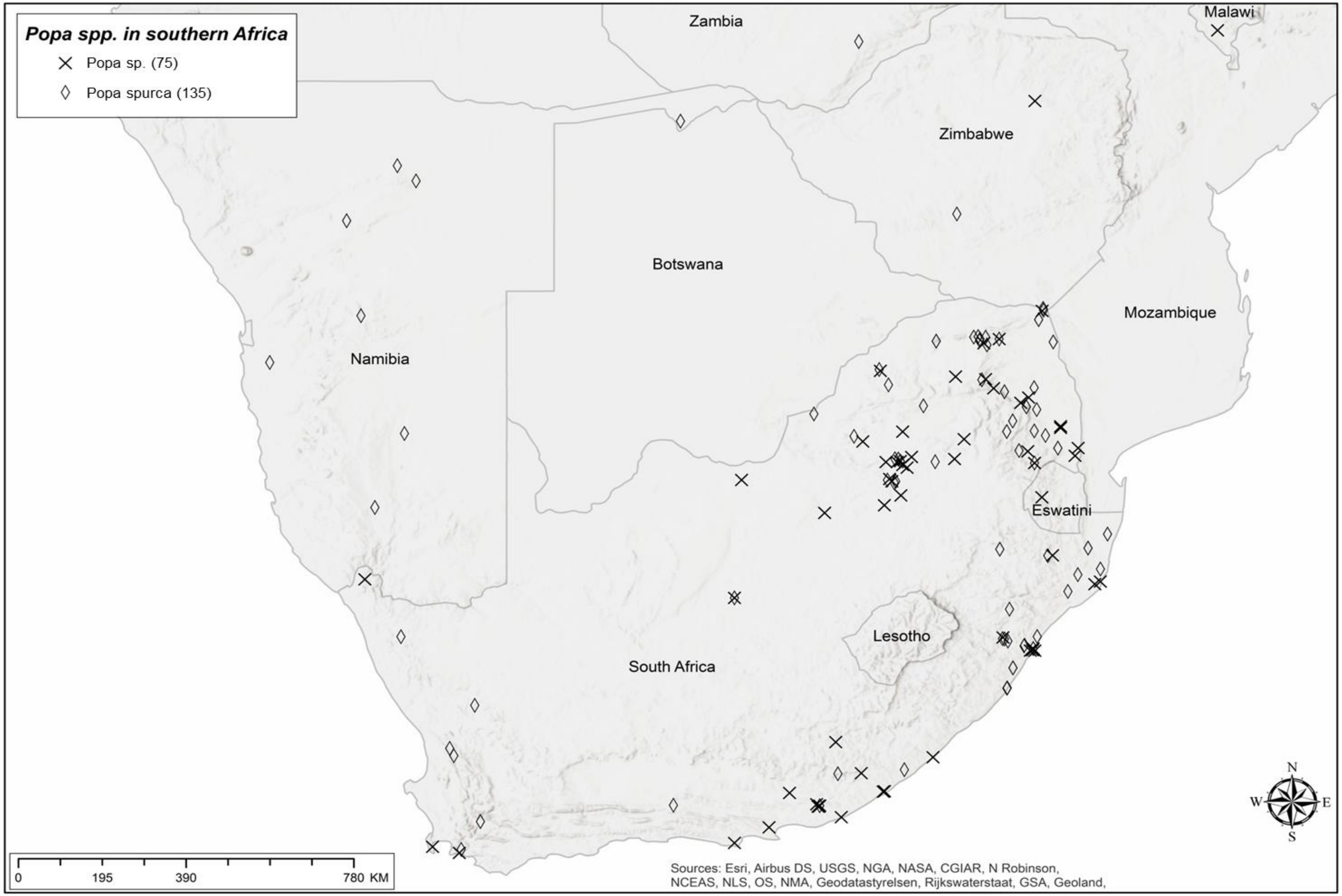


Figure 6.3. Distribution records of *Popa spurca* and *Popa* spp. that occur in southern Africa. Numbers in brackets indicate the number of records per species.

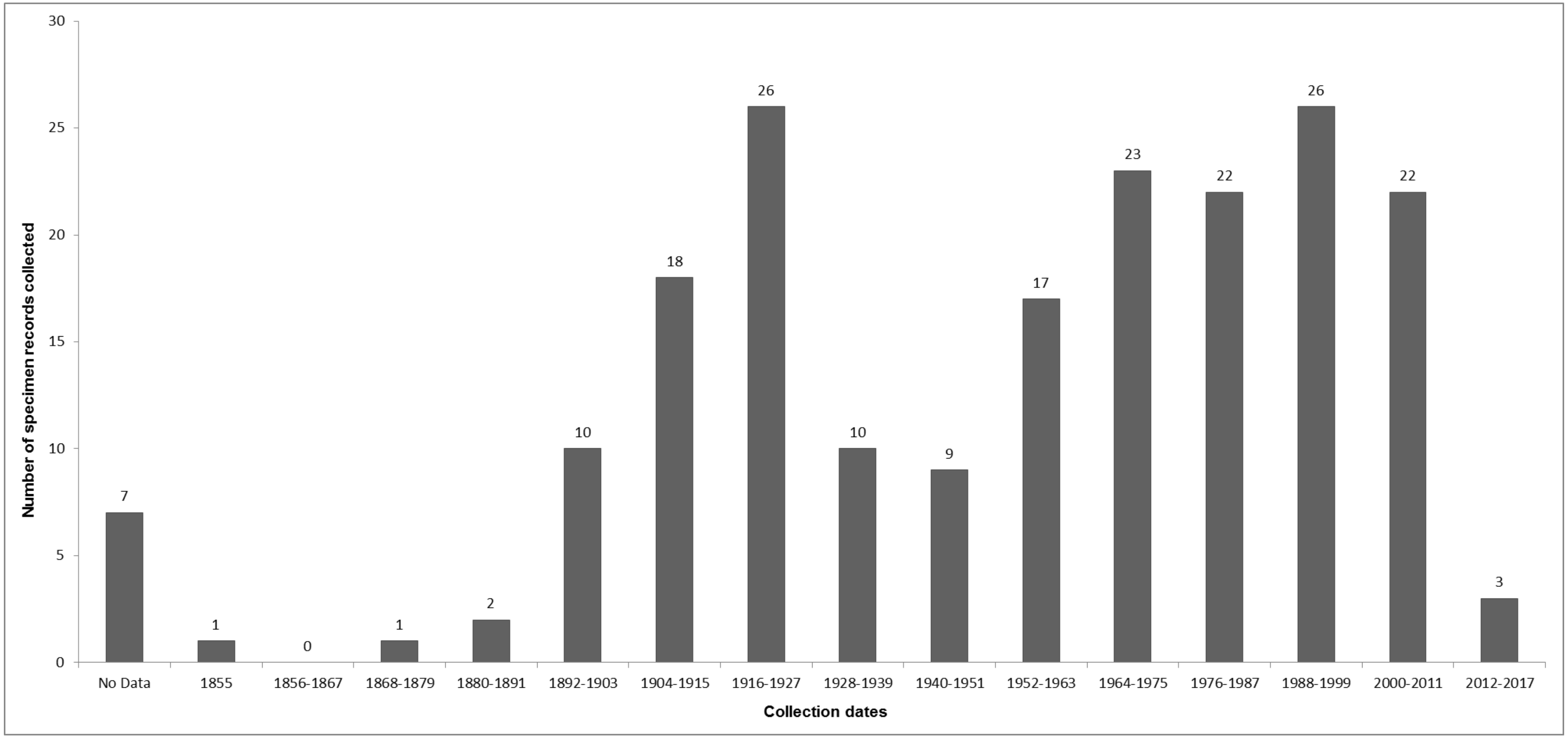
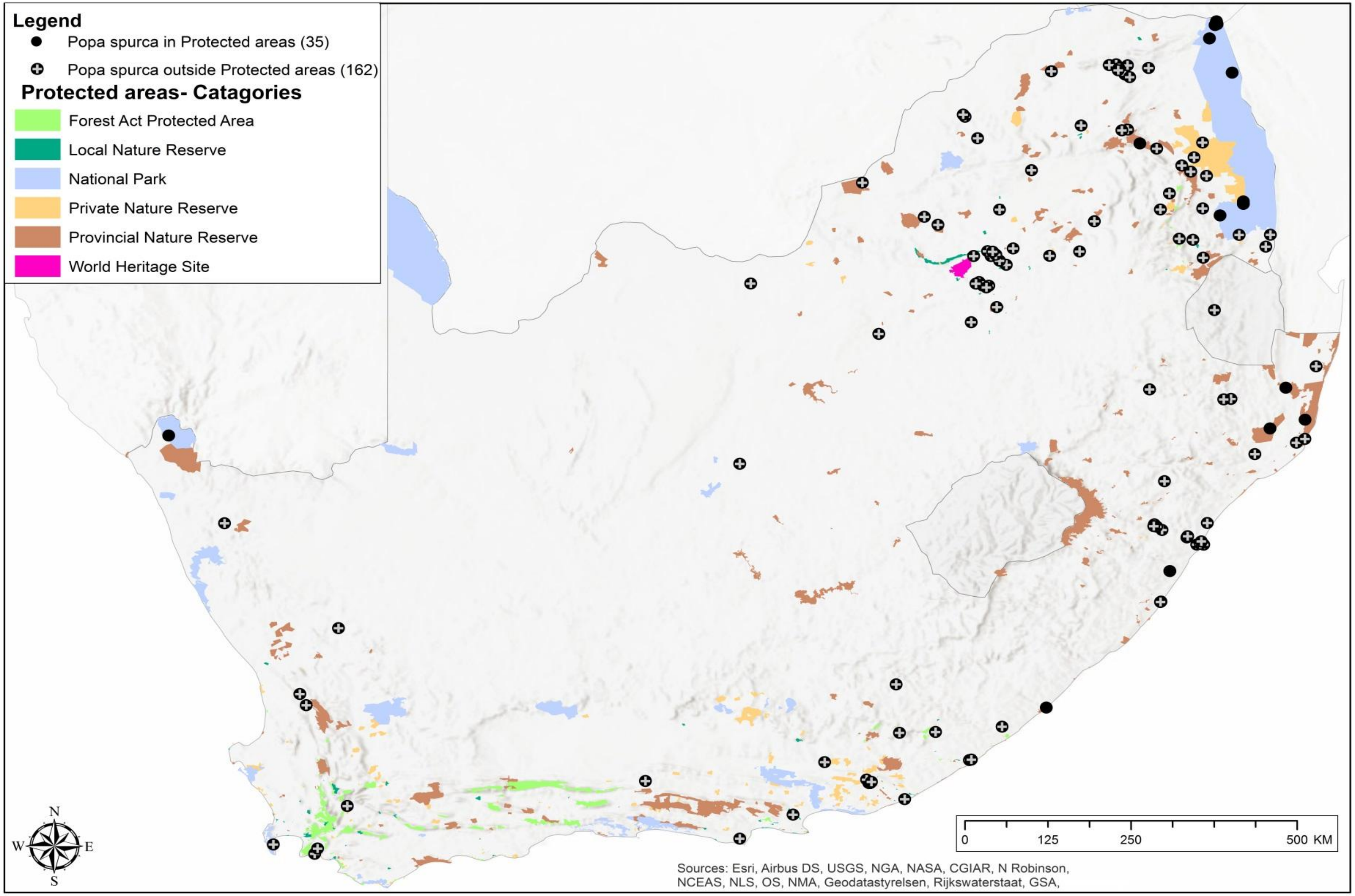


Figure 6.4. Number of *Popa spurca* specimen records collected in South Africa during different time periods between 1855 and 2017.



Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA,

Figure 6.5. Distribution records of *Popa spurca* collected in protected and non-protected areas of South Africa.

CHAPTER 7: ARTICLE 5

Distribution of the False Flower mantids, *Harpagomantis* spp., in southern Africa and the life history of *Harpagomantis tricolor* (Mantodea: Galinthiadidae).

(Submitted for review to **Austral Entomology**)

Bianca Greyvenstein[1]**, Hannalene du Plessis**[2] **& Johnnie Van den Berg**[3]

1: orcid.org/0000-0003-2033-7113; **2**: orcid.org/0000-0003-1163-1468; **3**: orcid.org/0000-0002-6831-3180

1-3: Unit for Environmental Sciences and Management, North-West University, Potchefstroom, 2520, South Africa

***** biagrey90@gmail.com

Running Title

False flower mantid in South Africa

7.1 Abstract

The false flower mantis is the common name for three Mantodea species in the *Harpagomantis* genus. These species are plant mimicking mantids that use crypsis as a defence mechanism. No information exists on its distribution in southern Africa or about its life history. The aim of this study was to, based on museum collection records, determine the distribution of this genus in southern Africa, and to study the biology of *Harpagomantis tricolor* L. under captive breeding conditions. The distribution of *Harpagomantis* was determined by utilising the historic insect collection records of seven National museums throughout South Africa. Field collected *H. tricolor* males and females were mated and reared under laboratory conditions to record their life history parameters, i.e. nymphal duration, oothecae structure, size and incubation duration, adult longevity and sex ratio. The results of this study indicated that the mean duration of the lifecycle of *H. tricolor* was 191.33 ± 37.96 days. All but three, *H. tricolor* individuals had five nymphal instars and the mean duration of the nymphal stage was 140.20 ± 31.03 days. The mean duration of copulation was six hours, while the average incubation period of oothecae was 144.71 ± 9.33 days. These results indicated that oothecae of *H. tricolor* probably over winter under field conditions and that males of this species have evolved various mechanisms to increase the likelihood of ensuring its own genetic offspring. This study bridges the gap in rudimental research in which Mantodea in general have been overlooked, and established a basis on which ecological interactions, habitat preferences and imminent threats to this genus and *H. tricolor* can be established.

Key words
copulation, longevity, mimicry, praying mantis

7.2 INTRODUCTION

Harpagomantis Kirby is one of four genera in the newly rearranged family of Galinthiadidae (Otte *et al*. 2020; Svenson *et al*. 2015). Within the *Harpagomantis* genus there are three known species i.e. *Harpagomantis tricolor* L., *Harpagomantis discolor* Stäl and *Harpagomantis nana* Lucas. *Harpagomantis*, *Galinthias, Congoharpax*, and *Pseudoharpax* were previously classified as Hymenopodidae, however, due to molecular evidence and the phylogenetic results reported by Svenson *et al*. (2015), these genera were found to be outside of Hymenopodidae and was moved to the new family Galinthiadidae. Svenson *et al*. (2015) reported that the high level of homoplasy in external morphology of these mantids contributed to the discrepancies in species identifications based on molecular and morphological characteristics, since these did not align and thus these genera were originally classified within the Hymenopodidae family.

Harpagomantis species have been described as the “false flower” mantids and are pink with green bands and sometimes have yellow eyes (Figure 1). *Harpagomantis* is reported to live on flowers where they camouflage and wait motionlessly for prey (O’Toole 2003). *Harpagomantis tricolor* has been recorded during biodiversity surveys studies in South Africa, largely in the western Cape region (Grobbelaar *et al*. 1999; Brand & Samways 2009; Magoba & Samways 2010) and the Highveld grassland biome (Botha *et al*. 2018; Greyvenstein *et al*. 2020b). Yet, the distribution of this genus in southern Africa remains unknown. Similarly, Svenson *et al*. (2015) reported the ecology of most Mantodea species remains unknown. The information which is available about species ecology, observations and biology is based on either citizen science or very old publications.

Cardoso *et al*. (2020) recently reported a deep concern about the world-wide decline of insect populations and that only 20% of the total insect diversity has been named. Research is required to bridge this gap in knowledge and correct the bias in insect studies which has largely focused on specific taxa such as butterflies and pollinators (Cardoso *et al*. 2020). Samways *et al.* (2020) indicated that mapping of the distribution of specific species could contribute to determining their range expansion, threat identification and habitat favourability. This will ultimately aid in bridging the gap in knowledge which exists regarding the distribution and biology and ecology of the majority of insect species.

The aim of this study was to determine the distribution of the genus *Harpagomantis* in southern Africa and to study the biology of *H. tricolor* under captive breeding conditions.

7.3 MATERIALS AND METHODS

7.3.1 Species distribution data base

Distribution records of *Harpagomantis* spp. were collected during visits to the following institutions that host curated insect collections in South Africa: Ditsong Museum of Natural History (Pretoria), Agricultural Research Council (Biosystematics Division, Pretoria), National Museum (Bloemfontein), Albany Museum (Grahamstown), Rhodes University (Grahamstown), Durban Natural Science Museum, Iziko South African Museum (Cape Town) and KwaZulu-Natal Museum (Pietermaritzburg). Most specimens in these collections were previously identified by foreign visiting taxonomists while many were sent for identification to the Vienna Museum in Germany, the University of Drexel in Philadelphia, USA, the Muséum National d’Histoire Naturelle (MNHN) in Paris, France and the research collection of Nicolas Moulin in Montérolier, France.

Harpagomantis specimens and distribution labels where photographed (Canon D1300) and digitized, after which this data was used to compile a distribution database of the species. This database contains the following information for each specimen record: genus and species name (to the available level of identification), collector's details and collection date where available, and the geo-referenced locality. A website (http://Mantodea.speciesfile.org) (Otte et al. 2020) and scientific literature were used to determine the current nomenclature within the genus. All locality data was georeferenced using the principles suggested by Wieczorek (2004). Subsequently, all coordinates were converted from degrees, minutes, and seconds (DMS) to decimal degrees (DD) with the use of the website (gps-coordinates.net). Decimal degrees were used for developing the distribution maps for *H. spp.* in southern Africa and *H. tricolor* in South Africa by means of GIS software (ArcMaps, Version 10.6.1). The collection dates recorded for each specimen was used to generate intervals of 11 years (i.e. 1856-1867, 1868-1879) to compile a graph indicating the number of specimens collected over time and during certain intervals.

7.3.2 Rearing and biology of *Harpagomantis tricolor*

Specimens were collected in the Grassland biome in the North West and Free State provinces of South Africa during the summer of 2016/2017 with the use of sweepnets. Adults of these field-collected individuals were mated and nymphs that emerged from oothecae were used to rear a sufficient number of individuals to observe under captive breeding and rearing conditions. A sub-sample of the field-collected specimens was identified by Nicolas Moulin (honorary associate to MNHN), to confirm the species identification.

For breeding purposes, pairs of males and females were placed in glass containers. One-litre glass containers were used to ensure that ample space was available for the male to avoid sexual cannibalism before, during or after mating. To further limit the likelihood that females would cannibalize the males, ample food was provided before the male was introduced into the breeding container. The duration of copulation was recorded per breeding pair (Fig. 7.1c). After copulation concluded, males were removed from the breeding containers. The terrariums (15 cm x 10 cm x 20 cm) in which females were kept after mating was checked daily for the presence of oothecae that were laid overnight. Oothecae were removed and put into small containers (5 cm diameter and 5 cm high) inside a desiccator. A humidity level of 68 ± 5% was maintained in the closed desiccator, following the method described by Solomon (1951). The desiccator was kept in an insect rearing room at a temperature at 27 ± 1°C with 14L: 10D photoperiod cycle until nymphs emerged from the oothecae.

Rearing of nymphs was done under controlled conditions (Fig. 7.1d). Each specimen was placed into a terrarium (7 cm diameter and 15 cm high) with three holes (each 2 cm in diameter) covered with gauze to allow air flow. Thin twigs (5 mm x 10 cm) were placed inside each jar for climbing and hanging purposes, especially during moults. Food was provided every second day when fine water mist was also sprayed into each container. Live aphids (*Brevicoryne* spp.) (Hemiptera: Aphididae) were provided as food for first- to third-instar nymphs after which live crickets (*Acheta* sp., Orthoptera: Gryllidae) of different sizes (nymphal instars, i.e. pinheads) were provided. After moulting to the second-instar, nymphs were removed from the communal terrariums and placed in separate terrariums to prevent cannibalism. Nymphs were reared until adulthood after which males and females were identified. This was done by counting the number of abdominal segments and the appearance of the wings. *Harpagomantis tricolor* females have shorter wings (barely covering the abdomen) and six abdominal segments, while males have eight segments and wings that are longer than the abdomen (McMonigle 2013; Fatimah *et al*. 2016; Brannoch *et al*. 2017) (Fig. 7.1a & b).

The following life history parameters were recorded during this study: size of oothecae, number of egg chambers inside fertilized and unfertilized oothecae, copulation duration, numbers of days between moults and survival rate (based on nymphs reaching the adult phase). The mean number of days between moults and days to adulthood were calculated separately for males and females. The data discussed in this paper were recorded for 45 individuals (13 males and 31 females) that completed their life cycles. The mean duration of male and female life cycles was calculated and the hatch and survival rates determined. A distinction was also made between different types of oothecae, i.e. fertilized and unhatched (produced by field-collected females of which the mating status was not known). The length, width and height of each ootheca were recorded, based on descriptions by Brannoch *et al*. (2017). The ootheca length was measured along the area of emergence, excluding the residual process (Greyvenstein *et al*. 2020a; Brannoch *et al*. 2017). To determine the number of eggs per ootheca, oothecae were dorsally dissected along the length and inspected under a microscope as was done by Greyvenstein *et al*. (2020a). Measurements of ootheca parameters were done as indicated in Fig. 7.1e.

7.3.3 Data analysis

The descriptive statistics (Means and Standard Error) and the statistical analyses of the developmental parameters were done using Statistica Version 13.3 (TIBCO Software Inc., 2017). Shapiro-Wilk normality test was used to determine if the data was normally distributed, subsequently data that was not normally distributed was Log-transformed. T-tests were used to determine if differences existed between the length, width and height and the number of eggs per ootheca between the two types of oothecae (i.e. fertilized and unfertilized). T-tests were also used to determine if differences existed between the mean numbers of days between moults, adult longevity and mean number of days required by nymphs to reach adulthood.

7.4 RESULTS

7.4.1 Distribution of *Harpagomantis* spp.

Distribution records reported in this paper were compiled from records that are available in the seven South African institutions that host curated arthropod collections. Results should be viewed in this context, since no museum records beyond those residing in South Africa were included. The distribution records included records of *Harpagomantis* spp. from the following southern African counties: Botswana, Eswatini, Lesotho, Mozambique, Namibia and Zimbabwe (Fig. 7.2).

A total of 290 specimen records within the *Harpagomantis* genus were accounted for of which 272 were collected within the borders of South Africa (this includes specimens collected in Lesotho and Eswatini). The remaining 18 records were distributed as follows: one specimen each of *H*. sp. and *H. tricolor* collected in Botswana, six *H. tricolor* specimens collected in Namibia, four (one *H. discolor* and three *H*. sp.) specimens collected in Mozambique, and six (one *H. tricolor*, one *H. discolor* and four *H.* sp.) collected in Zimbabwe (Fig. 7.2). Of the 272 specimens collected in South Africa, 165 were only identified to genus level, while 66 were identified as *H. tricolor* and 41 as *H. discolor* (Fig. 7.2).

Harpagomantis tricolor records were collected throughout South Africa and neighbouring countries (Fig. 7.2). The distribution of the *Harpagomantis* genus in South Africa seems to be predominantly towards the eastern region of the country, with a few specimen records from the western region, specifically in the western Cape province (Fig. 7.2). Although the distribution of *H. discolor* seems to be more towards the north-eastern region, four records of *H. discolor* were recorded in the southern region of South Africa.

The oldest specimen record within this genus (*H. tricolor*), was collected in 1876 in Cape Town. Only four specimens were collected between 1876 and 1887, while the largest number (37) were collected between 1912 and 1923 (Fig. 7.3). Between 1972 and 2019, the average number of specimens collected during the three 11-year intervals was 31 (Fig. 7.3).

Only 48 specimen records were collected within protected areas of South Africa, while 224 records were collected outside these areas. These 48 specimens were collected in 11 different provincial nature reserves (19 records), four private nature reserves (14 records), two National Parks (9 records) and one specimen was collected in a World Heritage site, a Forest protected area and a local nature reserve (Fig. 7.4). The localities at which *H. tricolor* specimens were collected in South Africa are widely distributed throughout the country (Fig. 7.5).

7.4.2 Biology of *Harpagomantis tricolor*

The ootheca of *H. tricolor* is not covered in the usual foamy sheath which is characteristic of the Mantidae family (McMonigle 2013). The oothecae are usually small, light brown in colour, almost rectangular in shape and slightly dorsally flattened (Fig. 7.1e). The residual process is not elongated or extended into any shape or point. In cases where the oothecae of *H. tricolor* were attached to the stem of a flowering plant in the field, it would most likely resemble a thorn. Eggs were arranged in adjacent rows of between three and five eggs each (Fig. 7.1e). The residual process was also investigated but did not contain any egg chambers.

Nineteen oothecae were used in this study. Seven of these did not hatch (produced by field-collected females but never hatched) while 12 oothecae did hatch. The latter oothecae were laid by 12 field-collected females that were mated under captive breeding conditions. In total, 65 nymphs emerged from the 12 fertile oothecae under captive breeding conditions.

No significant differences were recorded between the length, width, height or number of eggs of the fertilized or unhatched oothecae. Mean ootheca length was 8.5 ± 4.11 mm, containing 17.26 egg ± 6.66 chambers per ootheca (Table 7.1). The mean width and height of an ootheca was 4.37 ± 0.76 mm and 6.15 ± 0.83 mm respectively (Table 7.1).

7.4.3 Developmental parameters

Of the 63 neonate nymphs that hatched from the 12 different oothecae throughout this study, 45 completed their lifecycles (14 males and 31 females). The mean duration between mating and the production of an ootheca was 11.82 ± 9.51 days and the act of copulation itself continued for approximately six hours (Table 7.3). The incubation period of an ootheca was approximately 20 weeks (143 days). The mean hatch rate was 31%, while the average survival rate was almost 68% (Table 2). The sex ratio differed between the various oothecae but the mean sex ratio (M:F) was 1:1.5. Two of the oothecae only produced only males while another two produced only females (Table 7.2).

No significant differences were recorded between the average duration per instar of females and males. The nymphal period took approximately 20 weeks to complete (Table 7.3). However, females required a longer nymphal period (145.71 ± 29.88 days) than males (128.00 ± 31.09 days), even though this difference was not significant. The mean duration of the lifecycle of *H. tricolor* individuals in this study was six months (191.33 ± 37.96 days).

7.5 DISCUSSION

7.5.1 Distribution patterns of *Harpagomantis* spp. in southern Africa

Although three species are listed within this *Harpagomantis* genus (*H. tricolor, H. discolor, H. nana*), there is an anomaly within this genus. Specimens records exist for both *H. tricolor* and *H. discolor*, however, as reported by Kaltenbach (1996) the taxonomic status of *H. discolor* was and remains unclear. According to Giglio-Tos (1927), *H. discolor* males do not have a brown spot on the hindwings and this species is generally larger than *H. tricolor*. Rehn (1927) reported that *H. tricolor* is a much smaller species with limited distribution (mostly in the western Cape region of South Africa) while *H. discolor* occurs throughout South Africa but predominantly in the northern region. The latter species is also larger and have elongated processes on the eyes (non-visual elongations that do not contain ommatidia).

However, Karny (1908) indicated that *H. discolor* could be a variety of *H. tricolor*. This view was shared by Beier (1955) which stated that *H. discolor* was a “pigment-poor” variety of *H. tricolor*. A similar conclusion was drawn by Kaltenbach (1996) and this species was therefore considered an intra-species variety (in size and colour) of *H. tricolor* and, according to Kaltenbach (1996), *H. discolor* is a synonym of *H. tricolor.* Ehrmann (2002) agreed with Beier (1935, 1955) and Kaltenbach (1996) and noted that *H. discolor* was a synonym for *H. tricolor*. Since the Mantodea species file (Otte et al. 2020) recognizes both of these species of *Harpagomantis* and no clear indication on the status of *H. discolor* is provided, it was considered a separate species in this study. The third species within the *Harpagomantis* genus is *H. nana*, which, according to literature, occurs in Cameroon (Otte et al. 2020). However, this species was not mentioned by Erhmann (2002) or Kaltenbach (1996; 1998) in their reviews of global and African mantids. No specimen records of *H. nana* were recorded in any of the museum collections in this study. Otte *et al.* (2020) and Svenson *et al*. (2015) both indicated that revision of several subfamilies, tribes and genera within the Mantodea are required. *Harpagomantis* is but one example of a genus in need of revision.

Literature about *Harpagomantis* is scarce but some studies reported on the distribution of this genus. For example, in 1999 *H. tricolor* was collected on an indigenous plant species, *Delairea odorata* (Asteraceae) (Cape Ivy), which occurs along the east coast of South Africa (Grobbelaar *et al*. 1999). This mantid species was also recorded in fynbos and native vegetation that were cleared of alien invasive trees (Magoba & Samways 2010) as well as in the De Hoop Nature Reserve, a World Heritage site in the western Cape (Brand & Samways 2009). *Harpagomantis* specimens were also recorded in the Highveld grassland biome of South Africa (Botha *et al*. 2018; Greyvenstein *et al*. 2020b). Beyond these studies, the distribution of this genus is recorded to be in throughout South Africa, but predominantly in

Western Cape, KwaZulu Natal and Transvaal (Beier 1955). Patel *et al*. (2016) reported the distribution of this genus to include Botswana, Namibia, Mozambique and Zimbabwe, which is similar to the distribution of the genus described by Kaltenbach (1996).

Svenson *et al.* (2015) suggested that a fundamental aspect of plant mimicking mantid ecology, such as that of *Harpagomantis*, is crypsis, which is also defense strategy. *Harpagomantis* species mimic flowering plants they could thus theoretically occur in most areas in which flowering plants are common.

Ectomorphs (morphologically similar characteristics that align with particular habitats) of mantids such as *Harpagomantis* (plant mimicking), for example, are suspected to have evolved several times in different geographic regions due to similar habitats and ecological pressures (Svenson & Whiting 2009; Wieland 2013; Svenson *et al*. 2015). The morphological foundation of Mantodea taxonomy has caused inconsistencies since the biogeographical distributions of ectomorphs' species were not previously considered, and because a range of species which are morphologically similar, occur on other continents. For example, species of *Harpagomantis* in South Africa and species of the genus *Theopropus* Saussure (Mantodea: Hymenopodidae) from Vietnam are morphologically similar. Due to the above-mentioned taxonomic inconsistencies it is difficult to assess the taxonomic status of one of the *Harpagomantis* spp. in South Africa. Although the distribution records in this study indicate that *H. discolor* occurs predominantly in the north-eastern region of South Africa, more research is needed to determine if two or three phenotypes of *Harpagomantis* exists in the region.

A large number of specimens were collected in the Gauteng province which is the region in South Africa with the highest human population density. This high population density could explain the large numbers of specimens collected in this region (Greyvenstein *et al*. 2020a). However, as reported by Grytnes and Romdal (2008), this could also be due to ease of access to natural areas where specimens can be collected outside of protected areas. In this study, most specimens were collected in Provincial Nature reserves. Davis *et al*. (2005) indicated that the Department of Agriculture, Conservation, Environment and Land Affairs has focused on protecting as much local flora and fauna as possible in provincial and local nature reserves in highly populated areas throughout South Africa.

This study suggests that provincial nature reserves, more so than national parks, do perhaps create refuge areas for species in a mosaic of disturbed and highly populated areas. An example of a provincial and/or local area that can be regarded as refuges for birds in highly developed areas was reported by Wang *et al*. (2013) in China, where the Hengshui Lake Nature reserve, close to the city of Jizhou was created as a safe place for migratory and endangered bird species. However, more research is needed to determine if protected areas serve as refuges for less mobile species such as mantids. Future investigations should therefore be conducted to determine if *Harpagomantis* species are still present within provincial nature reserves as suggested by the historic specimen records.

H. discolor was last recorded in 1977 in Harkerville in the western Cape while *H. tricolor* (except for the specimen collected during this study) was also collected in the western Cape during 2015 at Stellenbosch. It should further be noted that 176 specimens in the various South African museums still have to be identified.

7.5.2 Biology of *Harpagomantis tricolor*

Since no information on the biology of *H. tricolor* or other members in the Galinthiadidae exists, comparisons of its biology are made with that of *Ephestiasula pictipes* (now known as *Ephestiasula rogenhoferi*) (Mantodea), which is in the Hymenopodidae, from where *H. tricolor* was moved, based on molecular evidence (Svenson *et al*. 2015). Due to the lack of literature about the biology of Mantodea in general, the study by Vanitha *et al*. (2016) will be used for comparison purposes in this study. The oothecae of *H. tricolor* were shorter than that of *E. rogenhoferi* but the width of the oothecae of these two species are similar (Vanitha *et al*. 2016). The oothecae of *H. tricolor* are similar in structure and form to that of *Empusa pennata* Thunberg (Mantodea: Empusidae) (Torres 2015).

It was suggested by Larsen (2002) that the structure and morphology of mantid oothecae provided it with the ability to survive harsh environmental conditions. The function of the shell-shape of some mantid oothecae, for example that of *Gongylus* Thunberg (Mantodea: Empusidae) and *Empusa* Illiger (Mantodea: Empusidae), is to divert heat. Other explanations for the unique shape and colour of oothecae of some species are to aid in crypsis of the oothecae itself (Thomann 2002). The shape and colour of *H. tricolor* oothecae resembles, to an extent, tubercle or auxiliary bud of plants, which could be an adaptation of this mantid species to blend into its environment, which is suggested to be predominantly on flowering plants. This could thus allow the oothecae to be more inconspicuous, limiting unwanted investigation from potential predators. The ootheca of *H. tricolor* is an example of the wide variety of structural diversity and cryptic adaptations that are found throughout the oothecae of Mantodea (Rivera and Svenson 2016). The small size (length, width and height) contributes to its inconspicuousness, especially on thorny vegetation. The number of eggs within the oothecae of *E. rogenhoferi* was unfortunately not reported by Vanitha *et al*. (2016). Suckling (1984) did report an average of 34 eggs per ootheca for *Orthodera ministralis* Fabricius (Mantodea: Mantidae), which is close to the maximum number of eggs recorded for *H. tricolor* in this study.

No differences were observed between any of the size parameters of fertilized and unhatched oothecae in this study. This is in contrast to the significant differences in size of fertilized and unhatched oothecae of *Galepsus lenticularis* Saussure (Mantodea:

Tarachodidae) (Greyvenstein *et al*. 2020a). Similarly, Greyvenstein *et al*. (2020a) reported differences with regards to the number of eggs inside fertilized and unhatched oothecae. This was however not the case for *H. tricolor* as no differences in this regard was recorded in this study. It was noted that no oothecae were laid by the captively reared adult females in this study, which is also in contrast to results reported by Greyvenstein *et al*. (2020a) for *G. lenticularis*. While the oothecae of *G. lenticularis* has been described as “primitive” and resembling that of the Blattodea (Greyvenstein *et al*. 2020a; Ene 1964), that of *H. tricolor* could suggest a more advanced species, based on their ectomorph evolutionary history. The difference in evolutionary traits/age of the species, environmental stimuli, food related resources or survival strategy could have been the reason that captively reared *H. tricolor* females did not oviposit unfertilized oothecae (oothecae produced without mating).

7.5.3 Developmental parameters

The extended incubation period of *H. tricolor* oothecae (145 days) recorded in this study was much longer than that reported by Vanitha et al. (2016) for *E. rogenhoferi*. It is possible that under natural environmental conditions the oothecae of *H. tricolor* undergoes diapause during winter but under captive rearing conditions at a constant temperature and humidity, this incubation period was shorter. Overwintering of oothecae has been reported for some Mantodea species, for example *Brunneria borealis* Scudder (Mantodea: Coptopterygidae); *Tenodera aridifiola sinensis* (Mantodea: Mantidae) and *Empusa* sp. (Kaltenbach 1963; McMonigle 2013; Maxwell 2014; Svenson *et al*. 2015; Hurd *et al*. 2019).

A high hatch rate and low survival rate was reported by Vanitha *et al*. (2016) for *E. rogenhoferi,* while the opposite was recorded for *H. tricolor* in this study. Hatch and survival rates can be influenced by frequency of feeding, food resources, genetics, and temperature, depending on the survival strategy of the species (Matthews & Matthews 1978; Hurd & Eisenberg 1984; Suckling 1984; Iwasaki 2006; Vanitha *et al*. 2016; Christensen & Brown 2018). The average duration of the period between mating and production of an ootheca in this study was 12 days, while E. *rogenhoferi* only required a week to produce the first ootheca after females mated (Vanitha *et al*. 2016).

The average duration of copulation between males and females of *H. tricolor* was six hours. McMonigle (2013) reported that sperm transfer occurs within 30 minutes of the initial copulation action of mantids. The extended copulation period is suggested to be a form of safe guarding of the genetic prodigy of the male since this behaviour results in decreased competition with other males (Prokop & Vaclav 2005). Beyond decreasing sperm competition, males in a better condition (fitness) were also reported to copulate longer with females (Prokop & Vaclav 2005; Holwell 2006). Strategic ejaculation and adjustment of developmental duration has also been reported in males of *Pseudomantis albofimbriata* Stäl

(Mantodea: Mantidae), when these males were reared in a male-dominated environment (Allen *et al*. 2011). The latter authors reported that male development was slower under conditions where many males were present, while the opposite was observed when many females were present. Allen *et al*. (2011) indicated that male mantids took longer to mature, and suggested that this could indicate more investment in the development of testes. These males also copulated for a significantly longer time and transferred more sperm per copulation event (Allen *et al*. 2011). Multiple paternity has been documented for *T. aridifiola* by Watanabe *et al*. (2011) who suggested competition between males of the same mantis species for copulation or mating opportunities. The duration of the adult stages did not differ significantly between male and female of *H. tricolor*.

Sexual dimorphism in size, where males are smaller than females has been observed in various mantid species (Wieland 2013). Some examples of mantid species with size sexual dimorphism are: *Hymenopus coronatus* Oliver (Hymenopodidae) *Creobroter* sp. Westwood (Hymenopodidae), *Polyspilota aeruginosa* Goeze (Mantidae) and *Theopropus elegans* Saussure (Mantidae) (McMonigle 2013) Differences in size and colour between sexes was noted for *H. tricolor* in this study. Differences in antennal morphology were also noted between male and female *T. aridifiola* from the sixth-instar onwards (Carle *et al*. 2014). *Pseudomantis albofimbriata* and *G. lenticularis* exhibit sexual dimorphism as the wings of males are fully developed while females are flightless (Holwell *et al*. 2006; Greyvenstein *et al*. 2020a). Sexual dimorphism between males and females in wings and size could be due to the males that have to find potential reproductive partners. Thus males of a smaller size could be more cryptic thus and more difficult to be observed by predators. The smaller size of males also has dispersal advantages as it could increase the ease of flight for males.

7.6 CONCLUSIONS

Distribution of false flower mantids in South Africa seems to be predominantly towards the north eastern region, in the Savanna and Grassland biomes. The wide distribution of this mantid could also indicate a possible tolerance to a variety of environmental variations. Extended copulation duration of this species could be a by-product of males trying to decrease sperm competition and this is also an aspect which could have led to the short duration of the male nymphs compared to female nymphs of *H. tricolor*. This study is the first attempt at mapping the distribution of Harpagomantis in South Africa and recording the biology of *H. tricolor*. It is suggested that this species goes into diapause in the ootheca phase.

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7.9 TABLES

Table 7.1. Mean size and number of egg chambers inside the various types of oothecae of *Harpagomantis tricolor* reared under captive breeding conditions. SD = Standard deviation.

Oothecae (19)		Length (mm) ± SD	Width (mm) ± SD	Height (mm) ± SD	Number of eggs/ootheca ± SD
T-test	t-value	0.573	0.986	0.058	0.267
	p-value	0.574	0.338	0.954	0.792
Overall (19)		8.58 ± 4.11	4.37 ± 0.76	6.15 ± 0.83	17.26 ± 6.66
Unhatched (7)		7.86 ± 2.24	4.14 ± 0.69	6.14 ± 1.21	16.71 ± 7.20
Fertilized (12)		9.00 ± 4.63	4.50 ± 0.80	6.17 ± 0.58	17.58 ± 6.63

Table 7.2. The mean hatch rate, survival rate and gender dynamics throughout the study that resulted from each of the field-collected *H. tricolor* females (12 individuals) that were kept in the laboratory and each of their associated fertile oothecae (12).

Ootheca number	**Oothecae incubation (days)**	**No. of eggs per ootheca**	**Hatch rate (%)**	**Survival (%)**	**Male (%)**	**Female (%)**	**Sex Ratio (♂:♀)**
Ootheca 1	123	16	81.25	69.23	33.33	66.67	1:2
Ootheca 2	149	14	28.57	100	0.00	100.00	0:4
Ootheca 3	145	19	31.58	100	83.33	16.67	1:0.2
Ootheca 4	155	18	33.33	50	33.33	66.67	1:2
Ootheca 5	127	16	25.00	100	0.00	100.00	0:4
Ootheca 6	138	18	16.67	100	33.33	66.67	1:2
Ootheca 7	145	15	20	33.33	100.00	100.00	1:1
Ootheca 8	156	9	44.44	50	100.00	0.00	2:0
Ootheca 9	153	36	13.89	60	33.33	66.67	1:2
Ootheca 10	147	12	25.00	66.67	0.00	100.00	0:2
Ootheca 11	143	21	14.29	66.67	50.00	50.00	1:1
Ootheca 12	139	17	35.29	16.67	60.00	40.00	1:0.67
Mean ± (SD)	143.33 ± 10.31	17.58 ± 6.63	30.78 ± 18. 35	67.71 ± 28. 04	43.89 ± 36.15	64.44 ± 33.46	1:1.5

Table 7.3. Mean duration (in days) of each of the life stages of *Harpagomantis tricolor* and differences between male and female development under captive breeding and rearing conditions. Three of the females developed to the sixth-instar and were not included in the table below.

	Mean duration (days ± SD)				
Life stage	Overall	Males	Females	t-value	p-value
Ootheca (incubation period)	144.71 ± 9.33	142.51 ± 10.90	145.68 ± 8.55	1.057	0.297
First-Instar	26.62 ± 11.07	25.36 ± 9.91	27.19 11.67±	0.373	0.710
Second-Instar	24.67 ± 15.63	28.57 ± 17.51	22.90 ± 14.66	-1.110	0.273
Third-Instar	27.67 ± 13.06	33.38 ± 18.5	25.42 ± 9.37	-1.784	0.082
Fourth-Instar	41.55 ± 22.91	49.00 ± 29.63	39.24 ± 20.47	-0.838	0.407
Fifth-Instar	51.50 ± 13.28	54.00 ± 9.00	51.06 ± 14.06	-0.499	0.624
Copulation to oothecae (days)*	11.82 ± 9.51	12.27 ± 8.67	11.63 ± 9.99	-0.135	0.894
Copulation duration (hours)**	06:10 ± 0.04	06:15 ± 0.04	06:08 ± 0.03±	-0321	0.750
Total nymphal period (days)***	140.20 ± 31.03	128.00 ± 31.09	145.71 ± 29.88	1.776	0.082
Adult longevity (days)****	51.11 ± 39.76	31.57 ± 29.72	59.93 ± 40.97	-0.509	0.613
Period from hatch to death (days)	191.33 ± 37.96	161.71 ± 20.47	204.71 ± 36.58	-0.509	0.613

* duration of period between male and female copulation and production of ootheca

** duration of male and female copulation

***from ootheca hatch to final moult (First-instar-fourth/fifth-instar).

****duration of adult phase.

Figures

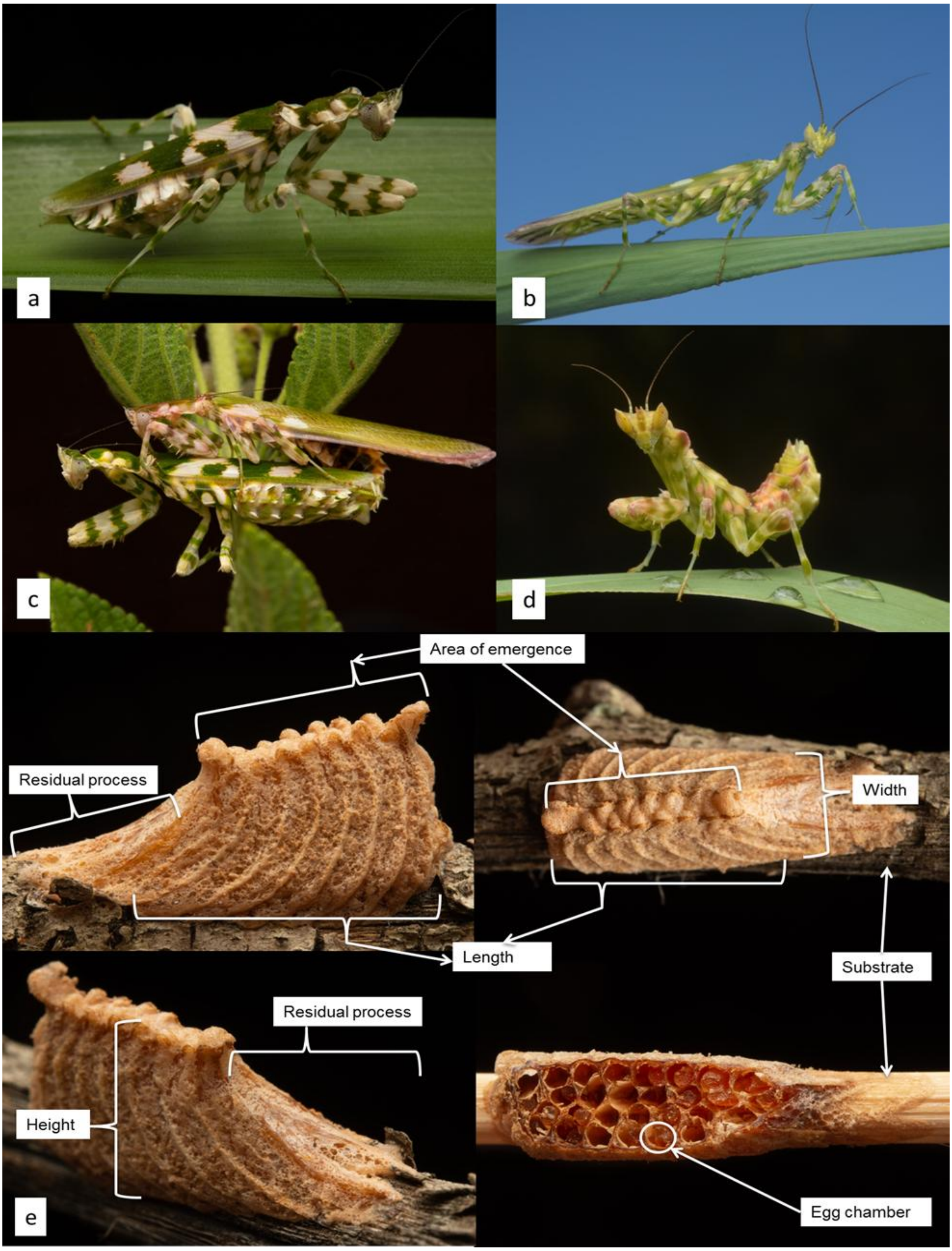


Fig. 7.1. *Harpagomantis tricolor* female (a), male (b), copulating adults (c), fifth-instar nymph (d) and general morphology of the oothecae (e), indicating different parameters and areas of interest as suggested by Brannoch et al. (2017). **Photographs by Paul Janse van Rensburg.**

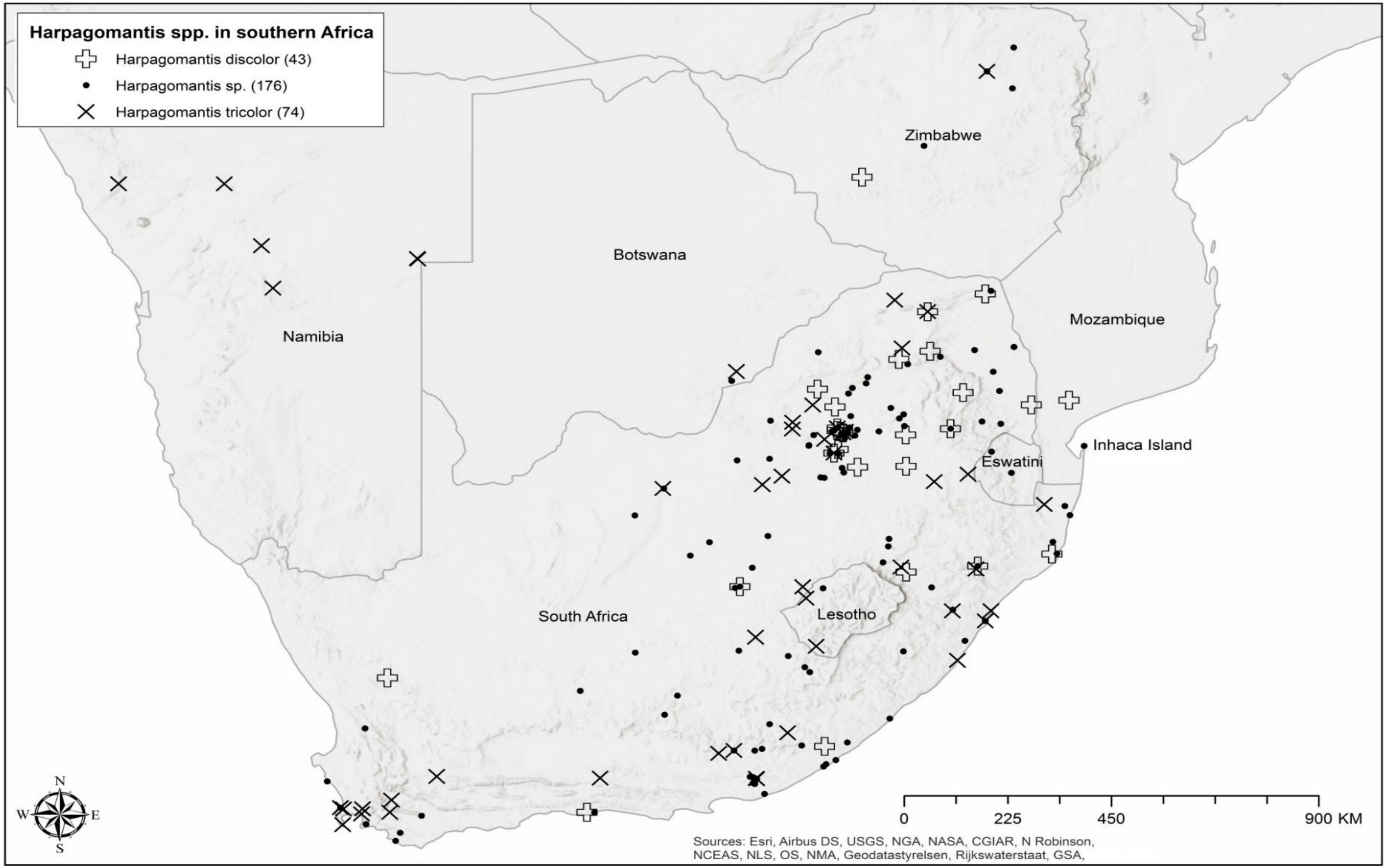


Fig. 7.2. Distribution records of *Harpagomantis* species that occur in southern Africa. Numbers in brackets indicate the number of individual records per species.

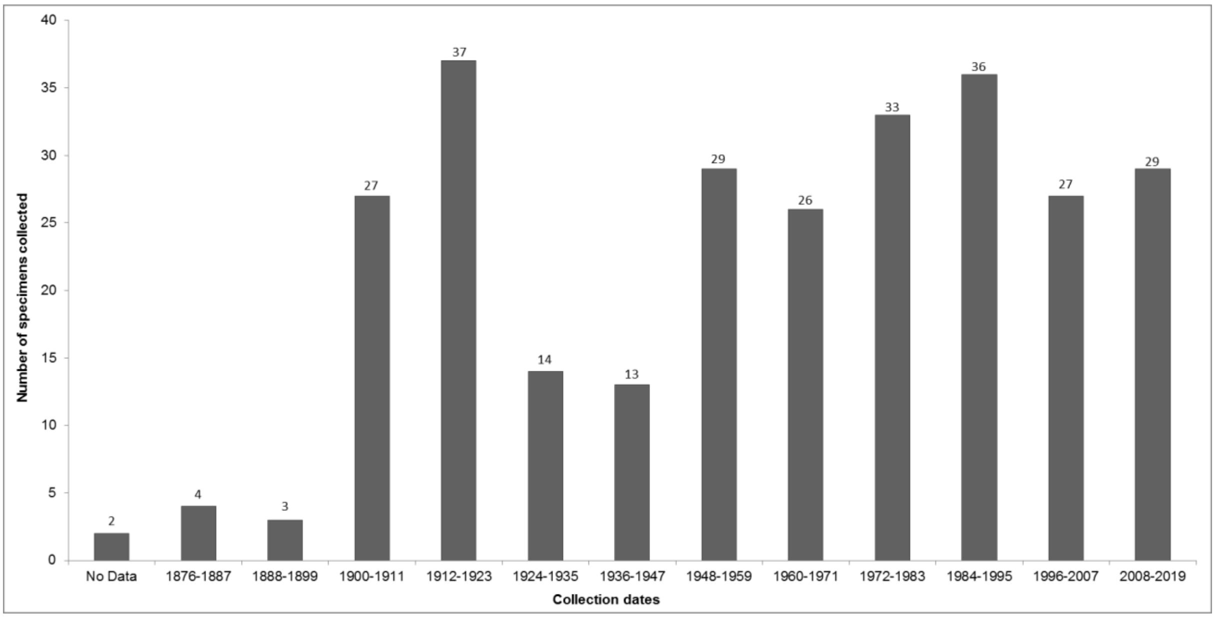
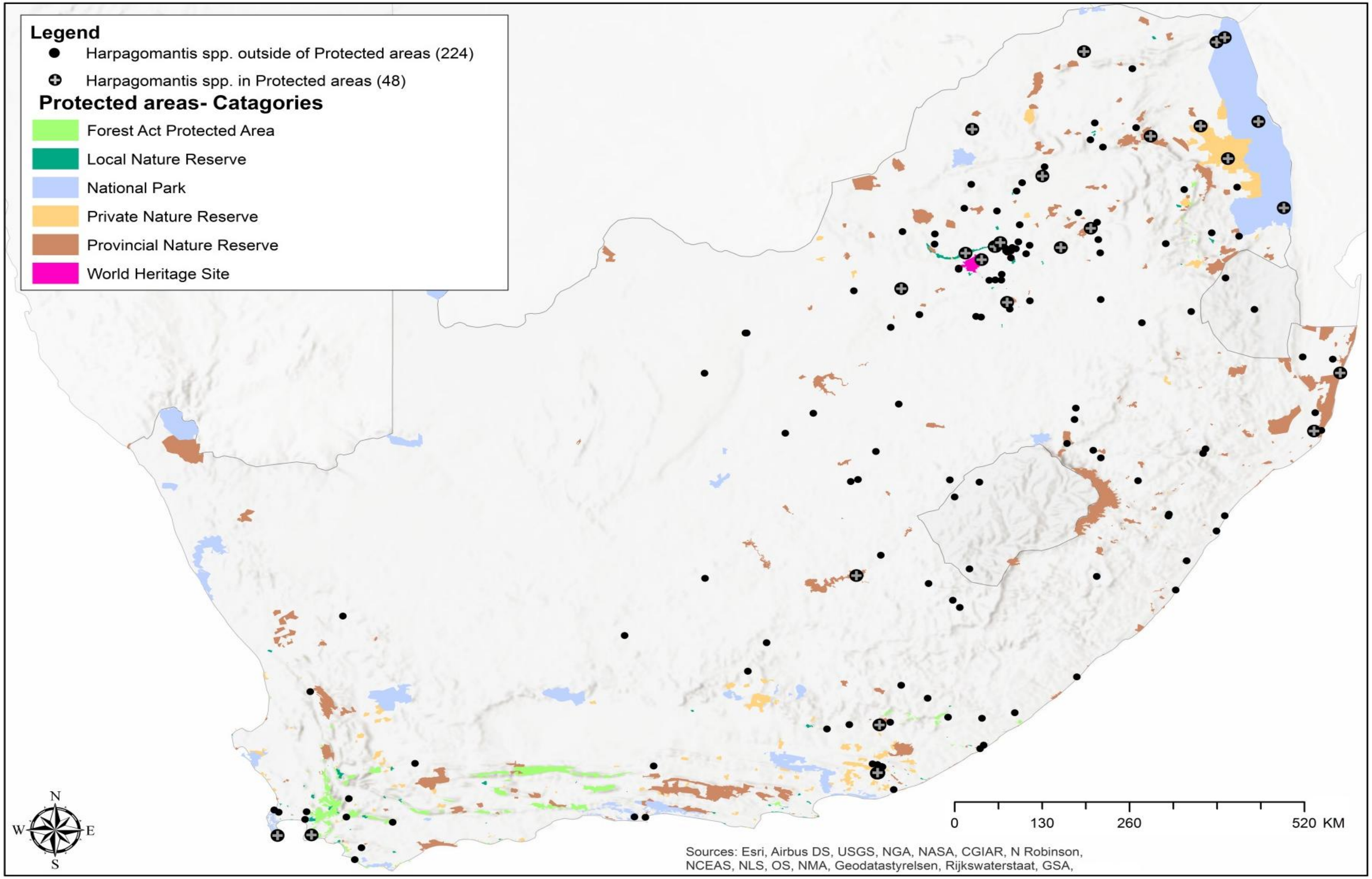
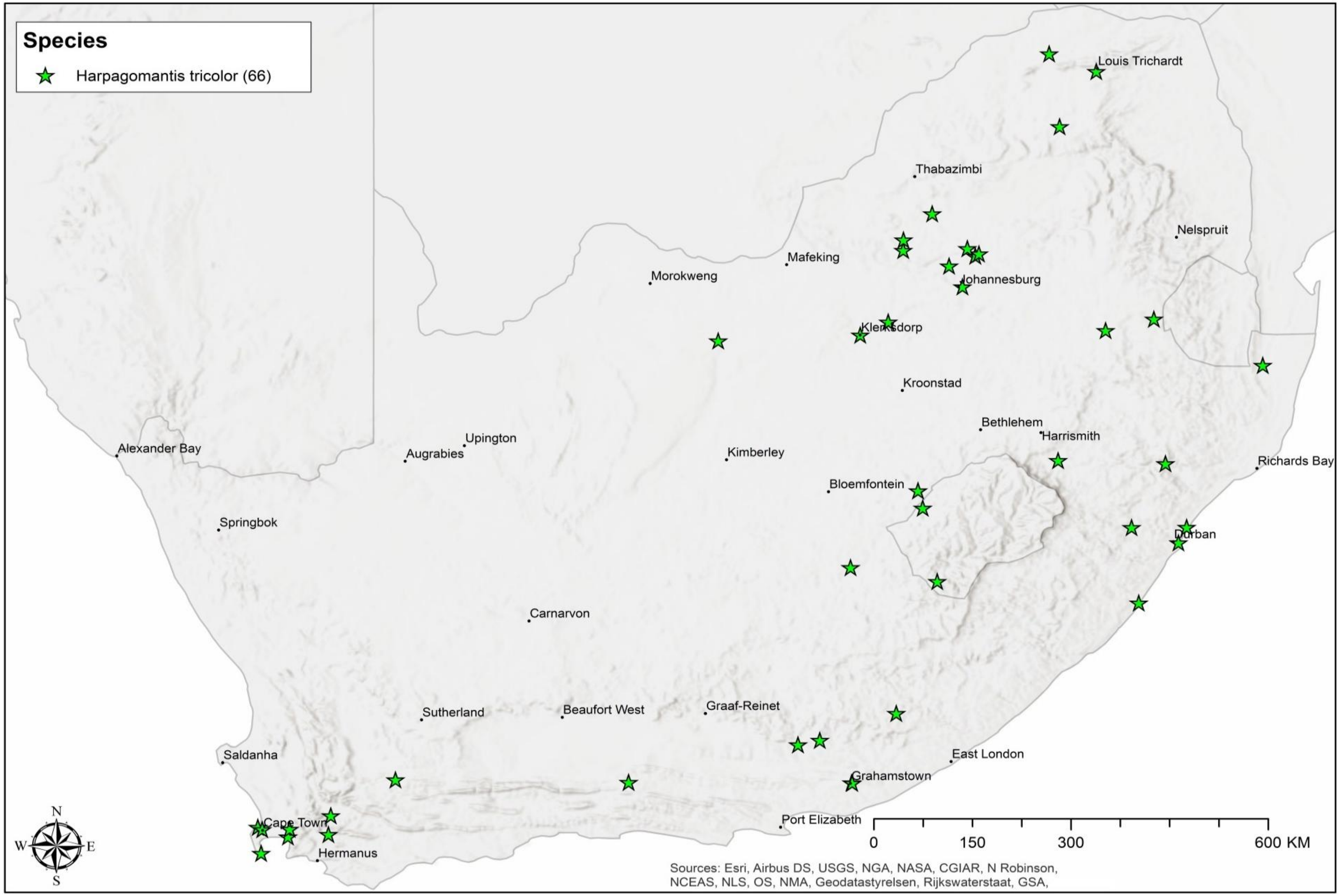


Fig. 7.3. Number of *Harpagomantis* species records collected in southern Africa during different time periods.



Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA,

Fig. 7.4. Distribution records of *Harpagomantis* species collected in protected and non-protected areas of South Africa.



Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA,

Fig. 7.5. Distribution of Harpagomantis tricolor in South Africa based on museum collection records**.**

CHAPTER 8: ARTICLE 6

Distribution of Mantodea in southern Africa

(Prepared for submission to **Insect Diversity and Conservation**)

BIANCA GREYVENSTEIN[1], HANNALENE DU PLESSIS[2] & JOHNNIE VAN DEN BERG[3]

1: orcid.org/0000-0003-2033-7113

2: orcid.org/0000-0003-1163-1468

3: orcid.org/0000-0002-6831-3180

1-3: Unit for Environmental Sciences and Management, North-West University, Potchefstroom, 2520, South Africa

1: Corresponding author E-mail: biagrey90@gmail.com

8.1 Abstract. 1. The Mantodea is a relatively small order of insects and very little knowledge exists about their distribution, especially in southern Africa.

2. The available literature addresses species list compiled 20 years ago, and did not include specimens held in all the national collections in South Africa. The aim of this paper was to compile distribution maps using specimen records of the Mantodea fauna held in South African collections.

3. In total 178 spp. (90 genera in 11 families) and 4292 distribution records were recorded from 14 African countries and Indian Ocean Islands. The distribution of the Mantodea within South Africa suggests that the north-Eastern parts of the country contains the most species, however further investigations are required to confirm this phenomenon.

4. Although 94 possibly endemic species were previously reported to occur in the region, only 35 of these were recorded throughout the museum collections accessed during this study. Ninety-one “rare” species with very few collection records were identified and distribution records mapped.

5. The data presented in this paper contributes to identification of endemic and threatened mantid species in the region and to development of future conservation strategies. The limited data on many species necessitates further investigation to establish the current state of their biogeography and phenology.

8.2 Introduction

The Mantodea consists of 21 families and approximately 2400 species worldwide (McMonigle, 2013; Wieland, 2013). The largest of these families is the Mantidae which consists of approximately 1000 species. Mantids are thermophilic and their distribution is linked to more tropic and subtropical regions between 45-46 degree latitudes (Klass and Ehrmann, 2003). Exceptions do however exist, for example, *Mantis religiosa* (L.)(Mantodea: Mantidae) and *Empusa pennicornis* (Pallas)(Mantodea: Empusidae), which occurs beyond the 50 degree latitude in the northern hemisphere. Mantids that occur in temperate regions largely seek arid habitats and are xerophytic (Shcherbakov and Savitsky 2015).

South Africa has been ranked the third most biologically diverse country in the world (Cadman et al., 2010), even though it only occupies 2% of earth’s surface (CBD, 2018). There are nine recognised biomes (i.e. Albany thicket, Desert, Forest, Fynbos, Grassland, Indian Ocean costal Belt, Nama-Karoo, Savanna and Succulent Karoo) with 13 centres of endemism and many endemic species (von Maltitz and Scholes, 2006). Apart from the unique Cape Floristic region (known for the Fynbos of the area) which is one of only six Floral kingdoms in the world, South Africa also has a rich and diverse arid plant community (Succulent Karoo)(Rutherford et al., 2000; Pryke and Samways, 2009). The Convention on

Biological Diversity estimates that South Africa has an endemism rate of 56%, 65% and 70% respectively for amphibians, plants and invertebrates and contains 10% of the world's plant species and 7% of the world's bird, reptile and mammal species (CBD, 2018).

Despite the rich literature on the fauna and flora of southern Africa, there is hardly any information available on the biology, diversity and distribution of Mantodea in the region. The only available information on southern African Mantodea are the checklist compiled by Kaltenbach between 1996 and 1998 (Kaltenbach, 1996;1998) as well as a survey that was done by the Mantodea Project which is in affiliation with the Cleveland Museum of Natural history in Ohio, USA, in 2005. Furthermore, the subfamily Sibyllinae in the family Hymenopodidae is known to be exclusively in Africa (Roy, 1996).

The dispersal or distribution of an insect species is mostly a response to biological and environmental factors such as temperature, food availability and habitat suitability and is the basis on which baseline studies are founded (Matthews and Matthews, 1978). A common practise is to use visual representation, for example maps, to indicate the localities at which specimens were observed, and these localities are presumed to fulfil their biotic and abiotic requirements. The patterns observed from these maps can be interpreted as the likely distribution of a species on a larger scale and may facilitate conservation efforts if required. For example, according to Chefaoui et al. (2005) the potential distribution of *Copris hispanus* L. (Coleoptera, Scarabaeidae) and *Copris lunaris* L. (Coleoptera: Scarabaeidae) may aid in conservation efforts by identifying possible reintroduction localities and increasing gene flow by establishing corridors or greenbelts that allow movement through the maze of disturbances such as cities or agro-ecosystems.

Another example is mentioned by Dippenaar-Schoeman and Leroy (2003) of SANSA (South African National Survey of Arachnida) that collected spiders during several surveys to establish the diversity and distribution of spiders in South Africa. In one survey the approximation of 103 species increased to 305 species in the Kruger National Park. The distribution of termites for example indicated that conservation is required on a broader scale as termites are ecosystem engineers and that local conservation efforts do not fulfil in conserving a distinct and endemic subset of termite species in South Africa (Muller et al., 1997).

Large scale surveys could be conducted to address the gap with regards to the lack of distribution and diversity data of Mantodea in southern Africa. However, this would be very expensive and time consuming. Muller et al. (1997) indicated together with surveys, museum records (4003 records) were used to determine potential areas of conservation value for termites in South Africa. Suarez and Tsutsui (2004) indicated that specimen records held in well-curated national collections and herbariums are an important tool in conservation and that the data residing within museum records can aid in establishing of species distribution patterns, biodiversity patterns, alien species introductions and even provide some ecological insights with regards to a specific species. These records should however be considered as inconsistent and observationally biased (Ross et al., 2012). Museum records are therefore somewhat consistent in its inconsistency, but nonetheless very useful, especially for developing distribution maps based on historic data. At the very least, museum records can be considered a starting point to which more data can be added as it is collected.

Currently only 13 Mantodea species are listed on the International Union for Conservation of Nature (IUCN) Red Data list of threatened species (Table 1) (IUCN, 2020; Gerlach, 2012; Battiston, 2014a, b; Battiston, 2016a-c; Battiston et al., 2016a-g). None of these records occur in South Africa. The distribution of only eight of these 13 species are indicated on the IUCN website (Fig. 1) (IUCN, 2020; Gerlach, 2012; Battiston, 2014a, b; Battiston, 2016a-c; Battiston et al., 2016a-g). While one of these species (*Ameles fasciipennis* Kaltenbach Mantodea: Mantidae) is classified as Critically Endangered, no distribution data is available for this species, as is the case of four of the other species listed on IUCN. Of these four species, one is classified as Vulnerable, while the others are Least concern. In descending order are the classifications of the other 12 mantid species: Least concern (5 species), Data deficient and Vulnerable (3 species each) and Endangered (1 species). The lack of knowledge with regards to their basic species specific attributes i.e. distribution, biology, ecology and behaviour is mirrored by the extent of Mantodea species present on the IUCN Red data list.

No data on Mantodea of Africa are available on the IUCN database. Without the fundamental knowledge of Mantodea distribution, the effects of climate change and habitat destruction on mantids are difficult to monitor and impossible to anticipate and mitigate. Data on diversity and distribution about Mantodea in South Africa should be generated since this will play a critical role in future conservation efforts. Lastly, this will give a glimpse into the basic aspects of an insect group which has not just fascinated the human race but entertained us so much that myths, legends and superstitions were created in their honour. The aim of this study was to generate data on the distribution of Mantodea in southern Africa and especially in South Africa.

8.3 Material and methods

Distribution records were collected during visits to all of the seven national insect collections and museums throughout South Africa: Ditsong Museum of Natural History (Pretoria), Agricultural Research Council (Biosystematics Division in Pretoria), National Museum (Bloemfontein), Albany Museum (Grahamstown), Rhodes University (Grahamstown), Durban Natural Science Museum, Iziko South African Museum (Cape Town) and KwaZulu-Natal Museum (Pietermaritzburg). Most specimens in these collections where already identified by taxonomists during previous visits to these institutions, while many were sent for identifications the Vienna museum in Germany, the University of Drexel in Philadelphia, USA, the Muséum national d'Histoire naturelle (MNHN) in France as well as the research collection of Nicolas Moulin in Montérolier.

All mantid specimens and distribution labels where photographed (Canon D1300) and digitized and a database compiled. This database contains the following information for each specimen record: genus and species name (to the level of identification), collector's details and collection date if available and geo-referenced locality. The website (Mantodeaspeciesfile.org) and literature was used to determine the current nomenclature within the order. All locality data was georeferenced using the principals suggested by Wieczorek et al. (2004) and all coordinates were converted from Degrees, minutes, and seconds (DMS) to Decimal degrees (DD) with the use of the website (gps-coordinates.net). DD were used for plotting the occurrences of the variety of Mantodea species in southern Africa with GIS software (ArcMaps version 10.6.1).

8.4 Results

A total of 4292 Mantodea specimen records were recorded with approximately 178 species in 70 genera and 11 families. These records were from 989 localities such as cities, towns and nature reserves throughout southern Africa. All the Mantodea species referred to in this study and which were recorded in the national collections, as well as their distribution in South Africa is provided in Supplementary material S3.

These specimens were collected in 16 southern African countries, with 3559 (83%) of the total number collected within South Africa. The other 14 countries were: Angola, Botswana, Comoros Islands, Democratic Republic of the Congo (DRC), Gabon, Kenya, Lesotho, Madagascar, Malawi, Mozambique, Namibia, Swaziland (eSwatini), Tanzania, Zambia, Zanzibar (part of Tanzania) and Zimbabwe. Namibia and Zimbabwe respectively contributed 291 and 202 Mantodea specimen records, while the Comoros Islands, Gabon, Kenya, Madagascar and Zanzibar each contributed only one specimen record (Supplementary material S1).

Species within the Mantidae family were the most abundant in countries neighbouring South Africa, while only one record within the Toxoderidae family was recorded in Angola (Fig. 8.1). The distribution of the museum specimen records of Toxoderidae tended to be more towards the North western parts of southern Africa i.e. the coastal regions of Namibia and Angola.

The four Amorphoscelidae specimens were collected in the Caprivi region of Namibia and Zimbabwe (Fig. 8.2). One specimen of the Iridopterygidae was recorded in Zimbabwe while records of Angelidae were predominantly from Zimbabwe. The Empusidae and Galinthiadidae were recorded in several southern African countries (Fig. 8.2).

Liturgusidae was recorded in the DRC and one specimen in the northern part of Tanzania, which are predominantly forest areas. Hymenopodidae, Mantidae and Tarachodidae were the Mantodea families with the widest distribution which included the islands of Madagascar and the Comoros (Fig. 8.2). Thespidae records are widely distributed, however, not to the same extent as the Mantidae or Tarachodidae. Only two records were located in Botswana while Namibia, Zimbabwe, Mozambique and the DRC had several Thespidae records. Mantidae is the family with the largest number of museum collection records i.e. 1671 while Tarachodidae contributed 756 records. Toxoderidae seems to be more distributed towards the northern parts of South Africa with the grassland and savannah biomes (Fig. 8.2).

In contrast to the above mentioned distribution of the Mantodea families in southern Africa, the distribution of the families in South Africa itself is quite different. Amorphoscelidae was recorded in the north eastern part of South Africa, while Angelidae records were more scattered with the majority of records from the north eastern part of the country (Fig. 8.3). While the number of Empusidae records from South Africa was much higher than those from other countries in the region, these records were scattered all over South Africa and no pattern was evident. This phenomenon of scattered distribution was also evident for Mantidae, Galinthididae, Hymenopodidae, Tarachodidae and Thespidae (Fig. 8.3).

Liturgusidae had the fewest museum records (4). Records of these highly cryptic species, *Theopompella westwoodii* Kirby and *Zouza radiosa* Giglio-tos, were from protected areas (Kruger National Park, Ndumo Game reserve and Umhlanga Lagoon Nature reserve) (Fig. 8.3), which are all predominantly forested areas. Greyvenstein et al. (2020) indicated that this was contrary to nearly all the other specimens in South African collections, which were collected outside of protected areas. The occurrence of Liturgusidae in South Africa has not been reported before, previously their distribution was defined to be only as far south as Mozambique and Zimbabwe (Moulin et al. 2017; Patel et al. 2016).

The total number of mantid species recorded in southern Africa was 178. Of these, 63% (112 species in 49 genera) occur in both South Africa and the northern neighbouring countries (Fig. 8.4). Kaltenbach (1996) listed 94 species that were possibly endemic to southern Africa (Supplementary S2 Table 2). However, only 35 of these 94 listed possibly endemic species were recorded in museum collections during this study, and are distributed throughout southern Africa. Thirteen of the 35 possibly endemic species occur in South Africa (Fig. 8.5).

Although, the neighbouring countries have 13 species in 12 genera that are unique to the area, none of these species were classified by Kaltenbach (1996) as endemic to the region. Five of the 13 unique species were only recorded in one of the neighbouring countries (Fig. 8.4). For example, *Pseudoharpax ugandanus* Giglio-tos (Galinthididae), *Sphodromantis viridis* Forskal (Mantidae) and *Tarachodes (Tarachodes) bicornis* Giglio-Tos (Tarachodidae) only have collection records from Zimbabwe, while *Carvilia saussurii* Stal (Mantidae) was only collected in Namibia. Similarly, *Miomantis monacha* Fabricius (Mantidae) and *Galepsus (Onychogalepsus) damaranus* Giglio-tos (Tarachodidae), were only recorded in Mozambique and Botswana respectively (Fig. 8.5).

In South Africa however, 51 unique species were recorded in 32 genera, including 13 possibly endemic species as classified by Kaltenbach 1996 (Fig. 8.4). Most of these possibly endemic species were recorded in the north eastern part of South Africa, with a few in the western Cape region (Fig. 8.5).

The first Mantodea record was collected in 1845 while the latest addition to the Mantodea database in South Africa (Greyvenstein et al. 2019) was collected in 2019, thus 174 years of collections culminated in 4292 mantid specimen records, an average of 24 specimens a year. For 91 of the species that were collected over the past 174 years, and of which records exist in South African museums, there are fewer than 10 records per species. For 31 species (in seven families) only a single distribution record is available, while a further 31 species (in eight families) have between 2 and 4 distribution records (Fig. 8.6). Lastly, for another 30 species (in six families) only between 5 and 9 records could be found in South African museums (Fig. 8.6). These species will be referred to as the "rare" species within this paper. The geographical distribution of these "rare" species in South Africa is depicted in Figs. 8.7 and 8.8.

The majority of the "rare" species records were collected between 1957 and 1965 in the north eastern part of South Africa, while only six of these species records were collected before 1885. Nine of the rare species were collected between 2005 and 2019 (Fig. 8.9).

A total of 1863 Mantodea records in South Africa were collected in the 13 centres of Endemism of South Africa. Of the 163 spp. recorded in South Africa, 21 species were not collected inside these 13 centres of Endemism (Supplementary S3 Fig. 7).

8.5 Discussion

A lack of taxonomic expertise in Africa adds to and complicates the development of data sets and distribution maps for Mantodea species. This lack of expertise requires that specimens collected in the region be identified by experts outside the continent. These specimens and thus distribution records of Mantodea are widely dispersed. For example, in European and American museums such as the MNHN (France), United States National Museum, The Natural History museum (London) and various German institutes have many records of African Mantodea (Battiston et al., 2012; Beier, 1969, Kevan, 1954; Rehn, 1911).

Distribution records reported in this paper were compiled from records that are available in seven South African institutions that host curated arthropod collections and were identified by taxonomists with expertise in Afro-tropical Mantodea and who are based in Europe. The results presented in this paper should be viewed in this context, since no specimen records were included other than those residing in South Africa.

It should be noted that no consistency with regards to sampling methods exist for museum records. The distribution map of the 178 species of Mantodea that occur in southern Africa, seem to indicate that most are associated with the grassland and savanna biomes (North eastern parts of South Africa). This could explain the fewer records from the Cape Floristic region which is one of the most biologically diverse regions in South Africa (Pryke & Samways, 2008; Kemp & Ellis, 2017). Despite the research conducted in this region, the only literature regarding or including Mantodea indicated that only four mantids representing two Mantodea families (Mantidae and Amorphoscelidae) have been collected by Proche and Cowling (2006) as part of their insect diversity study in the Cape floristic region.

The lack of clear distribution patterns for some of the Mantodea families that emerged from this study could possibly be ascribed to habitat modification. It should be noted that the localities where a species once was collected may have been modified and thus the species might have needed to shift to another habitat thus resulting in a collection record in a different locality. Beier (1968) indicated that the mantis *Empusa pennicornis* Pallas (Empusidae) for example, occurs in and up to the 50 degree latitudes in Europe, but the population was established before habitat modification and urban expansions became so rapid. Some species of Mantodea i.e. *Mantis religiosa* L. (Mantidae) have been indicated to expand their distribution Linn and Greibeler, 2016; Zieliński et al., 2018). This species was originally only found in Europe but was accidentally introduced into the USA in 1899 on plants shipped to a nursery (Gurney, 1950). *Mantis religiosa* is now reported to occur throughout the eastern USA and even in southern Canada (Ontario, Quebec and British Columbia) (Cannings, 2007; McMonigle, 2013). In 2001, observations of *M. religiosa* was made in Wisconsin, USA (Kisselburg and Cochran, 2001). The European distribution of this species also expanded from the southern Europe (Spain, Italy and Balkan states) to include France, western Germany, the Ukraine and southern Poland (Linn and Greibeler, 2016; Zieliński et al., 2018). This species was also recorded in Latvia which is estimated to be the northern most border of its distribution (Pupiņš et al., 2012). This species is also found throughout Africa and Asia (Pupiņš et al., 2012; IUCN, 2020). The range expansion of this species is ascribed to climatic changes (Shcherbakov and Savitsky, 2015; Linn and Griebeler, 2016). Beier (1969) indicated that because female mantids in some cases do not have wings and males mostly move to hunt or to find a mate, therefore their dispersal remains quite local. However, due to the oothecae being attached to various objects including all kinds of human transport, a species can have a large distribution.

A pattern which did emerge from the distribution records of the Liturgusidae is that they are largely associated with forest-type vegetation, similar to what Edmunds (1972) suggested for species in this family in Ghana. Svenson (2014) indicated that the genus *Liturgusa* Saussure (Liturgusidae) is predominantly found on branches and trunks of trees and that they are extremely fast runners, this was also found by O'Hanlon (2011) for another species within the Liturgusidae family i.e. *Ciulfina biseriata* Westwood. *Theopompella orientalis* Giglio-Tos (Liturgusidae) have been recorded in Amani, Tanzania. Amani is classified as rain forest, and this species was collected on a grass slope within this forest (Lomardo, 1997).

In southern Africa an estimated 20% of the surface area is classified as forest (Brink & Eva, 2009). Countries where forests dominate in southern Africa include the DRC, Gabon and the Republic of Congo, but forest patches also occur on the eastern coast of southern Africa. These forests have been over utilised but some mosaics still exist (Trimble & Aarde, 2014). These patches of forest that remain (Olson et al., 2001) are in accordance with the distribution records of the Liturgusidae family in southern Africa. The Liturgusidae records used in this study were collected between 1914 and 1963, during a period when forested areas were less disturbed and modified than is currently the case. While no data exist to show that Liturgusidae is strongly associated with forest vegetation, this could be the case, which would increase the risk of this species being threatened.

Southern Africa has a large variety of Mantodea species despite the aridity of the region. Europe for example, has only 38 species belonging to four families i.e. Mantidae, Amorphoscelidae, Empusidae and Tarachodidae. Egypt which is largely arid has a relatively diverse mantis fauna, consisting of 59 species in 21 genera within four families (Sawaby et al. 2010). It has been suggested that the river Nile acts as a corridor for mantids for example the species in the genera *Heterochaeta* and *Miomantis*, to navigate and survive the unsuitable desert areas (Marabuto, 2014). Similarly, Pryke and Samways (2012) established that landscape scale ecological networks that consist of small linear finger like extensions can act not only as corridors between agricultural areas and protected areas for taxa i.e. Formicidae, Araneae, Orthoptera, Lepidoptera and Scarabaeidae and thus can, if the extensions are wider than 64m, sustain large arthropod diversities themselves.

McGeoch et al. (2011) stated that the conservation status of most invertebrates excluding butterflies, dragonflies and trap- and baboon spiders in South Africa is unknown. This is evident in the Mantodea order; even the status of the possible endemic species identified by Kaltenbach (1996) has some anomalies and thus remains to be unclear. Kaltenbach (1996) listed 60 species to be endemic of which no record was found in any of the museum collections in South Africa. Only 35 of the 94 possible endemic species were recorded during this study. Furthermore, *Miomantis caffra* Saussure (Mantidae), while listed as endemic to South Africa and Mozambique, was reported as an alien invasive species with established populations in New Zealand (Ramsay 1984; 1990) and Portugal (Marabuto, 2014). Lastly, contrasting information about two other species that are possibly endemic to southern Africa (Kaltenbach, 1996) exists. According to Kaltenbach (1996) *Geothespis australis* Giglio-Tos (Mantidae) and *Miomantis australis* Beier (Mantidae) only occur in Namibia, however, Patel and Singh (2016) indicated that these species also occurred in Australia. A similar species, *Miomantis gracilis* Karsch (Mantidae) have been recorded in the African Island, Madagascar by Paulian (1957). No other information is available about these species and they could possibly be endemic or near endemic species. This suggests that the proposed 94 mantid species that are listed as possible endemic species in southern Africa (Kaltenbach 1996) is outdated and it should be considered to be reinvestigated and possibly revised.

Marabuto (2014) suggested that *Miomantis paykulli* Stal (Mantidae) is not a threatened species due to its large geographic distribution in southern Africa. However, it may be at risk in the Euro-Mediterranean region since a very limited number of observations of this species have been made over long period of time. The species identified in this paper as “rare” does not suggest a conservation status but suggests that as it was interpreted by Agabiti et al. (2010) these species could be at “potential risk” in the southern Africa region, based on the lack of observations of these species over the past 174 years. These species require further investigation to assess their current population demographics, distribution and to ultimately build towards identifying endemism and their threat status. Identification of the “rare” species in this study is a starting point for further investigations, especially as only 13 species or 0.5% of all Mantodea worldwide are on the IUCN red data list.

The majority of species in South Africa were collected within the 13 centres of Endemism, this is probably due to the large surface area that these centres encapsulate. Despite this, 21 species were collected in areas in of South Africa which do not form part of the 13 centres of Endemism.

The distribution records recorded in this paper are essential especially with the current and future disruptions as a result of climate change. Although these records are based on historic collections, they still provide 174 years of observations on an insect order of which little knowledge exists about their biology, ecology and biogeography (Ursani et al., 2017).

Old records or museum data can contribute to establishing data regarding biodiversity within a region (Giberson & Burain, 2017). Historical data is also a source of distribution records and potential biodiversity and ecological information (Sikes et al., 2017; Hogan et al., 2019). Battiston et al. (2012) indicated that old records and descriptions were important with regards to the ecology of mantids in the Mediterranean area, and since little was known about mantids in this region, old records were used in highlighting conservation issues for Moroccan mantids. For example, mantid specimens in museum collections in Morocco were collected 78 years prior to the investigation (Battiston et al. 2012), and when the locality description information of *Tenodera rungsi* Uvarov (Mantidae) was revisited in 2011, a population of *T. rungsi* was still present at the described locality (Battiston et al. 2012). Similarly, by including citizen science platforms i.e. ISpot and INaturalis, Hogan et al. (2019) added 278 specimen records to the already existing data of *Vanhornia eucnemidarum* Crawford (Hymenoptera: Vanhorniidae) and these new records transcribed to eight new distribution records for this species.

The information on occurrences and distribution of the Mantodea species reported in this paper, can be used as a stepping-stone to identify possible areas of high Mantodea diversity. These records, in combination with ecological modelling, could even identify areas to investigate for future conservation actions. The threat status of “rare” species and information on endemism will point out possible areas of high conservation value.

8.6 Conclusion

The distribution records of Mantodea show their prevalence in the north eastern parts of South Africa. Mantidae and Tarachodidae were the most collected of the 11 families and their distribution has no discernible pattern as they occur or were collected throughout the region. The “rare” species require future investigation and could possibly be endemic, endangered or threatened, which would require conservation efforts. The lack of records may however also be due to insufficient sampling. *Miomantis caffra* is possibly endemic to the region and has been reported as an alien invasive species in two other continents, thus, revision of the endemic list is required as other similar possible anomalies could exist. This study highlights the valuable information recorded in museum collections and indicates the contribution that such collections can make regarding studies on distribution and diversity of the Mantodea.

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8.8 References

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8.9 Tables

Table 8.1. Mantodea species currently on the IUCN Red data list (IUCN, 2020; Gerlach, 2012; Battiston, 2014a, b; Battiston, 2016a-c; Battiston et al., 2016a-g). Localities in (brackets) are suggested localities by Otte et al. 2020

Family	Species	Author	Threat status	Distribution as indicated by IUCN
Empusidae	*Blepharopsis mendica*	Fabricius	Least concern	No data (Egypt)
Empusidae	*Hypsicorypha gracilis*	Burmeister	Least concern	No data (Tunisia)
Mantidae	*Ameles fasciipennis*	Kaltenbach	Critically Endangered	No data (Italy)
Mantidae	*Ameles gracilis*	Brulle	Vulnerable	No data (Canary Islands)
Mantidae	*Ameles limbata*	Brulle	Vulnerable	No data (Canary Islands)
Mantidae	*Apteromantis aptera*	Fuente	Least concern	Southern Spain and Portugal
Mantidae	*Mantis religiosa*	Linnaeus	Least concern	No data (Africa, Eurasia, USA, Australia)
Mantidae	*Polyspilota seychelliana*	Giglio-Tos	Least concern	Seychelles
Mantidae	*Pseudoyersinia betancuriae*	Wiemers	Data deficient	Puerto del Rosario
Mantidae	*Pseudoyersinia canariensis*	Chopard	Endangered	Santa Cruz de la Palma
Mantidae	*Pseudoyersinia pilipes*	Chopard	Data deficient	La Gomera
Mantidae	*Pseudoyersinia subaptera*	Chopard	Vulnerable	Santa Cuz de Tenerife
Mantidae	*Pseudoyersinia teydeana*	Chopard	Data deficient	Santa Cuz de Tenerife

8.10 Figures

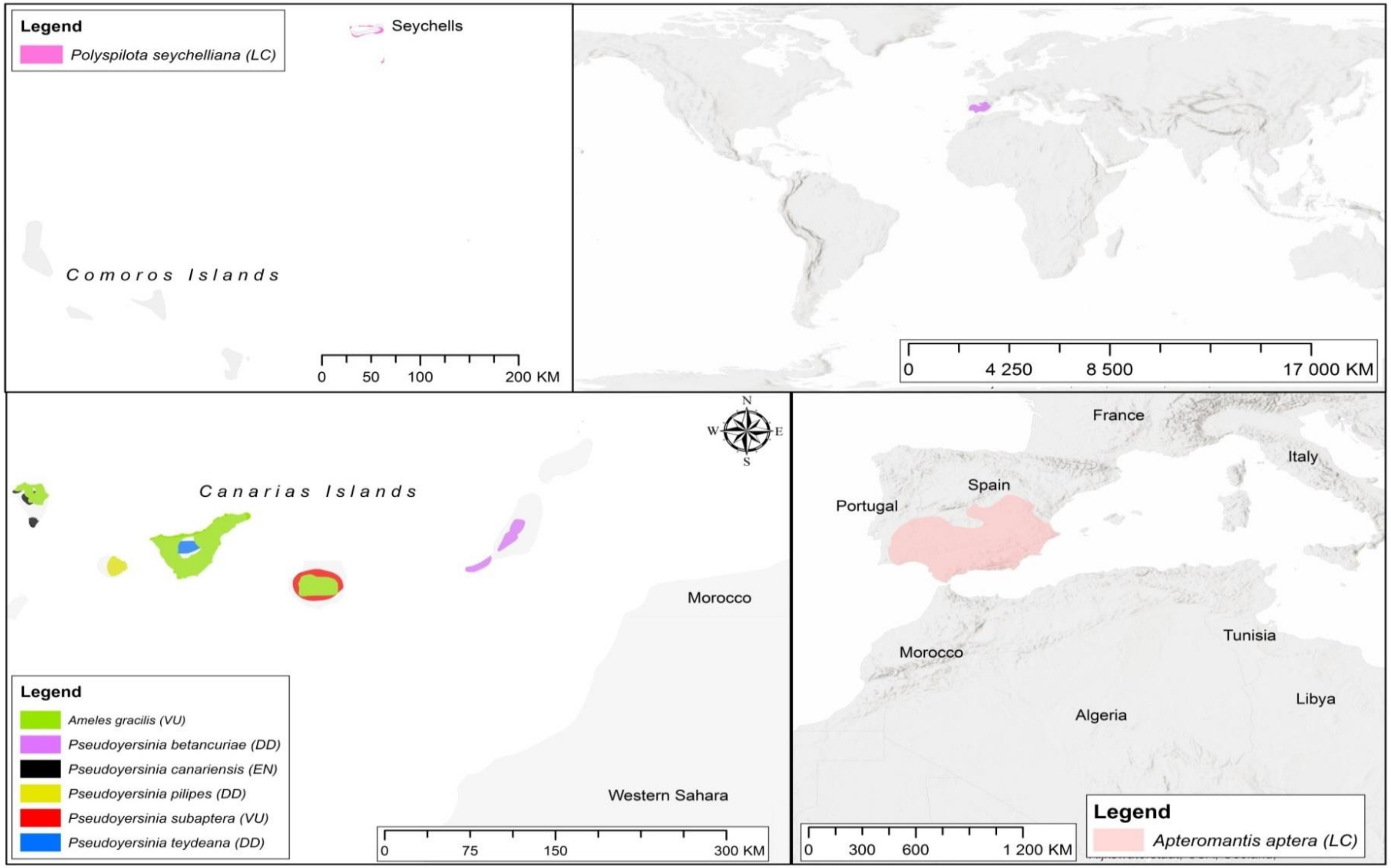

Fig. 8.1. Distribution range of six Mantodea species and their current threat status. VU= Vulnerable, DD = Data deficient, EN = Endangered and, LC = Least concern. Map developed from data available on the IUCN Red Data list (IUCN, 2020; Gerlach, 2012; Battiston, 2014a, b; Battiston, 2016a-c; Battiston et al., 2016a-g).

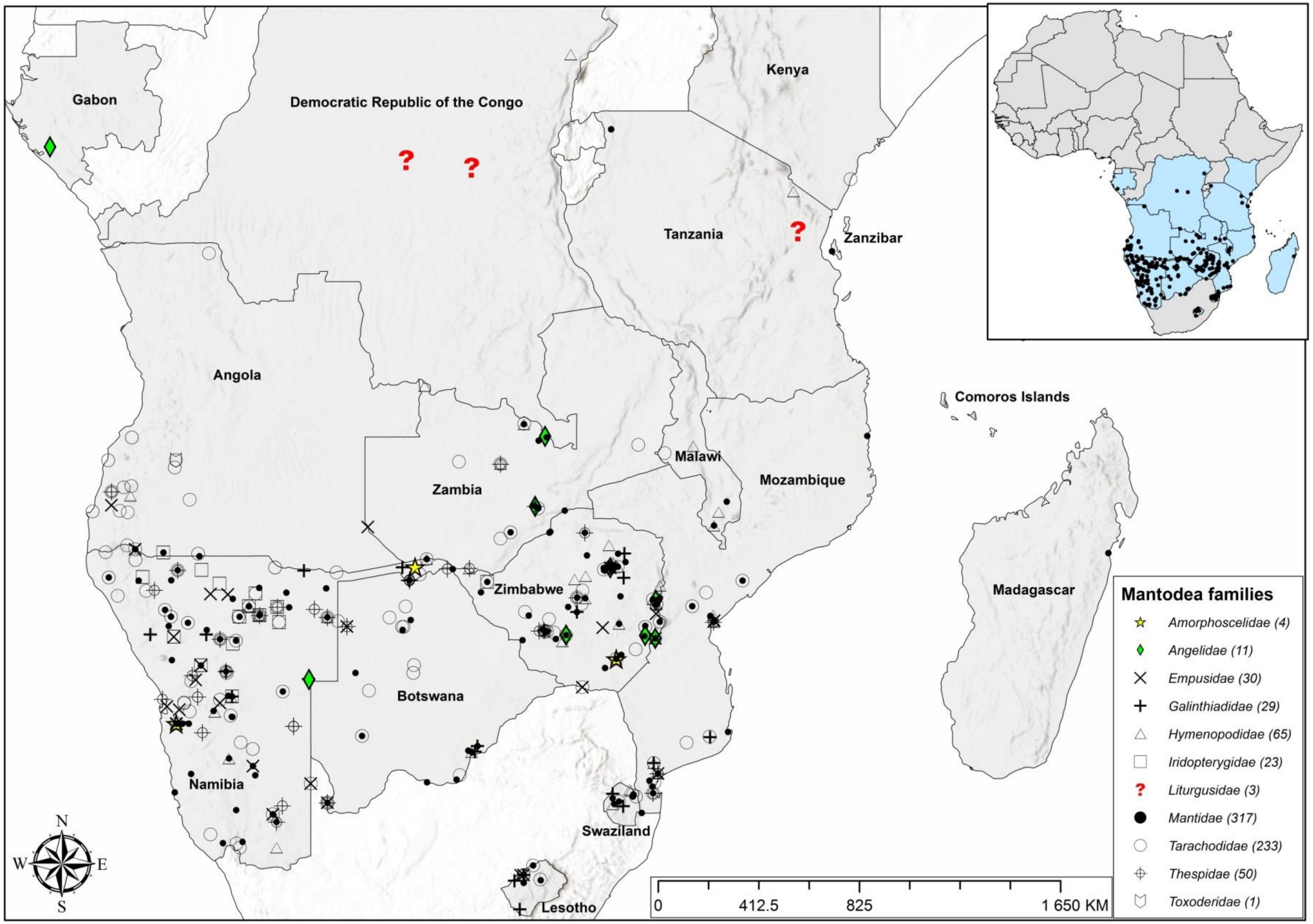

Fig. 8.2. Map indicating the distribution of Mantodea families outside of South Africa, based on museum records in southern Africa.

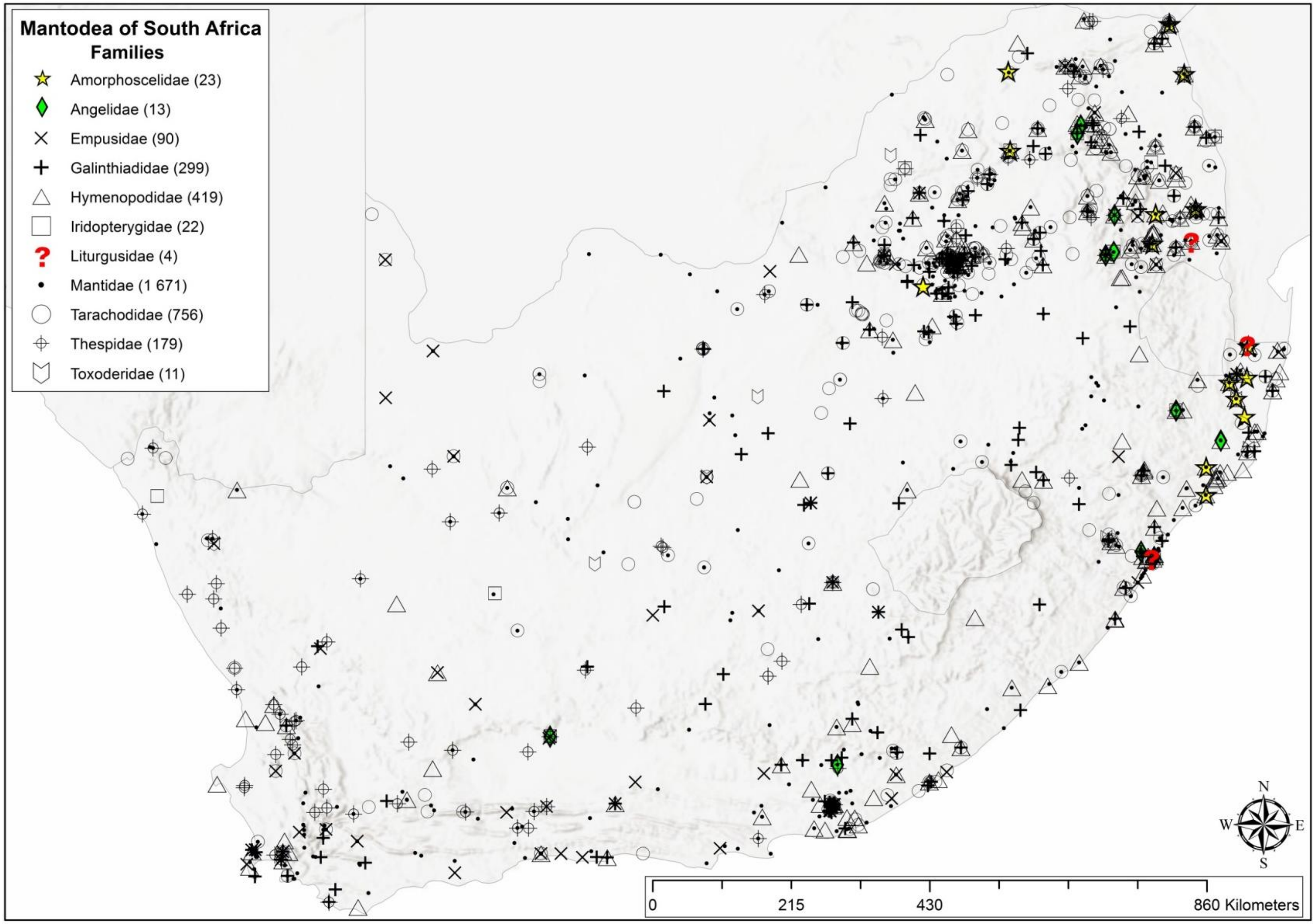

Fig. 8.3. Map indicating the distribution of Mantodea families in South Africa.

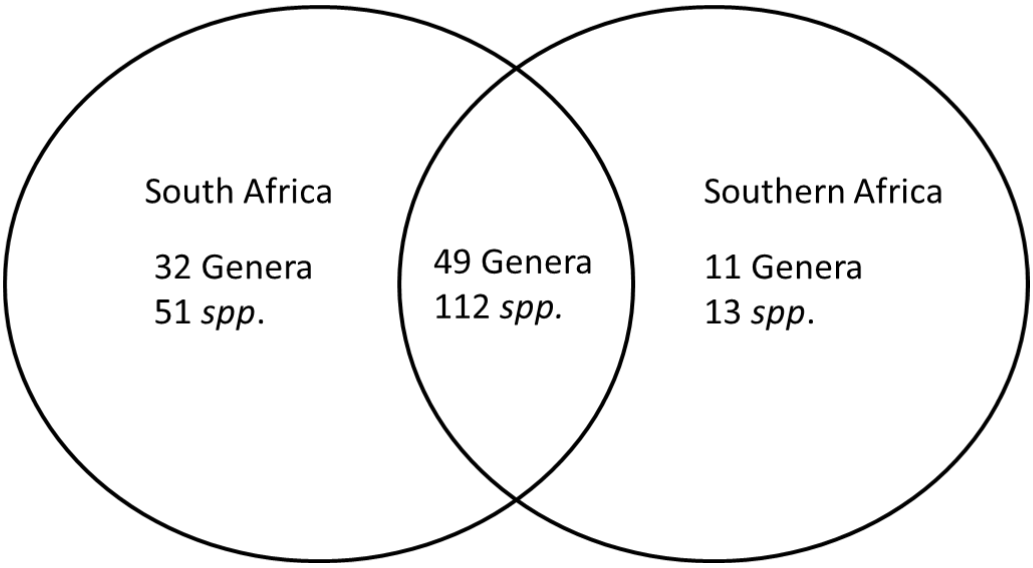

Fig. 8.4. Venn diagram of the shared and unique number of Mantodea species in the different parts of southern Africa.

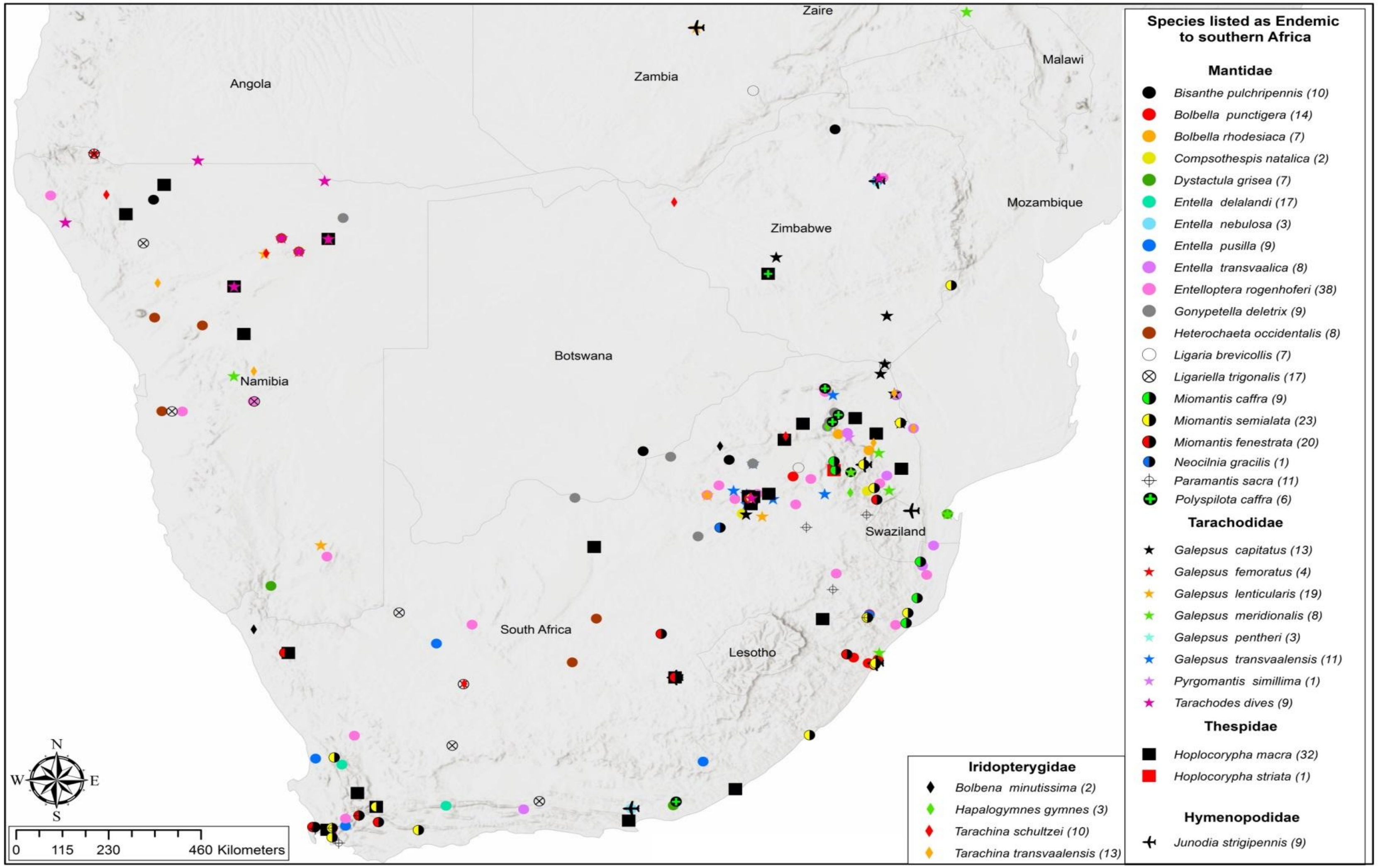

Fig. 8.5. Distribution of possible endemic Mantodea species in southern African as identified by Kaltenbach (1996). The numbers in brackets indicate the number of museum records per species.

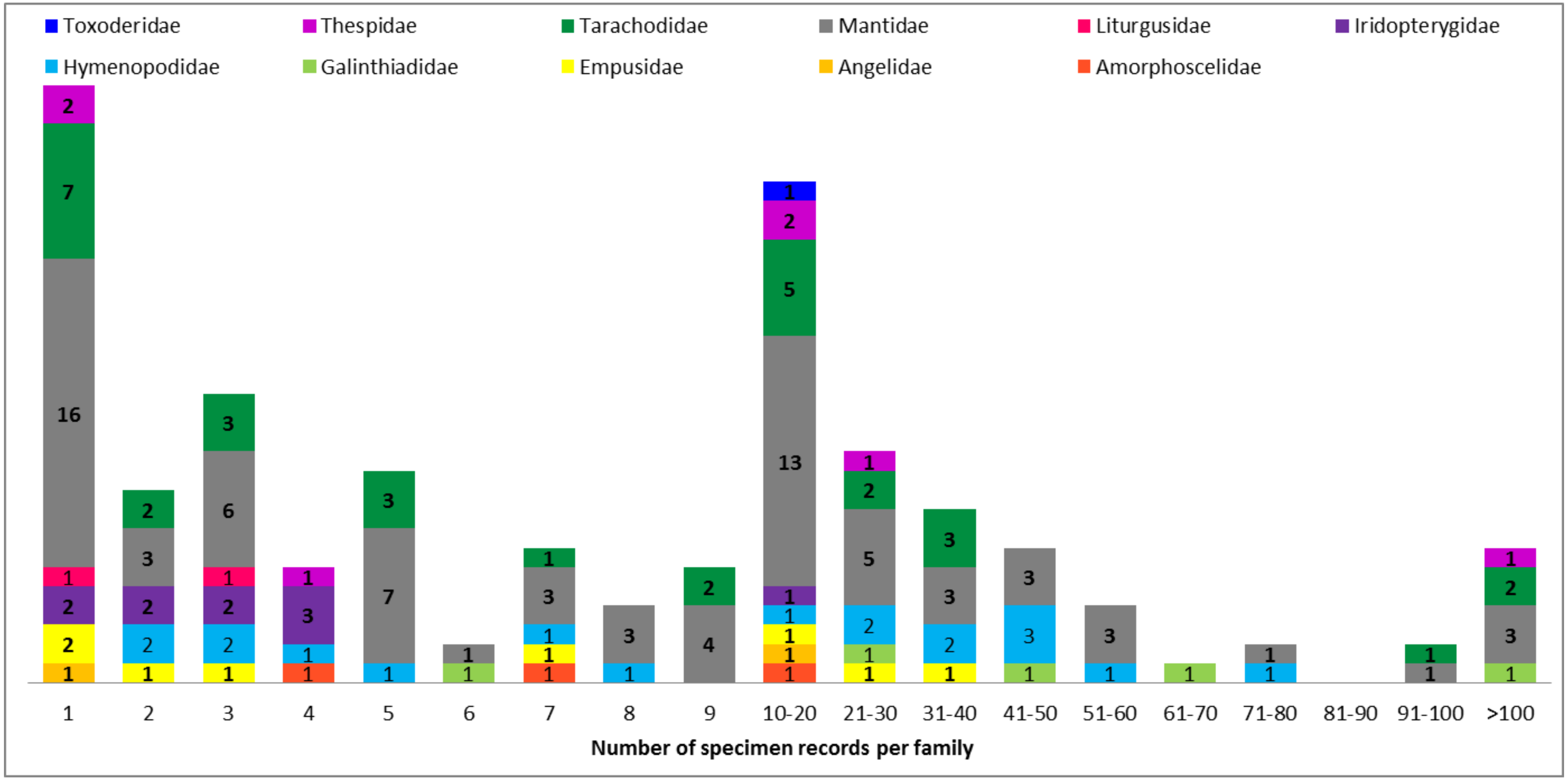

Fig. 8.6. Numbers of specimen records per Mantodea family of which records exist in South Africa.

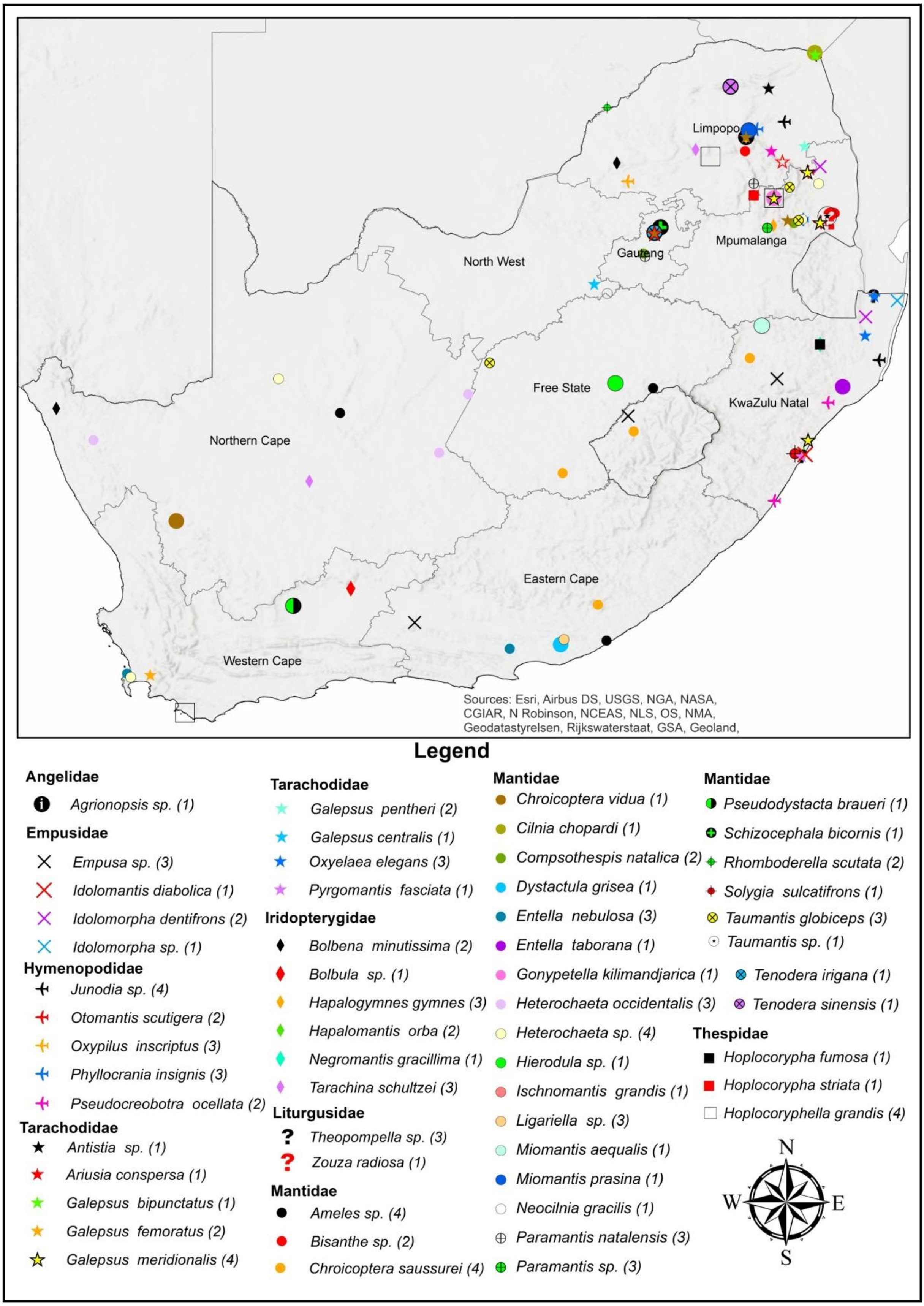

Fig. 8.7. Distribution of the "rare" mantid species that only have between one and four records per species in South Africa.

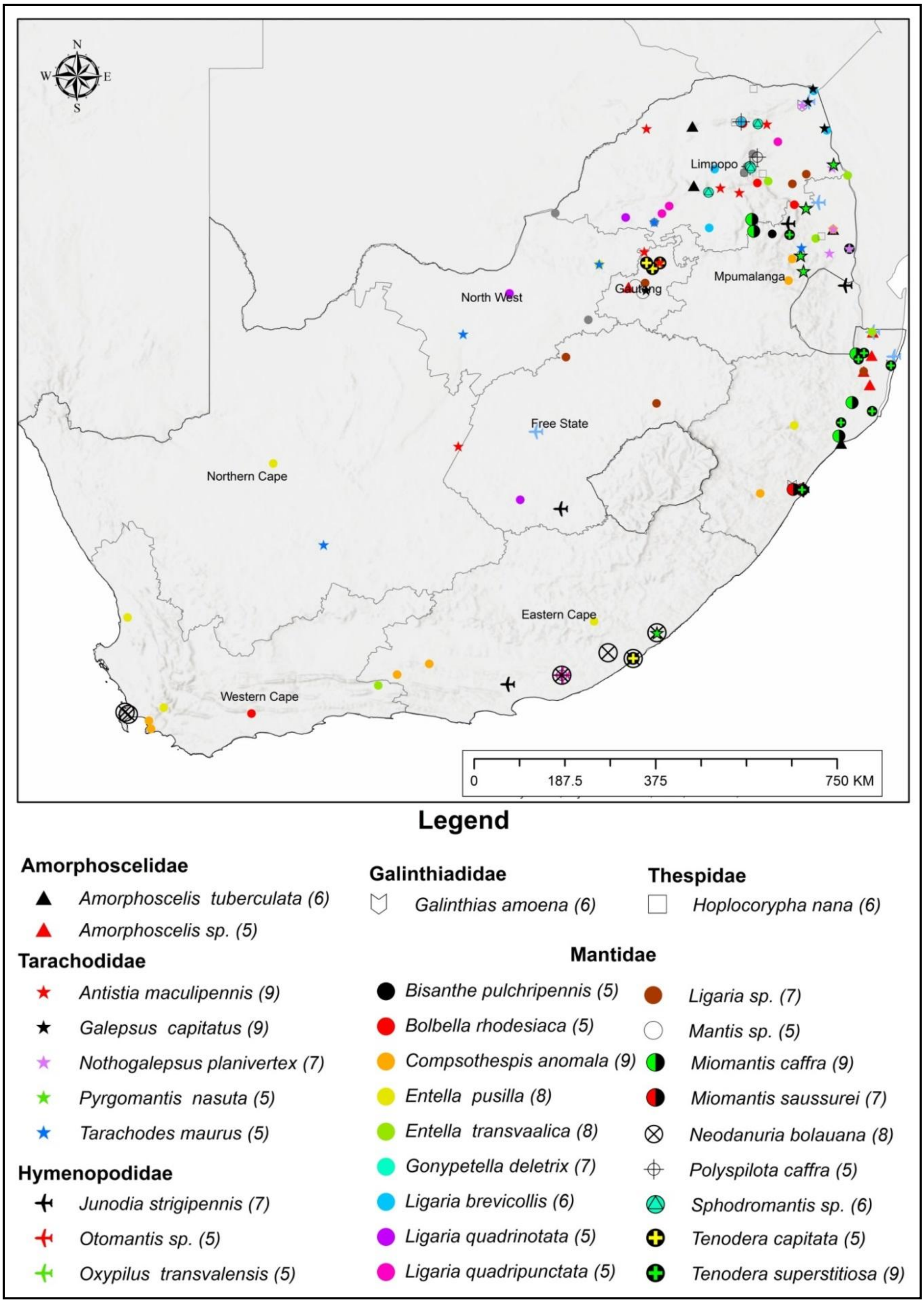

Fig. 8.8. Distribution of the "rare" mantid species that only have between five and nine records per species in South Africa.

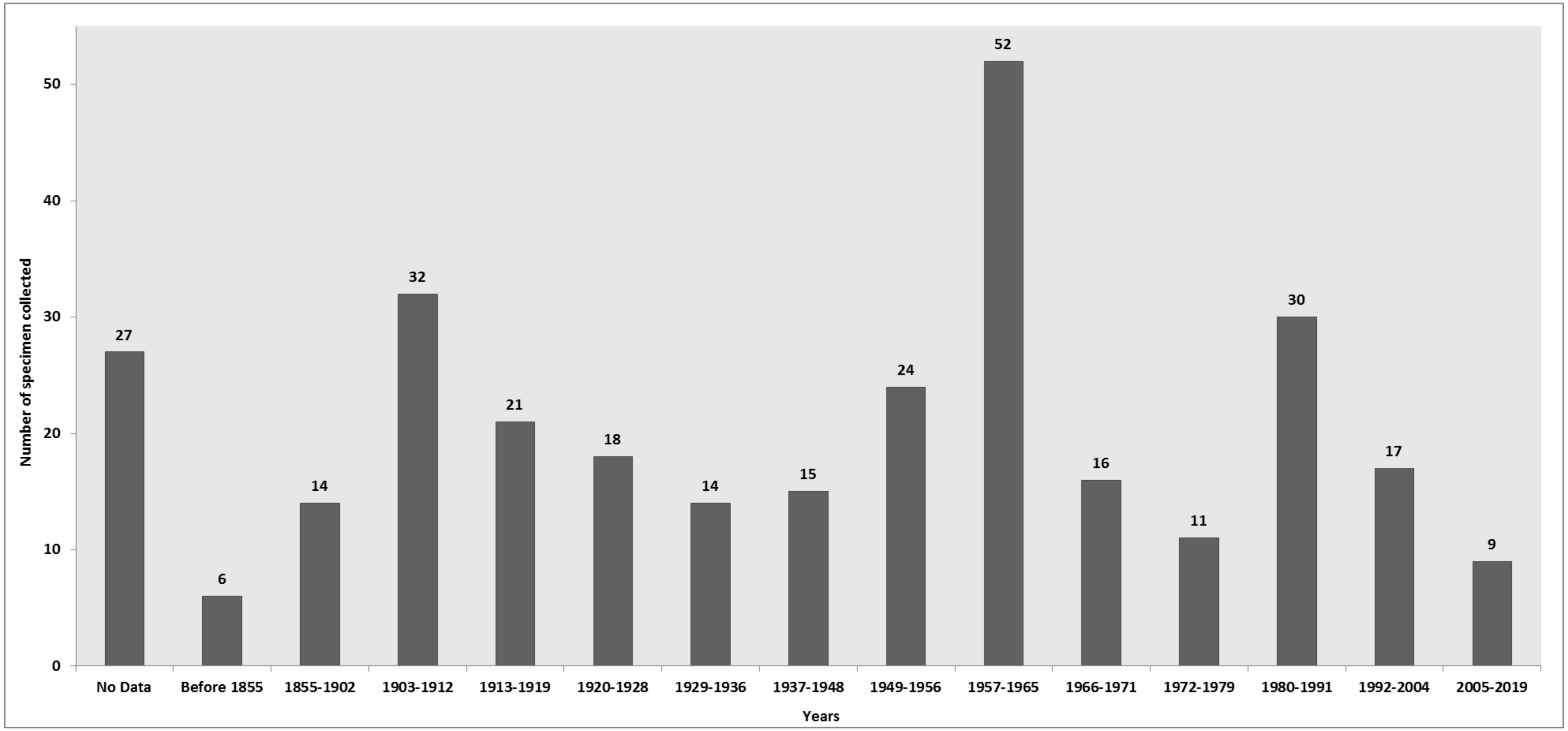

Fig. 8.9. The Mantodea specimen records of which less than 10 records were collected throughout South Africa in the past 174 years.

8.11 Supplementary Materials

S1. Distribution records of Mantodea species recorded in southern African countries, excluding South Africa. The asterisk (*) indicates the 13 Mantodea species that were not recorded in South Africa

Family and Species	Angola	Botswana	Comoros Islands	DRC	Gabon	Kenya	Lesotho	Madagascar	Malawi	Mozambique	Namibia	Swaziland	Tanzania	Zambia	Zanzibar	Zimbabwe
Amorphoscelidae																
Amorphoscelis spp.	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Amorphoscelis tuberculata	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	2
Angelidae																
Agrionopsis distanti	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	5
Agrionopsis spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
**Leptocola stanleyana*	-	-	-	-	1	-	-	-	-	1	1	-	-	-	-	-
Empusidae																
Empusa guttula	-	2	-	-	-	-	-	-	-	-	6	-	-	-	-	-
Empusa spinosa	1	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-
Empusa spp.	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-
Hemiempusa capensis	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	4
Hemiempusa spp.	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-
Idolomorpha dentifrons	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-
Galinthiadidae																
Galinthias spp.	-	-	-	-	-	-	-	-	-	1	3	-	-	-	-	-
Harpagomantis discolor	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1
Harpagomantis spp.	-	1	-	-	-	-	3	-	-	-	-	2	-	-	-	4
Harpagomantis tricolor	-	1	-	-	-	-	2	-	-	-	6	-	-	-	-	1
**Pseudoharpax ugandanus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Hymenopodidae																
Junodia spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Junodia strigipennis	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	1

Family and Species	Angola	Botswana	Comoros Islands	DRC	Gabon	Kenya	Lesotho	Madagascar	Malawi	Mozambique	Namibia	Swaziland	Tanzania	Zambia	Zanzibar	Zimbabwe
Hymenopodidae																
Otomantis scutigera	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Otomantis spp.	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	1
Oxypiloidea spp.	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-
Oxypiloidea tridens	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Oxypilus capensis	-	-	-	-	-	-	-	-	-	-	3	-	-	1	-	-
Oxypilus spp.	-	1	-	-	-	-	-	-	-	-	2	1	-	1	-	2
Oxypilus transvalensis	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Phyllocrania paradoxa	1	-	-	1	-	-	-	-	-	-	3	-	-	-	-	3
Phyllocrania spp.	-	-	-	-	-	-	-	-	-	2	-	-	-	1	-	3
Pseudocreobotra spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	1
Pseudocreobotra wahlbergi	-	-	-	-	-	-	-	-	1	2	-	-	1	-	-	2
Sibylla pretiosa	-	-	-	-	-	-	-	-	-	-	4	1	-	-	-	4
Sibylla spp.	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	3
Iridopterygidae																
*_Bolbena hottentotta_	1	-	-	-	-	-	-	-	-	-	11	-	-	-	-	-
Tarachina schultzei	-	-	-	-	-	-	-	-	-	-	6	-	-	-	-	1
Tarachina transvaalensis	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-
Liturgusidae																
*_Theopompella aurivillii_	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-
*_Theopompella fusca_	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Mantidae																
Bisanthe pulchripennis	-	1	-	-	-	-	-	-	-	-	2	-	-	-	-	2
Bisanthe spp.	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-
Bolbella rhodesiaca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
*_Carvilia saussurii_	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
Chroicoptera saussurei	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-

Family and Species	Angola	Botswana	Comoros Islands	DRC	Gabon	Kenya	Lesotho	Madagascar	Malawi	Mozambique	Namibia	Swaziland	Tanzania	Zambia	Zanzibar	Zimbabwe
Mantidae																
Cilnia humeralis	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	1
Compsothespis spp.	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
*_Danuria kilimandjarica_	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	2
Danuria spp.	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	2
Danuria thunbergi	-	-	-	-	-	-	-	-	-	-	2	-	-	2	-	7
Dystacta alticeps	-	-	-	-	-	-	-	-	-	1	7	-	-	-	-	6
Dystacta spp.	-	2	-	-	-	-	-	-	-	-	1	1	8	-	-	4
Dystactula grisea	-	-	-	-	-	-	-	-	-	4	1	-	-	-	-	1
Entella pusilla	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Entella spp.	-	1	-	-	-	-	-	-	-	-	2	-	-	2	-	2
Entelloptera rogenhoferi	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-
Gonypetella deletrix	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Gonypetella kilimandjarica	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	10
Gonypetella spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Heterochaeta occidentalis	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-
Heterochaeta spp.	-	1	-	-	-	-	-	-	-	-	9	-	-	-	-	-
Ischnomantis fatiloqua	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	6
Ischnomantis spp.	-	1	-	-	-	-	6	-	-	1	5	-	-	-	-	-
Ligaria brevicollis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Ligaria chopardi	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	1
*_Ligaria dentata_	1	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-
Ligaria quadrinotata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Ligaria quadripunctata	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	1
Ligaria spp.	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	1
Ligariella trigonalis	-	-	-	-	-	-	-	-	-	-	6	-	-	-	-	-
Mantis religiosa	-	-	-	-	-	-	-	-	-	1	1	2	-	-	-	6
Miomantis exilis	-	1	-	-	-	-	-	-	-	-	2	-	-	-	-	-

Family and Species	Angola	Botswana	Comoros Islands	DRC	Gabon	Kenya	Lesotho	Madagascar	Malawi	Mozambique	Namibia	Swaziland	Tanzania	Zambia	Zanzibar	Zimbabwe
Mantidae																
Miomantis helenae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
**Miomantis monacha*	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
Miomantis natalica	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	1
Miomantis saussurei	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1
Miomantis semialata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Miomantis spp.	-	1	-	-	-	-	10	-	-	1	10	1	-	2	-	17
Omomantis spp.	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	2
Omomantis zebrata	-	1	-	-	-	-	-	-	-	2	1	-	-	-	-	4
Polyspilota aeruginosa	-	-	-	-	-	-	-	-	-	1	4	-	-	-	1	3
Polyspilota caffra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Polyspilota spp.	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	1
Popa spp.	-	-	-	-	-	-	-	1	1	-	-	1	-	-	-	1
Popa spurca	-	-	-	-	-	-	-	-	-	-	9	-	-	-	-	2
Rhomboderella scutata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Rhomboderella spp.	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-
Sphodromantis gastrica	-	3	-	-	-	-	-	-	-	-	2	2	-	-	-	4
Sphodromantis spp.	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	1
**Sphodromantis viridis*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Tenodera capitata	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	4
Tenodera superstitiosa	-	-	-	-	-	-	-	-	-	4	-	-	1	1	-	1
Tarachodidae																
Antistia maculipennis	-	-	-	-	-	-	-	-	-	-	9	-	-	-	-	-
Antistia parva	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
Episcopomantis chalybea	-	1	-	-	-	-	-	-	-	-	7	-	-	-	-	1
Episcopomantis spp.	-	4	-	-	-	1	-	-	-	-	1	-	-	-	-	-
Galepsus capitatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
**Galepsus damaranus*	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Family and Species	Angola	Botswana	Comoros Islands	DRC	Gabon	Kenya	Lesotho	Madagascar	Malawi	Mozambique	Namibia	Swaziland	Tanzania	Zambia	Zanzibar	Zimbabwe
Tarachodidae																
Galepsus femoratus	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1
Galepsus intermedius	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Galepsus lenticularis	1	-	-	-	-	-	-	-	-	1	5	-	-	1	-	1
Galepsus meridionalis	-	-	-	-	-	-	-	-	1	1	1	-	-	-	-	-
Galepsus pentheri	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Galepsus rhodesicus	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Galepsus spp.	12	5	-	-	-	-	1	-	-	4	25	1	-	-	-	13
Nothogalepsus planivertex	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Pyrgomantis nasuta	-	1	-	-	-	-	-	-	-	1	7	-	-	-	-	1
Pyrgomantis rhodesica	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyrgomantis spp.	2	-	-	-	-	-	3	-	-	-	-	-	-	2	-	2
**Tarachodes bicornis*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Tarachodes dives	1	-	-	-	-	-	-	-	-	-	6	-	-	-	-	1
Tarachodes insidiator	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-	-
Tarachodes lucubrans	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	2
Tarachodes maurus	-	-	-	-	-	-	-	-	-	-	2	-	-	2	-	3
Tarachodes sanctus	-	-	-	-	-	-	-	-	-	2	1	-	-	1	-	8
Tarachodes spp.	13	1	-	-	-	-	-	-	-	1	19	-	-	1	-	6
Thespidae																
Hoplocorypha fumosa	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	1
Hoplocorypha macra	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-
Hoplocorypha saussurii	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Hoplocorypha spp.	3	1	-	-	-	-	-	-	-	1	19	-	-	2	-	3
Hoplocoryphella grandis	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toxoderidae																
Toxodera spp.	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

S2. Mantodea species listed as endemic by Kaltenbach (1996).

Family	Subfamily	Species	Author	Records in southern Africa
Hymenopodidae	Acromantinae	*Otomantis rendalli*	Kirby, 1899	-
Hymenopodidae	Acromantinae	*Oxypiloidea tridens*	Saussure, 1872	-
Hymenopodidae	Oxypilinae	*Junodia strigipennis*	Westwood, 1889	Yes
Iridopterygidae	Hapalomantinae	*Bolbena assimilis*	Kaltenbach, 1996	-
Iridopterygidae	Hapalomantinae	*Bolbena maraisi*	Kaltenbach, 1996	-
Iridopterygidae	Hapalomantinae	*Bolbena minor*	Giglio-Tos, 1915	-
Iridopterygidae	Hapalomantinae	*Bolbena minutissima*	Karny, 1908	Yes
Iridopterygidae	Hapalomantinae	*Hapalogymnes gymnes*	Rehn, 1927	Yes
Iridopterygidae	Hapalomantinae	*Tarachina constricta*	Werner, 1923	-
Iridopterygidae	Hapalomantinae	*Tarachina schultzei*	Karny, 1908	Yes
Iridopterygidae	Hapalomantinae	*Tarachina transvaalensis*	Beier, 1953	Yes
Mantidae	Amelinae	*Bolbella affinis*	Kaltenbach, 1996	-
Mantidae	Amelinae	*Bolbella brevis*	Beier, 1953	-
Mantidae	Amelinae	*Bolbella punctigera*	Stal, 1871	Yes
Mantidae	Amelinae	*Bolbella rhodesiaca*	Beier, 1930	Yes
Mantidae	Amelinae	*Dystactula grisea*	Giglio-Tos, 1915	Yes
Mantidae	Amelinae	*Gonypetella atrocephala*	Beier, 1930	-
Mantidae	Amelinae	*Gonypetella australis*	Giglio-Tos, 1915	-
Mantidae	Amelinae	*Gonypetella deletrix*	Rehn, 1927	Yes
Mantidae	Chriocopterinae	*Entella delalandi*	Saussure, 1870	Yes
Mantidae	Chriocopterinae	*Entella exilis*	Giglio-Tos, 1915	-
Mantidae	Chriocopterinae	*Entella natalica*	Beier, 1955	-
Mantidae	Chriocopterinae	*Entella nebulosa*	Serville, 1839	Yes
Mantidae	Chriocopterinae	*Entella pusilla*	Beier, 1953	Yes
Mantidae	Chriocopterinae	*Entella rudebecki*	Beier, 1955	-
Mantidae	Chriocopterinae	*Entella transvaalica*	Beier, 1955	Yes
Mantidae	Chriocopterinae	*Entelloptera rogenhoferi*	Saussure, 1872	Yes
Mantidae	Chroicopterinae	*Ligaria aberrans*	Karny, 1908	-
Mantidae	Chroicopterinae	*Ligaria affinis*	Kaltenbach, 1996	-
Mantidae	Chroicopterinae	*Ligaria brevicollis*	Stal, 1877	Yes
Mantidae	Chroicopterinae	*Ligaria dentata*	Giglio-Tos, 1915	-
Mantidae	Chroicopterinae	*Ligaria inexpectata*	Kaltenbach, 1996	-
Mantidae	Chroicopterinae	*Ligariella bicornuta*	Kaltenbach, 1996	-
Mantidae	Chroicopterinae	*Ligariella gracilis*	Karny, 1908	-
Mantidae	Chroicopterinae	*Ligariella trigonalis*	Saussure, 1899	Yes
Mantidae	Chroicopterinae	*Namamantis nigropunctata*	Kaltenbach, 1996	-
Mantidae	Compsothespinae	*Compsothespis cinnabarina*	Beier, 1955	-
Mantidae	Compsothespinae	*Compsothespis michaelseni*	Werner, 1923	-
Mantidae	Compsothespinae	*Compsothespis natalica*	Westwood, 1889	Yes
Mantidae	Heterochaetinae	*Heterochaeta occidentalis*	Beier, 1963	Yes

Family	Subfamily	Species	Author	Records in southern Africa
Mantidae	Mantinae	*Bisanthe lagrecai*	Kaltenbach, 1996	-
Mantidae	Mantinae	*Bisanthe menyharthi*	Brancsik, 1895	-
Mantidae	Mantinae	*Bisanthe pulchripennis*	Stal, 1876	Yes
Mantidae	Mantinae	*Paramantis sacra*	Thunberg, 1815	Yes
Mantidae	Mantinae	*Polyspilota caffra*	Westwood, 1889	Yes
Mantidae	Mantinae	*Polyspilota magna*	Giglio-Tos, 1911	-
Mantidae	Miomantinae	*Carvilia gracilis*	Kaltenbach, 1996	-
Mantidae	Miomantinae	*Carvilia saussurii*	Stal, 1876	-
Mantidae	Miomantinae	*Geothespis australis*	Giglio-Tos, 1916	-
Mantidae	Miomantinae	*Miomantis aequalis*	Rehn, 1904	-
Mantidae	Miomantinae	*Miomantis australis*	Beier, 1930	-
Mantidae	Miomantinae	*Miomantis caffra*	Saussure, 1871	Yes
Mantidae	Miomantinae	*Miomantis fenestrata*	Fabricius, 1781	Yes
Mantidae	Miomantinae	*Miomantis minuta*	Giglio-Tos, 1911	-
Mantidae	Miomantinae	*Miomantis natalica*	Beier, 1930	-
Mantidae	Miomantinae	*Miomantis semialata*	Saussure, 1872	Yes
Mantidae	Miomantinae	*Neocilnia gracilis*	Beier, 1930	Yes
Mantidae	Oxyothespinae	*Oxyothespis meridionalis*	Kaltenbach, 1996	-
Tarachodidae	Tarachodinae	*Galepsus aberrans*	Kaltenbach, 1996	-
Tarachodidae	Tarachodinae	*Galepsus beieri*	Kaltenbach, 1996	-
Tarachodidae	Tarachodinae	*Galepsus brincki*	Beier, 1955	-
Tarachodidae	Tarachodinae	*Galepsus capensis*	Beier, 1930	-
Tarachodidae	Tarachodinae	*Galepsus capitatus*	Saussure, 1869	Yes
Tarachodidae	Tarachodinae	*Galepsus femoratus*	Giglio-Tos, 1911	Yes
Tarachodidae	Tarachodinae	*Galepsus focki*	Werner, 1923	-
Tarachodidae	Tarachodinae	*Galepsus lenticularis*	Saussure, 1872	Yes
Tarachodidae	Tarachodinae	*Galepsus letabaensis*	Kaltenbach, 1996	-
Tarachodidae	Tarachodinae	*Galepsus meridionalis*	Saussure, 1872	Yes
Tarachodidae	Tarachodinae	*Galepsus pentheri*	Giglio-Tos, 1911	Yes
Tarachodidae	Tarachodinae	*Galepsus rhodesicus*	Beier, 1954	-
Tarachodidae	Tarachodinae	*Galepsus transvaalensis*	Beier, 1954	Yes
Tarachodidae	Tarachodinae	*Galepsus ulricae*	Kaltenbach, 1996	-
Tarachodidae	Tarachodinae	*Pyrgomantis rhodesica*	Giglio-Tos, 1917	-
Tarachodidae	Tarachodinae	*Pyrgomantis simillima*	Beier, 1954	Yes
Tarachodidae	Tarachodinae	*Tarachodes beieri*	Kaltenbach, 1996	-
Tarachodidae	Tarachodinae	*Tarachodes bicornis*	Giglio-Tos, 1911	-
Tarachodidae	Tarachodinae	*Tarachodes bispinosus*	Kaltenbach, 1996	-
Tarachodidae	Tarachodinae	*Tarachodes circuliferoides*	Kaltenbach, 1996	-
Tarachodidae	Tarachodinae	*Tarachodes dives*	Saussure, 1869	Yes
Tarachodidae	Tarachodinae	*Tarachodes namibiensis*	Kaltenbach, 1996	-
Tarachodidae	Tarachodinae	*Tarachodes natalensis*	Kaltenbach, 1996	-

Family	Subfamily	Species	Author	Records in southern Africa
Tarachodidae	Tarachodinae	*Tarachodes okahandyanus*	Giglio-Tos, 1911	-
Thespidae	Hoplocoryphinae	*Hoplocorypha brevicollis*	Beier, 1931	-
Thespidae	Hoplocoryphinae	*Hoplocorypha macra*	Stal, 1856	Yes
Thespidae	Hoplocoryphinae	*Hoplocorypha striata*	Beier, 1930	Yes
Thespidae	Hoplocoryphinae	*Hoplocorypha turneri*	Beier, 1930	-
Toxoderidae	Toxoderinae	*Calamothespis lineatipennis*	Werner, 1923	-
Toxoderidae	Toxoderinae	*Calamothespis oxyops*	Rehn, 1927	-

**Please note that the species listed above do not have records in South Africa but may be located at other museums or institutions in Europe.

S3. Specific Mantodea species distribution per family in South Africa.

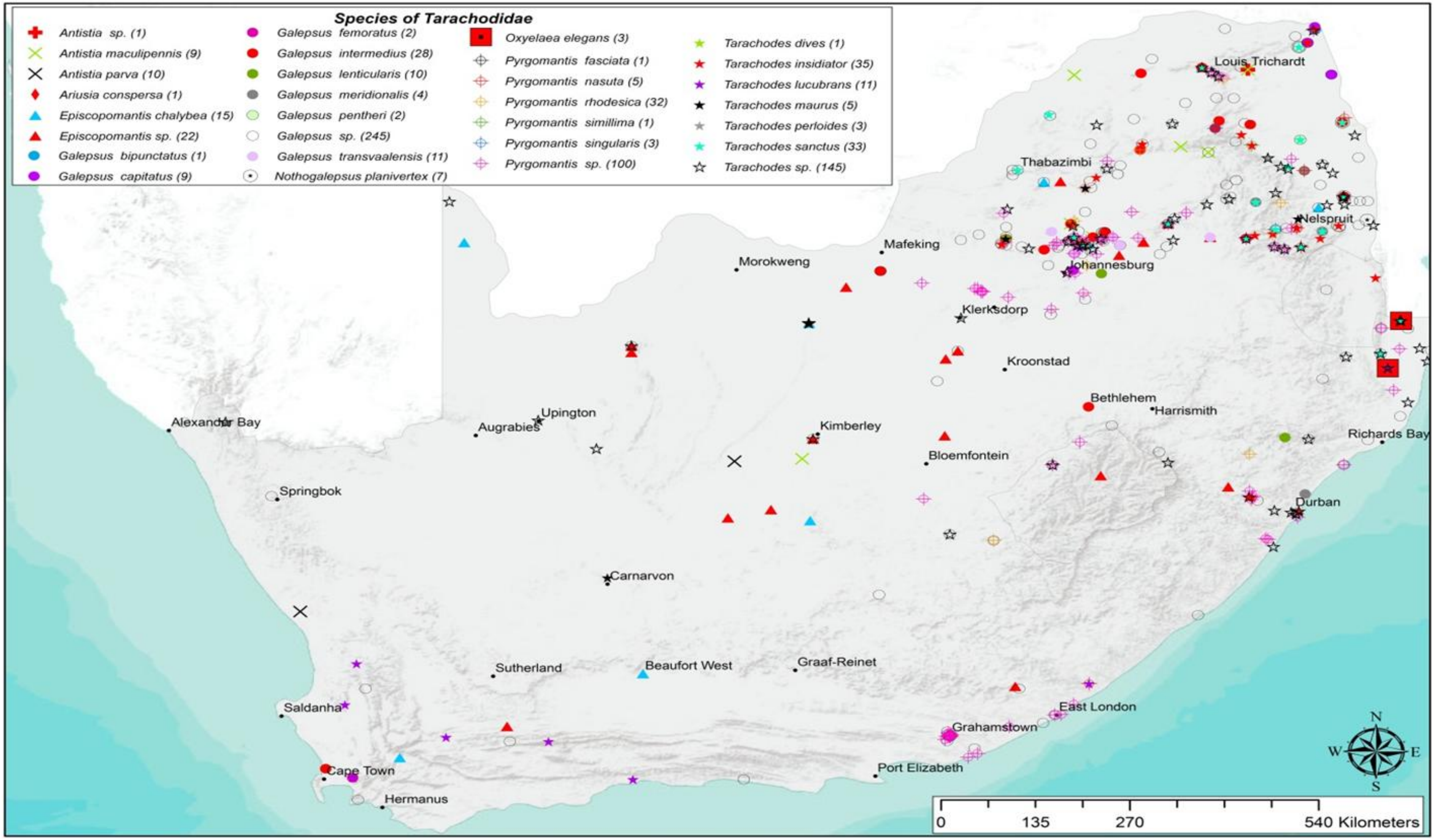

Fig. 1. Distribution records of species within the Tarachodidae family within South Africa.

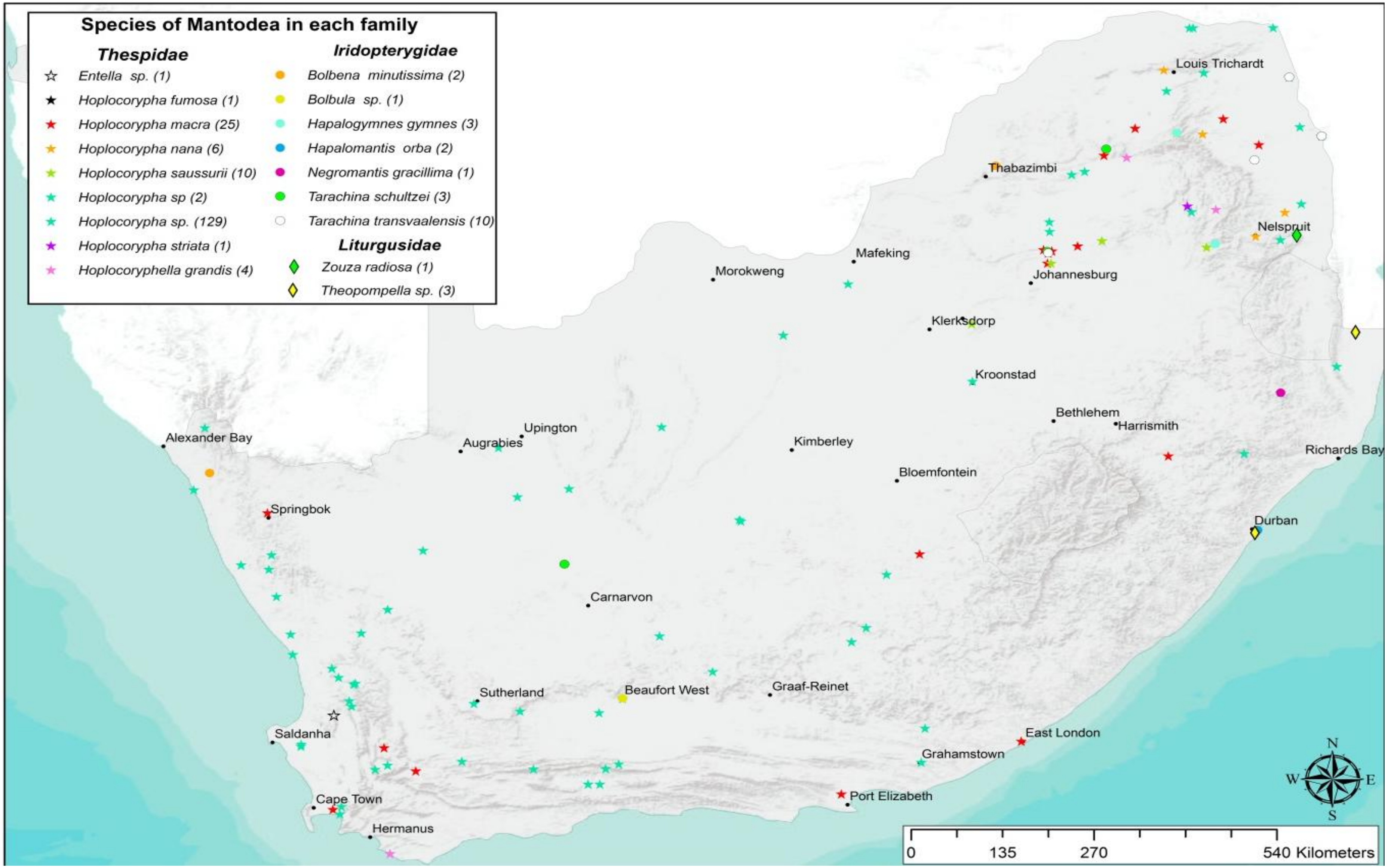

Fig. 2. Distribution records of species within the Thespidae, Iridopterygidae and Liturgusidae families within South Africa.

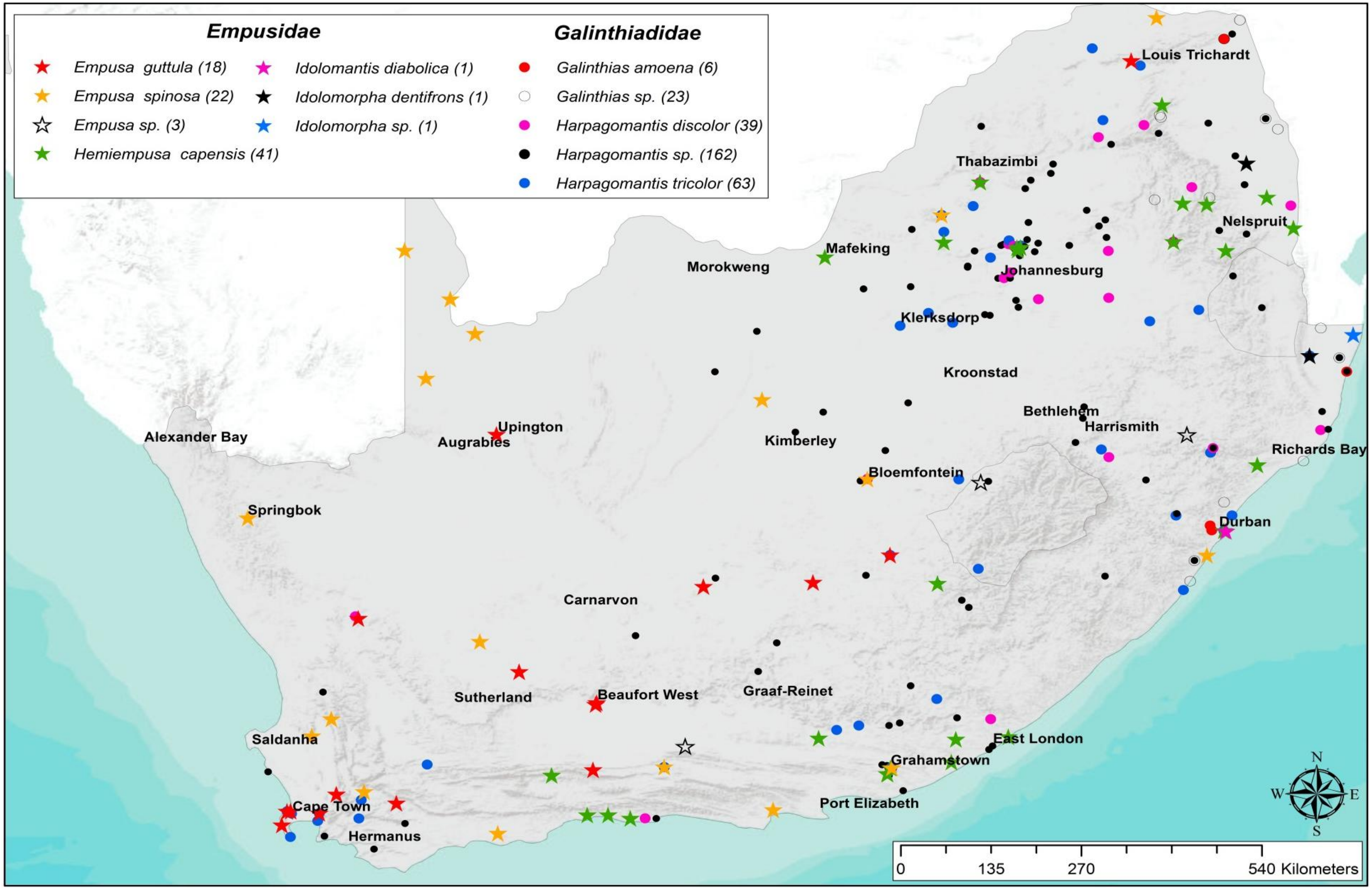

Fig. 3. Distribution records of species within the Empusidae and Galinthiadidae families within South Africa.

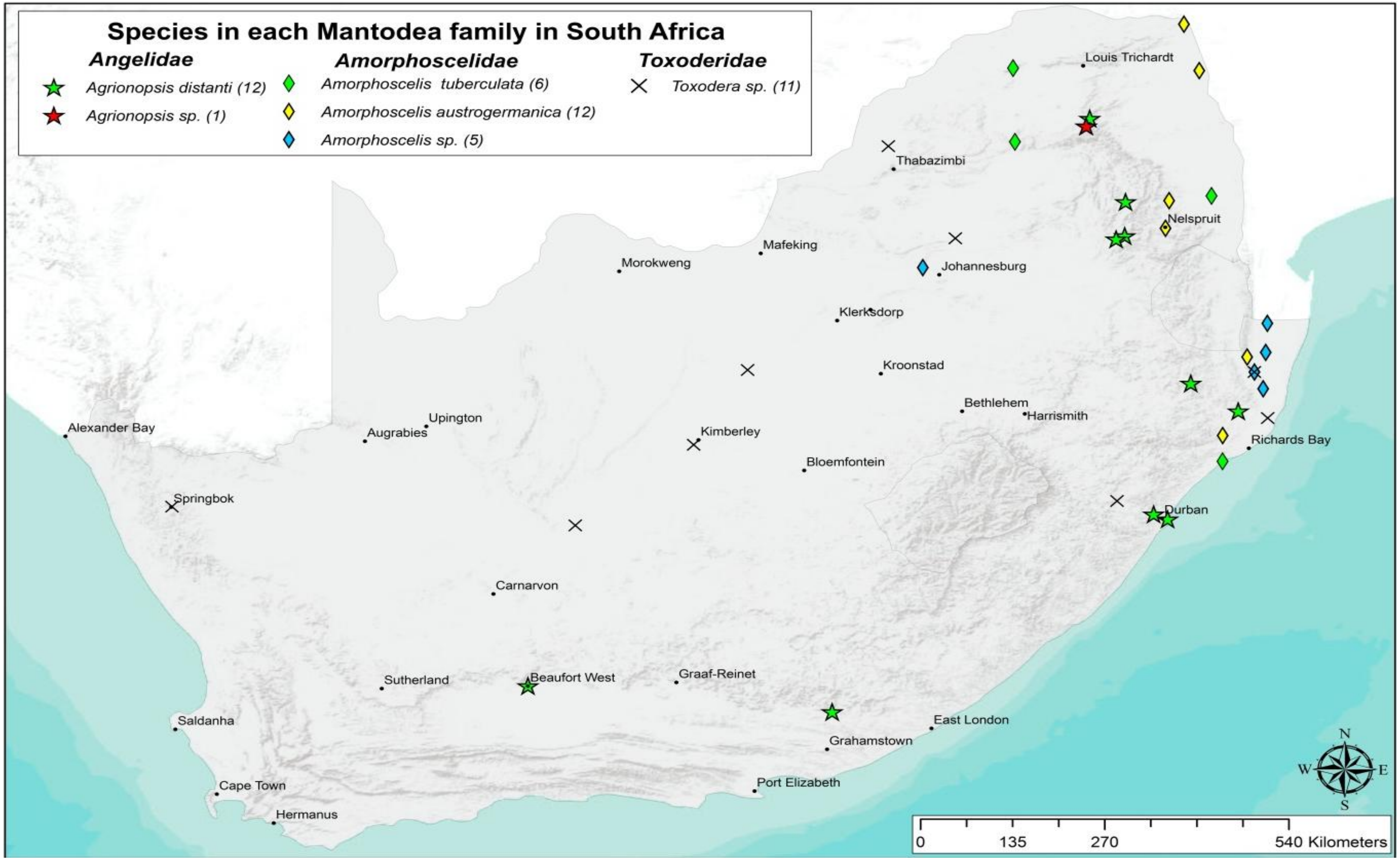

Fig. 4. Distribution records of species within the Angelidae, Amorphoscelidae and Toxoderidae families within South Africa.

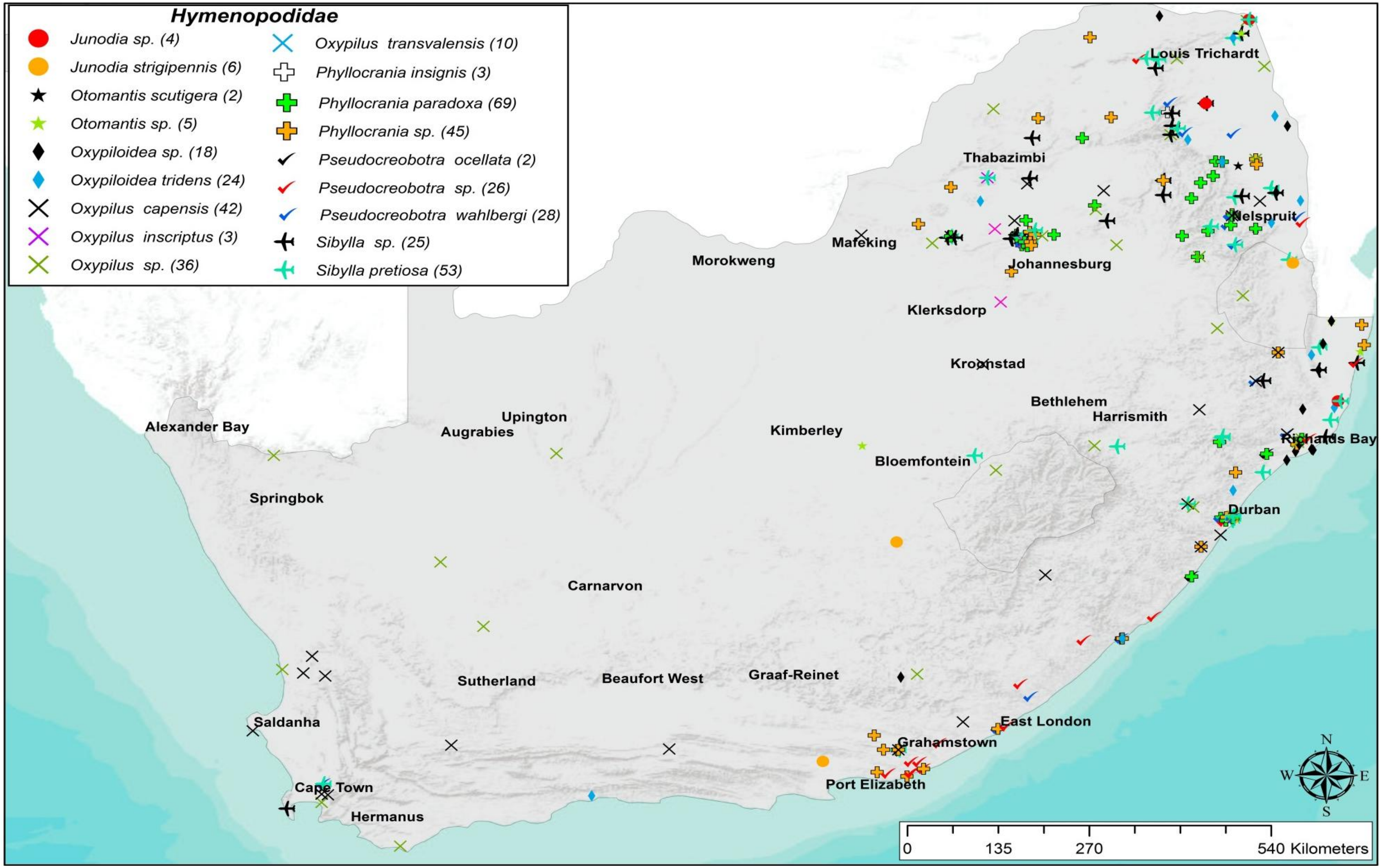

Fig. 5. Distribution records of species within the Hymenopodidae family within South Africa

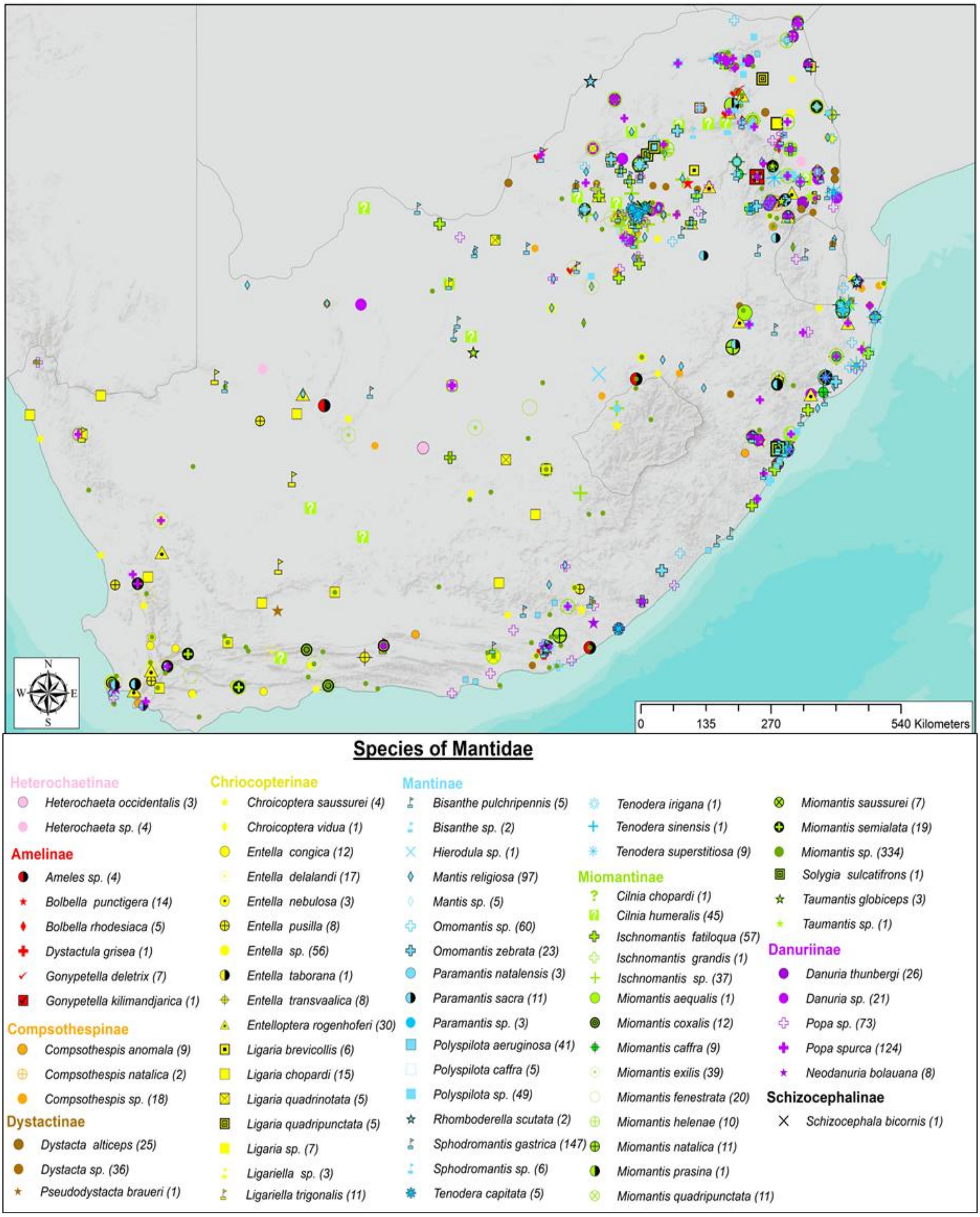

Fig. 6. Distribution records of all species within the Mantidae family within South Africa.

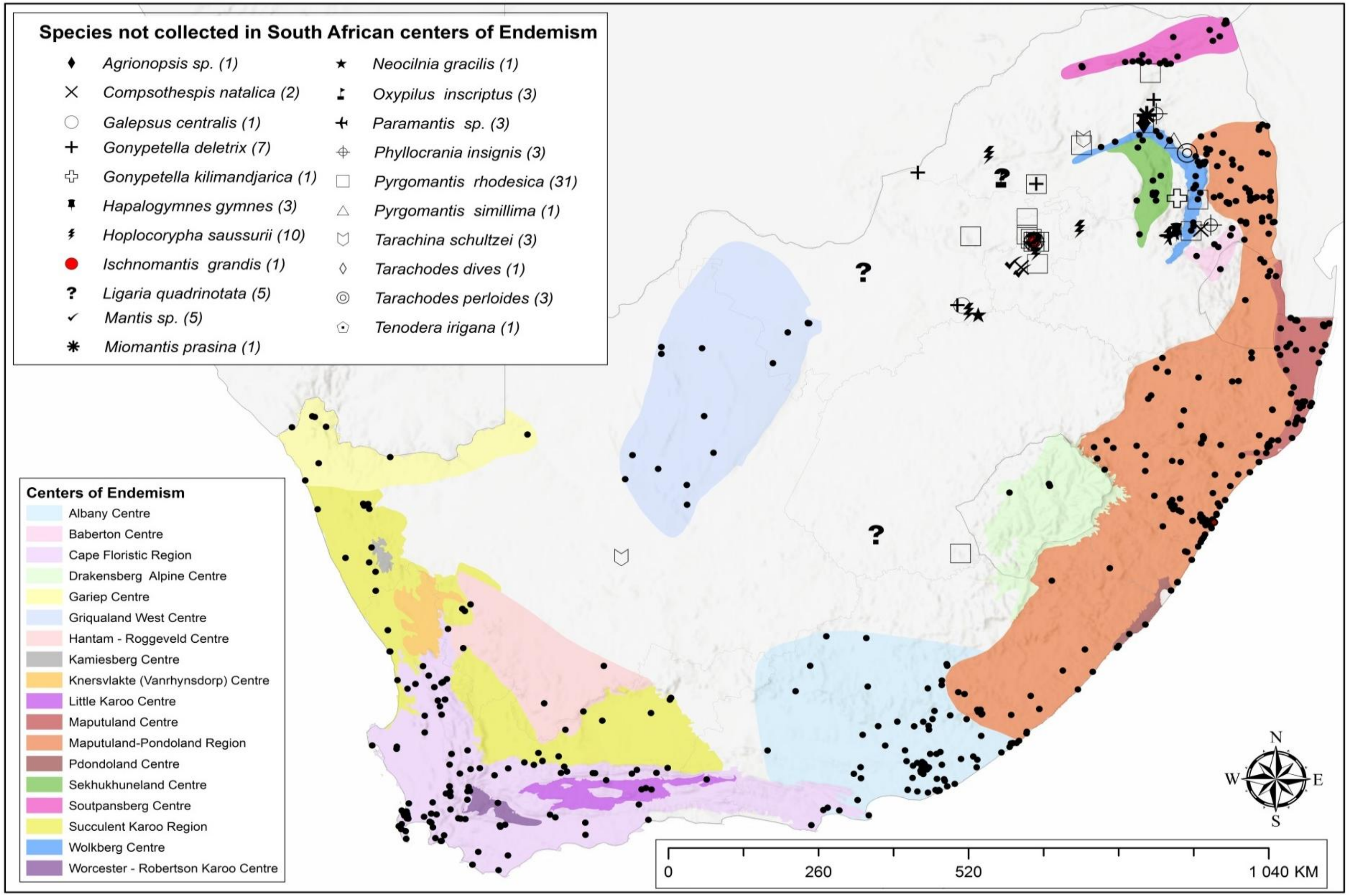

Fig. 7. Distribution records of mantids within the 13 centres of endemism in South Africa, and the 21 species that were not collected in the centres of endemism.

CHAPTER 9: ARTICLE 7

Identifying hotspots of Mantodea species in South Africa based on museum collection records

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Bianca Greyvenstein[1], Hannalene du Plessis[2] & Johnnie van den Berg[3]

1: orcid.org/0000-0003-2033-7113

2: orcid.org/0000-0003-1163-1468

3: orcid.org/0000-0002-6831-3180

1-3: Unit for Environmental Sciences and Management, North-West University, Potchefstroom, 2520, South Africa

1: Corresponding author E-mail: biagrey90@gmail.com

9.1 Abstract

Mantodea is a relatively small order of insects and very little knowledge exists about the species richness of this group in South Africa. A recently compiled data base which lists all specimens in the national museum collections in South Africa was used to assess the diversity of this group and its distribution in the country. A total of 3397 museum records representing 11 Mantodea families and 156 species were used to determine if there were any associations between mantid museum record distribution and different biomes in South Africa. Information in the data base was used to determine species richness and abundance and so to compare diversity between biomes and to identify possibly unique mantid hotspots in South Africa. This study provides knowledge about the Mantodea diversity based on historic museum records of the different biomes in South Africa. The statistical results indicated that a large number of Mantodea species are more prevalent in the Savanna, Grassland and Indian Ocean Coastal Belt biomes, this was corroborated by the hotspot analysis based on proximity of museum records. However, the hotspot analysis based on species frequency of records indicated that the most unique composition of Mantodea exists in the Fynbos and Savanna biomes of South Africa. This is largely ascribed to the non-woody plant species that dominate in these biomes. This will in future contribute to identification of areas that require investigation as they are possibly Mantodea hotspots. These areas could be sensitive to threats such as development or fragmentation and thus possible rare Mantodea species could be under threat. Certain Mantodea species (45) included in this study, occurred in only one biome, which indicates that these species should be the priority of future investigations to determine the extent of their rarity.

9.2 Introduction

A major world-wide decline in the diversity of insects and insect biomass has recently been reported (Cardoso et al. 2020; Samways et al. 2020; Hallmann et al. 2019; Habel et al. 2016). Approximately 40% of insect species are estimated to be threatened and on the verge of extinction (Sanchez-Bayo and Wyckhuys, 2019). The effects of these insect declines have an important influence on ecosystems (Seibold et al. 2019). Although many factors have been identified as the drivers of these declines, the most important are over exploitation, habitat loss and fragmentation, pollution and climate change (Cardoso et al. 2020; Johnson et al. 2016; Maxwell et al. 2015). Climate change has received much attention due to the global nature of the problem and possible effects thereof, for example, shifting species distribution ranges, extinctions and changes in ecological interactions (Ripple et al. 2019; Seibold et al. 2019; Ntiri et al. 2016). However, increased temperature due to climate change is not the only factor that influences insect distribution and ecology.

Stein et al. (2014) indicated that the positive relationship between environmental heterogeneity and high species richness across taxa and biomes is influenced more by topography and vegetation than climate, although the latter has a strong influence on species richness at broader scales (Stein et al. 2014; Siefert et al. 2012). The reason that heterogeneous vegetation has a greater influence on species richness was suggested to be its provision of more resources, shelters, breeding sites and more opportunities for divergent adaptation (Tews et al. 2004; Novotny et al. 2006; Stein et al. 2014). Heterogenous vegetation may be crutial to species richness but is under imminent threat as climate change has been reported to have and is expected to continue to have profound effects on the heterogeneity of vegetation (Dong and Sutton, 2015; Goa et al. 2017).

Furthermore, heterogeneous vegetation or high plant diversity has been shown to have a positive correlation with arthropod diversity. Recent studies in the Savanna and Grassland biomes in South Africa indicated that as the diversity of vegetation of an area increased, diversity of arthropods also increased and that distinct arthropod communities occurred in different biomes (Botha et al. 2015, 2016, 2018). These differences in arthropod communities between different biomes can be explained by differences in plant diversity and structure of the different types of vegetation which strongly influences arthropod habitats (Begon et al. 2006). Cardoso et al. (2020) indicated that arthropods, as a result of their small size, require smaller micro-habitats. Thus, if a biome or habitat is heterogenically diverse, more micro-habitats could occur in these environments, and the diversity within a certain biome or regions is therefore scale-dependent (Begon et al. 2006). This diversity refers to structural variation or different plant architectures, functional groups and species rich environments (Cardoso et al. 2020; Samways et al. 2020; Ng et al. 2018; Stein et al. 2014). Plants are primary producers in the food web and are therefore the template which animal and insect diversity (in most cases) follow (Faeth et al. 2011). Both floral diversity and different vegetation structures associated with different vegetation types create a variety of micro habitats (Barton et al. 2017; Ng et al. 2018) which are important to insect species and influences their abundance and diversity (Horak 2017; Haddadi et al. 2019). Since mantids are predators, and mostly cryptic, these diverse habitats could not only provide abundance of prey, but also areas with multiple opportunities for camouflage.

Major declines in arthropod biomass, abundance and species richness in Grasslands and Forests are largely driven by land use intensity and changes in plant communities (Seibold et al. 2019). For example, during an 11 year study (2008-2017) decreasing arthropod numbers in Grasslands were attributed to a decline or loss of abundance in arthropod species, specifically those species that were classified as “rare”, i.e. less abundant from the start. The decline in the grasslands was associated with agricultural activities on a landscape scale. However, in forest habitats, these less abundant species decreased in abundance while pest and invasive species as well as other generalist species increased in abundance over time (11 years) (Seibold et al. 2019). Isbell et al. (2011) stated that high plant diversity is required for maintaining ecosystem services, especially on a geographically large scale.

South Africa has a very rich biological diversity and encompasses nine recognized biomes (i.e. Albany thicket, Desert, Forest, Fynbos, Grassland, Indian Ocean costal Belt (IOCB), Nama-Karoo, Savanna and Succulent Karoo) (von Maltitz and Scholes 2006). A 10th "biome" or vegetation type is also found in South Africa, and, due to the complexities and dissimilarities within this biome, it is known as Azonal vegetation. Within the Western Cape, a unique floristic region exists. This Fynbos biome, is one of only six of the Floral kingdoms in the world. South Africa also has a rich and diverse arid plant community (Succulent Karoo) (Rutherford et al. 2000; Pryke and Samways, 2009).

Despite the larger volume of research on arthropod biodiversity and world-wide reports of their decline not much is known about population trends and possible declines in the diversity of Mantodea. This could be due to the lack of baseline data of this Order which is required to determine if declines are occurring. Only one study was recently published on Mantodea which indicated the effects of decreased plant architecture or simplification and of the ever looming climate change scenario (Hurd et al. 2019). This recent study by Hurd et al. (2019) indicated that a decrease in vegetative structural diversity resulted in a decline in a mantid population in a successional old crop field over time, while climate change could be responsible for the reduction in fitness of mantid populations. Climate change causes shifts in the season's duration, resulting in the mantid *Tenodera aridifolia sinensis* Saussure (Mantidae), to mature and oviposit earlier in the season. This earlier oviposition during a period when climatic conditions are still favorable for egg hatch, results in eggs not going into diapause, which leads to the death of newly hatched nymphs under unfavorable climatic conditions when winter commences (Hurd et al. 2019). Climate change thus can not only influence mantid fitness but also their habitat, through alteration of heterogenous vegetation.

Although a wealth of knowledge exists about the floristic diversity and that of some arthropod taxa (i.e. spiders, beetles and butterflies) in South Africa, very little is known about the Mantodea. While Schoeman (1985 a,b) estimated 120 species of mantids to occur in South Africa, Kaltenbach (1996; 1998) indicated this to be approximately 180 species. No information exists on the distribution and ecology of Mantodea in South Africa. Biomes encompass various variables i.e. temperature, rainfall and vegetation and thus can be seen as an encompassing factor to investigate and possibly identify mantid hotspots on a broad scale. This is a starting point to establish a region in which measured observations and sampling efforts should be conducted to ultimately determine the diversity of these insects in South Africa.

Therefore, the aims of this study were to investigate associations between mantid distribution and biomes, and to determine if mantid species differ between different biomes and if there are hotspots of Mantodea in South Africa, based on historic museum collection records.

9.3 Methods

Mantodea species distribution records were collected during visits to all of the National insect collections and museums throughout South Africa. The following seven institutions constitutes all of the insect collections throughout South Africa: Ditsong Museum of Natural History (Pretoria), Agricultural Research Council (Biosystematics Division in Pretoria), National Museum (Bloemfontein), Albany Museum (Grahamstown), Rhodes University (Grahamstown), Durban Natural Science Museum, Iziko South African Museum (Cape Town) and KwaZulu-Natal Museum (Pietermaritzburg). Most specimens in these collections where already identified by taxonomists during previous visits to these institutions, while many were sent for identifications to the Vienna museum in Germany, the University of Drexel in Philadelphia, USA, the Muséum national d'Histoire naturelle (MNHN) in France as well as the research collection of Nicolas Moulin in Montérolier. The results presented in this paper should be viewed in this context, since no specimen records were included beyond those residing in the above mentioned collections. The Mantodea records database used in this study is also available online (Greyvenstein et al. 2019).

All mantid specimens and distribution labels where photographed (Canon D1300) and digitized and a database compiled. This database contains the following information for each specimen record: genus and species name (to the level of identification), collector's details and collection date if available and geo-referenced locality. The website (Mantodeaspeciesfile.org) and literature were used to determine the current nomenclature within the order. All locality data was georeferenced using the principals suggested by Wieczorek et al. (2004) and all coordinates were converted from Degrees, minutes, and seconds (DMS) to Decimal degrees (DD) with the use of the website (gps-coordinates.net). DD were used for plotting the occurrences of the variety of Mantodea species in South Africa across the nine biomes with GIS software (ArcMaps version 10.6.1) (TIBCO software, 2017).

Distribution records reported in this paper were compiled from the records that are available in the above mentioned arthropod collections. In order to generate distribution maps and analyze Mantodea diversity per biome, the locality data was retrieved from the specimen record labels and used to determine in which of the nine biomes they were collected. The database was transformed (using decimal degrees) to XY coordinates (Latitude and Longitude coordinates) in ArcMap (GIS software), which displayed the collection locality of each of the specimen records. The shapefile layer of biomes of South

Africa that was used during this analysis is based on the maps compiled by Mucina et al. (2006). Using various geoprocessing tools in ArcMap the Mantodea database records were assigned into the nine biomes based on their localities. The nine subsequent shape files were converted to excel spreadsheets that contained all the taxonomic and collection information per specimen, per biome. This data was used to compile a matrix of Mantodea record abundance data per biome.

Replicates for use in analyses were generated by grouping the collection dates of the museum specimen into 11-year periods for each biome, for example, 1876-1881 and 1882-1887. Since the dataset consisted of records collected between 1876 and 2019, there were 12 replicates for each biome. This matrix was then used to determine the species richness and abundances per biome and was used for the various analyses. Specimen records without collection dates (220) were disregarded and 3397 records were used in the statistical analyses.

Furthermore, two types of hotspot analysis were conducted in ArcMap (GIS software). These were: optimized without ranking (based on distance measures) and an optimized with rank analysis (based on abundance of records per species). The hotspot analysis gives not only a visual representation of the areas with a high conglomeration of data points but also a statistically determined confidence level similar to a p-value of ANOVA's and T-tests. The latter of the two hotspot analyses included a ranking of species based on the rarity or frequency of records per species, thus species were ranked between one and four. Species that had between one and ten records were given the highest ranking (4) as these species were collected the least. Species with more records (11-30) were ranked as a three, species with 31-50 records were ranked as a two and lastly species with more than 51 records were ranked the lowest as they were the most frequent. This ranking was used as an analysis within the one hotspot analysis and thus identified areas in South Africa that are hotspots based on Mantodea species with a low museum collection record frequency. Furthermore, both hotspot analyses were interpolated using the IDW (Inverse distance weighted) tool to get a broader and overall indication of regions in South Africa that could be Mantodea hotspots. Biomes and major cities were overlaid on all four analyses to be able to deduce if hotspots coincided with these elements and if these could explain the various hotspots as identified by the analysis.

Due to a lack of specimen records from the desert biome, it was not included in any of the statistical analyses. However, the Azonal vegetation was included due to the abundance of records throughout South Africa. The Azonal vegetation or riparian vegetation (in this paper) is associated with the major rivers and wetlands of South Africa (Mucina et al. 2006). Although Azonal vegetation is often complex and/or abundant in alien plant species, grasses, tall shrubs and trees, it can also include simplified vegetation that is for example dominated by only reeds (Masubelele et al. 2015).

Primer 6 software (Clarke and Gorley 2006) was used to determine the Species Richness and Abundance per biome. Due to the abnormality i.e. different times, places, methods and collectors of the museum records, the heterogeneity of the data were tested in Statisitica (TIBCO Software Inc. 2017) with the use of the Levene's and the Brown-Forsythe test.

The diversity index values of the two indices (Species Richness, Abundance) were tested for normality with the Shapiro Wilk test and Log-transformed if the data were not normally distributed (Shapiro Wilk $p<0.05$). ANOVAs were done in Statistica (TIBCO Software Inc. 2017) to determine if differences existed between biomes in terms of Shannon diversity, species richness or abundance. Tukey’s (HSD) post hoc tests were performed and box and whisker plots compiled which were used for graphical data representation of the three diversity indices across the nine biomes. Due to the nature of the data and the bias involved in the collection of the data, the Welch F ANOVA was also done in Statistica (TIBCO Software Inc. 2017), this test compensates for the unequal variances of the data and thus is more robust than the other ANOVAs (Glantz et al. 2016).

9.4 Results

9.4.1 Descriptive results

Of the 4292 Mantodea records collected from the museums in South Africa, 3397 records were collected inside the country (Fig. 9.1). The 3397 utilized records represent 159 species, 58 genera and 11 mantid families and were collected in 989 different localities i.e. towns, cities, settlements and various other localities such as nature reserves. Furthermore, the 3397 records were collected by 940 different individual collectors and disregards the 367 records that were collected during specified museum expeditions and that were collected by various museum staff. Species richness was the highest in the Savanna biome (126 species) while the Nama Karoo had the lowest number of species (19) (Fig. 9.2). The number of species collected in the Nama Karoo was lower than that collected in the Fynbos biome, but number of genera and families were similar. The Grassland biome had 87 species and the other biomes between 19 and 57 species. The number of Mantodea families was highest in the IOCB despite the lower number of species in this biome (Fig. 9.2).

A list of the species collected in the different biomes is provided in Table 9.1. Several species were recorded in more than one biome and one species was recorded in eight of the biomes (Fig. 9.3). Forty-five species (32 genera and 8 families) were recorded only in a single biome. Only three genera, i.e. *Galepsus* (Tarachodidae), *Miomantis* (Mantidae) and

Popa (Mantidae) were recorded in all nine biomes. The Savanna biome had the highest number of “unique” species (24) which only occurred in this particular biome, while the Grassland and Nama Karoo biomes had no “unique” species. All species recorded in the Grassland and Nama Karoo biomes also occurred in the other seven biomes of South Africa (Table 9.1). The Forest, Fynbos and Succulent Karoo each had one species which was “unique” to these biomes.

9.4.2 Mantodea Diversity

The statistical analyses of homogeneity of data (Levene's test and Brown-Forsythe) indicated that the data were not homogenous. Thus the Welch F ANOVA was done to account for the bias within the data. Despite the heterogeneity within the data, mantid abundance and species richness index values differed significantly between biomes for both the Welch F ANOVA and the standard ANOVA ($p<0.0001$). Mantid diversity was the highest in the Savanna, Grassland, IOBC and Fynbos biomes (Table 9.2; Fig. 9.4). Mantodea species richness and abundance were higher in the Fynbos biome than the Nama Karoo but not in the Succulent Karoo. The Grassland and IOCB biomes were similar with regards to the abundance and species richness of Mantodea (Table 9.2; Fig. 9.4). Mantid abundance were similar in the Nama- and Succulent Karoo as well as in the Albany thicket biome and Azonal vegetation (Table 9.2; Fig. 9.4).

9.4.3. Mantodea hotspots in South Africa

9.4.3.1 Proximity based Hotspots

The hotspot analysis based on only the proximity of the collection records without factoring in the species and the frequency of the species indicated that a Mantodea hotspot (95% confidence level) is located in the north eastern region of the country which also coincides with the Savanna and grassland biomes (Fig. 9.5). This result could be due to the large number of records collected in this region, especially as this coincides with some of the largest cities in South Africa (Johannesburg and Pretoria). Contrastingly, a hotspot with a 90% confidence level was detected on the border of South Africa, Namibia and Botswana, approximately 250 km from the largest town in the region (Upington). This hotspot could be due to the large number of records collected in the Kgalagadi Transfrontier Park which is located in this region of the Savanna biome. Similarly, a hotspot was recorded in the IOCB on the border of South Africa and Mozambique (Fig. 9.5), which is also the locality of the Ndumo Game reserve. Significant cold spots in this analysis were identified as the IOCB and Fynbos biome, despite the number of records collected within this region. Similarly a significant cold spot was recorded in the Albany Thicket and the majority of the IOCB biome on the eastern coast of South Africa.

9.4.3.2 Species frequency based Hotspots

The hotspot analysis based on the species frequency (i.e. rarity of specific species), indicated the Fynbos area (associated with Cape Town and Worcester) as significant hotspot (Fig. 9.6). This suggests that species were uncommonly collected are conglomerated in this area. Similarly, the previous locality near Upington remains a hotspot with a 90% confidence level. Hotspots located within the IOCB biome spanned almost the entire biome North of Durban but did not include the Ndumo Game Reserve. The hotspot within the Savanna biome is located between Polokwane and Thohoyandou and also reaches towards the eastern border of South Africa and Mozambique (Fig. 9.6). This eastern range of the hotspot region is towards the Kruger National Park. Furthermore, two hotspots were recorded in the succulent Karoo biome, at Springbok and between Kimberly and De Aar. Therefore, identification of hotspots based on specific Mantodea species can either be associated with large towns, or not at all. This matter can be resolved by future investigations in these various hotspots.

Significant coldspots were recorded in this analysis for the Pretoria/Johannesburg region in the Grassland biome, Port Elizabeth region in the Albany Biome and between Oudtshoorn and Beaufort West in the Nama-Karoo biome (Fig. 9.6). Thus the results from this analysis indicated eight significant hotspots (in six biomes) of which one overlaps with a major city and one with two towns. Three significant coldspots were also recorded associated with two major cities.

9.5 Discussion

Suarez and Tsutsui (2004) indicated that specimen records held in well curated national collections and herbariums are an important tool in the study of species biodiversity patterns or invasive alien species introductions and that it can also provide ecological insights regarding specific species. Museum collection records are considered as inconsistent because they lack clear and structured collection methodology due to the fact that they are primarily based on the collection of specimens that were observed and not searched for (Ross et al. 2012). However, museum collections can also be considered as “biodiversity libraries” which contain historic information of species occurrences that can be utilized towards the monitoring of a species through time (Samways et al. 2020).

The number of museum records collected during this study represented 3397 mantid specimens, yet some bias existed within the study. The majority of specimen records were from areas with high population densities, i.e. near towns/cities for example Pretoria/Johannesburg (Fig. 9.1). This collection bias could further be due to accessibility of the areas in question (Grytnes and Romdal 2008). Despite this bias and random nature of museum collected data, these records represent an otherwise irretrievable amount of information and/or data that can be used to address the serious gap in knowledge regarding South African Mantodea. This is especially relevant when considering the low number of specimen records, the long collection period (1845-2019) and the wide geographical area (1.2 million km^2) represented in these collections.

As indicated by the hotspot analyses, the cities could have influenced the bias of records collected, however if the species frequency hotspot is interpreted, the locality of the major towns or cities was only associated with one major city and two towns.

This study indicated that the statistically highest Mantodea diversity was recorded in the Savanna, Grassland and IOCB biomes of South Africa. The Savanna biome has been defined as a tropical to near tropical seasonal biome with a continuous herbaceous layer, intermittent layer of trees and shrubs and is usually dominated by grasses (Skarpe 1992; Botha et al. 2016; van Coller et al. 2018). This variation in vegetation structure combined with the dominance of an herbaceous layer could explain the high diversity of Mantodea recorded in this particular biome. The Grassland and IOCB share this characteristic with the Savanna (Mucina et al. 2006), and therefore the relative high diversities of Mantodea species were also recorded in these biomes, although the Savanna biome had a higher species richness than these two biomes. According to Mucina et al. (2006) the subtropical grasslands are considered to include biomes such as the Savanna and the IOCB, while the Grassland, as referred to in this paper, refers to warm- and cool temperate Grasslands. These three biomes share the common feature which is a prominent herbaceous layer that has been shown to influence mantid population structures (Hurd et al. 2019). Gebeyehu and Samways (2002) indicated that grasshopper assemblages were influenced by vegetation composition and structure in particular grass height and ground cover. Similarly, a recent study by Hurd et al. (2019) indicated that a decrease in herbaceous vegetation or non-woody species resulted in a population decline of *T. aridifolia sinensis* in a field study conducted in the USA.

The highest number of “unique” species was recorded in the Savanna biome. This could be due to various abiotic factors i.e. altitude and temperature (Hodkinson 2007; Botha et al. 2016) and biotic factors such as habitat variability and vegetation structure (Gebeyehu and Samways 2002; Hatten et al. 2007) which provides a high abundance of suitable habitats in this biome. The possibility of specialist Savanna species also exists, which could explain why some species were only found in particular biomes. Grasshopper species have been reported to differ in sensitivity to disturbances such as grazing (Gebeyehu and

Samways 2002). In grazed areas *Orthochtha dasycnemis* Gerstaecker (Orthoptera; Acrididae) were not recorded due to their strong association with long grasses (Gandar 1979). Similarly, the Mantodea species that were "unique" to a particular biome could possibly have very specific micro-habitat requirements. A larger variation in vegetation structure accordingly increases the number of micro-habitats, thus insects that are cryptic and rely on their ability to camouflage for prey avoidance could find more opportunities to blend into their surroundings. Some Mantodea species camouflage or use mimicry as a defense mechanism by imitating dead leaves, grass, tree bark or flowers or use these abilities to catch prey (Fig. S2 Supplementary Material) (McMonigle 2013; Green 2014).

Watanabe et al. (2013) indicated that the position (height from the ground on vegetation) at which the mantid *T. aridifolia* was found differed depending on its nymphal developmental stage (instar). This could also be the case for other Mantodea species. The different plant heights required by different Mantodea instars could thus be a habitat requirement of certain Mantodea species and consequently the structural complexity of the vegetation in the Savanna biome for example, meets this habitat requirement. Although extrapolating between the small scale requirements of Mantodea in the case of plant height to these requirements being met in certain biomes is perhaps far reaching, it does indicate at least the extent of factors which could influence these predators. The mantid fauna (diversity and richness) in the Albany thicket and Forest biomes were similar. Although the Albany thicket biome is characterized by dense woody semi-succulent vegetation and is part of the broader "Mediterranean woodland, forest and shrubs description" (Mucina et al. 2006), Masubelele et al. (2015) indicated a significant increase in grasses in this biome over the last century. The Forest biome in South Africa are patches of different types of forest and mostly consist of woody plant species although many herbaceous species are also present (Mucina et al. 2006). The limited presence of the herbaceous layer within these three biomes could explain the less frequent collections of Mantodea specimens in these biomes.

The lower species richness of Mantodea recorded in the Fynbos, despite the floristic diversity in the Fynbos biome, could be ascribed to this biome being dominated by shrubs. Gess and Gess (2014) described the Fynbos, Nama Karoo and succulent Karoo regions as dwarf open scrubland with few grass species. Similarly, Braschler et al. (2012) found no significant differences between the Fynbos and the Succulent Karoo with regards to ant species richness. Despite the statistical lack of high species richness within this area, a hotspot was recorded in these three biomes based on "rarity of species". This illustrates that a different composition of species records occurred in these areas, and that there could possibility be endemic species within this dwarf shrub dominated region. The Mantodea order is suspected to have various ecomorphs (morphologically similar characteristics that align with particular habitats) which evolved in different region based on similar habitats

(Svenson & Whiting 2009; Wieland 2013; Svenson et al. 2015). Thus, the Fynbos hotspot could be indicative of an area with a unique assemblage of Mantodea species that are habitat based ecomorphs. This could also be the case for the other hotspots identified in this study.

Other factors beyond vegetation structure, for example altitude, temperature and rainfall could influence the species assemblages of Mantodea and should be further investigated. This study identified areas of concern (Savanna) in which to possibly initiate Mantodea conservation strategies as well as areas that are underrepresented (Desert) in terms of collection and research. Similarly, Samways et al. (2020) indicated that mapping of continental-scale distributions of insect diversity could aid in the identification of priority areas of conservation interest. Ultimately, this study is an example of exploring different mechanisms of statistical and visual representation of museum collection data records to identify geographical areas in which future investigations of a particular arthropod group that has been overlooked, should be pursued. This study gives an indication of possible priority areas of Mantodea species richness as opposed to conducting future investigations of Mantodea in areas selected at random, which could be an expensive and fruitless endeavor.

Since the studies by Kaltenbach (1996; 1998), one additional survey at three localities was done during 2005 in South Africa (Cape floristic region, Richards Bay in KwaZulu-Natal and the Kruger National Park in Mpumalanga). Recently however, Greyvenstein et al. (2020) published a paper on the distribution and biology of *Galepsus spp.* (Mantodea: Tarachodidae) in southern Africa. Excluding the latter study, a Scopus search indicated that only seven studies mentioning “Mantodea” have been conducted in South Africa since 1998. The only other study related to diversity patterns was done by Botha et al. (2018). Information about Mantodea in Africa is therefore very scarce, especially in terms of their abundance and species richness. This study provides information on this Mantodea species and emphasizes the point made by Isbell et al. (2011), that even species that seem functionally redundant fulfill services that might not be or acknowledged yet, but which could potentially be important in the future, especially in an ever changing environment.

9.6 Conclusion

Karlsson et al. (2020) indicated that “we desperately need baseline data to evaluate phenomena like insect decline and climate change”. The use of historic museum collection data is a relatively inexpensive method of gathering baseline data which is rapidly required. The findings of this study are based on museum collection records that were used to generate baseline information on Mantodea diversity in South Africa. The statistical analysis in study indicated that the Savanna and Grassland biomes were the most diverse with regards to Mantodea fauna. However, the species frequency-based hotspot analysis indicated hotspots in six of the nine biomes of South Africa. The evolutionary history of the Mantodea and the presence of ecomorphs could possible explain the various hotspots throughout the biomes in South Africa, but this needs further investigation. The presence of the herbaceous layer within a biome could explain the high diversity recorded in certain biomes. However, several other aspects regarding the biology and ecology of Mantodea species can influence the presence of a species in a given region, as well as abiotic factors and anthropogenic disturbances. This study only provides insight into the diversity of Mantodea on a broad geographical scale in South Africa. It indicated areas that could be diverse in Mantodea fauna and which could be the starting point for future investigations, sampling - and monitoring efforts.

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9.9 Figures

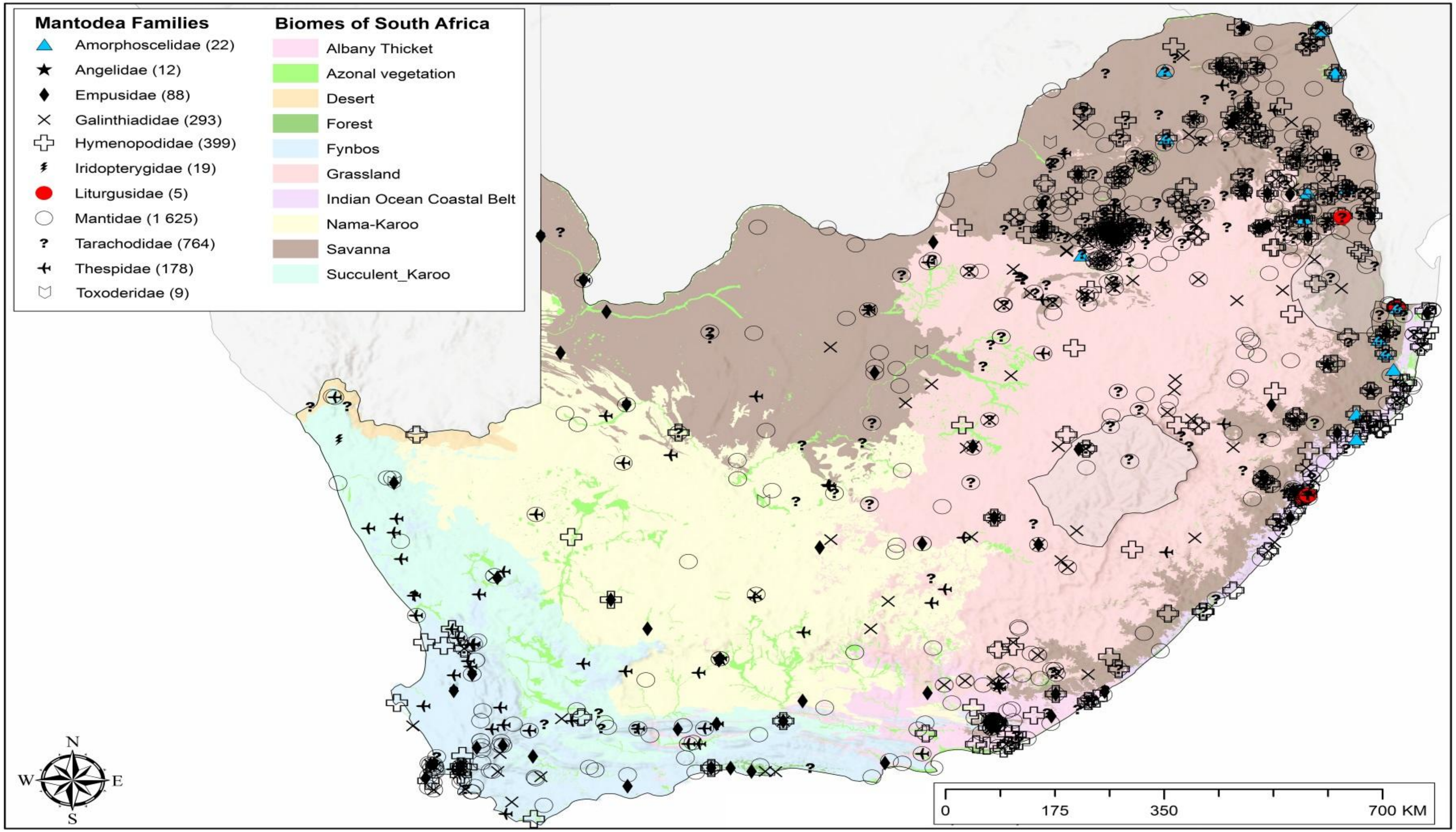


Fig. 9.1. Distribution records of specimens of the different Mantodea families in the nine biomes of South Africa. Data was compiled from South African museum records.

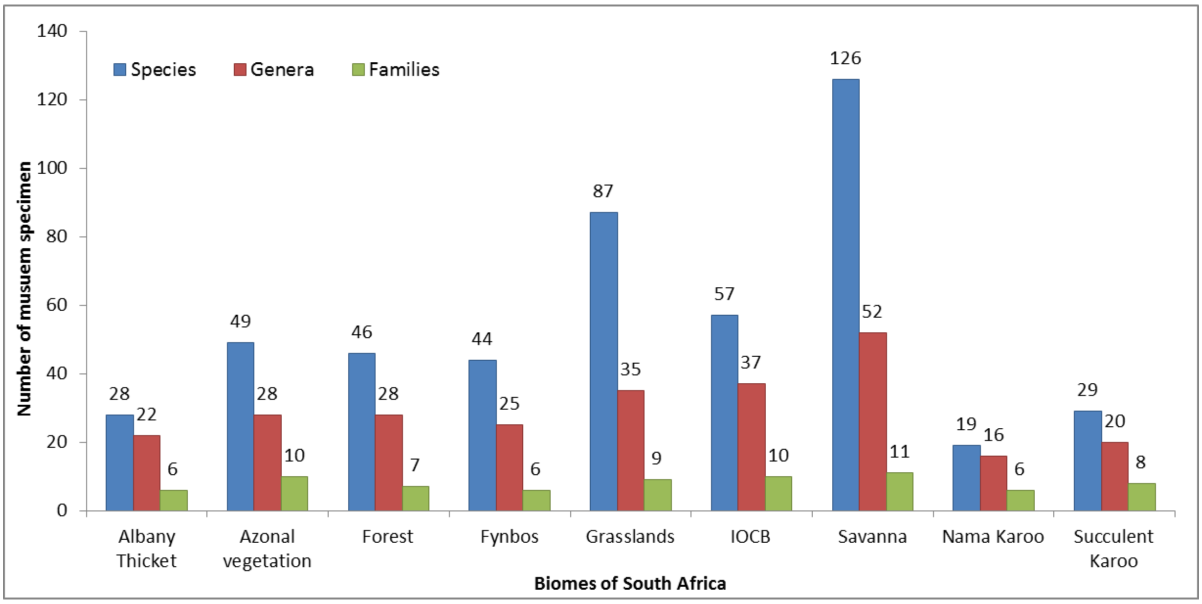


Fig. 9.2. Number of species, genera and families present in the nine biomes throughout South Africa.

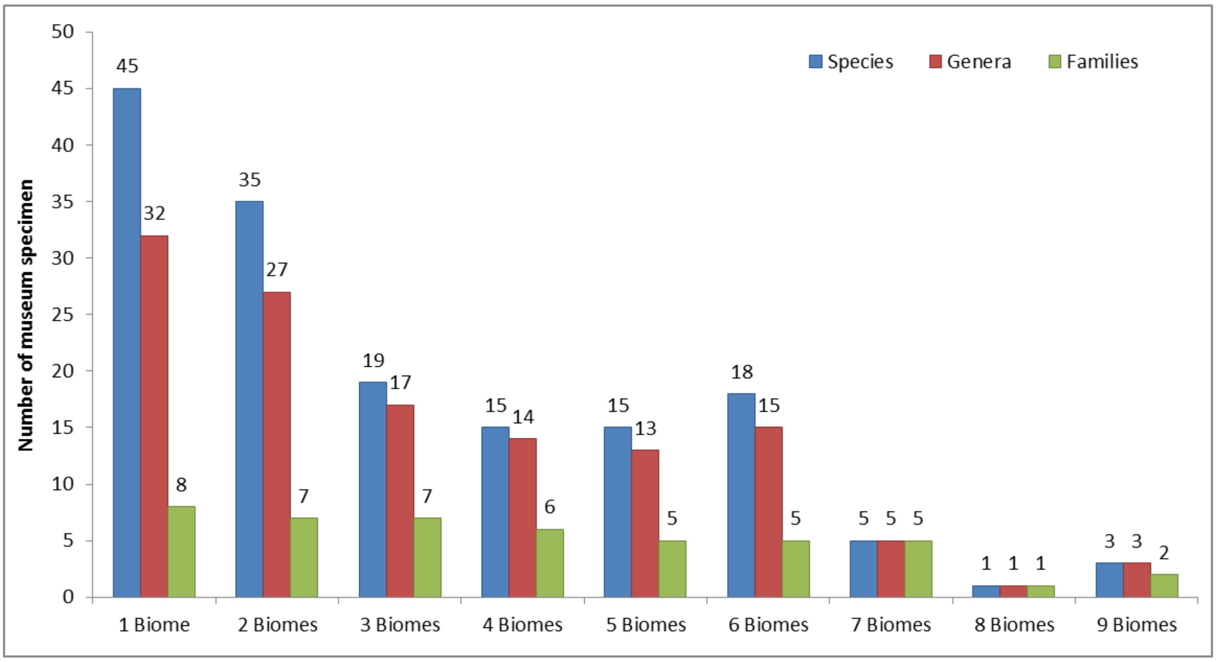


Fig. 9.3. Number of species, genera and families present in the various numbers of biomes throughout South Africa.

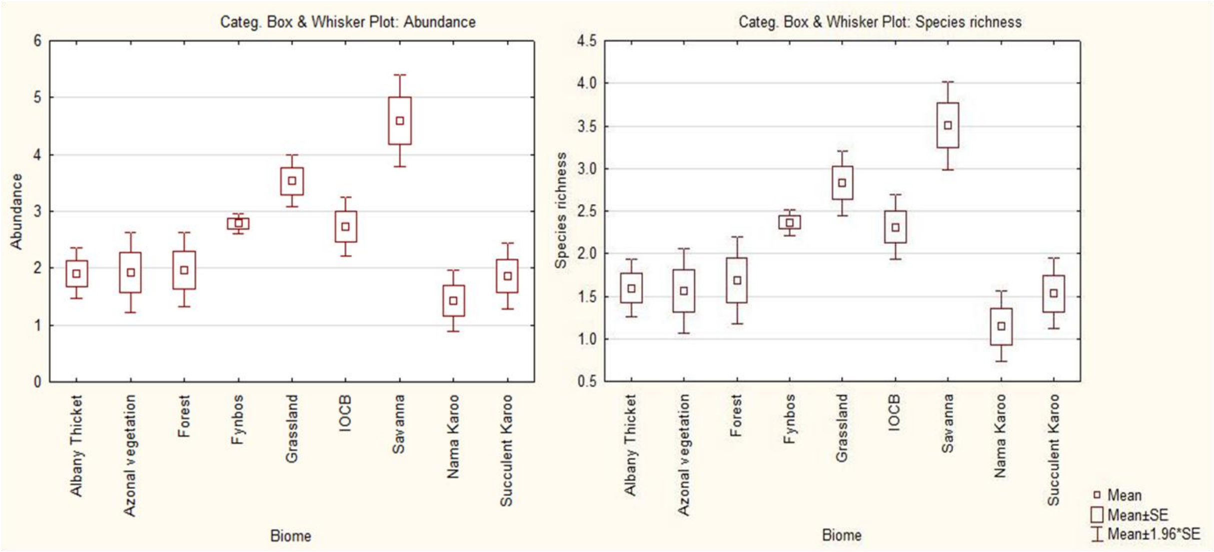


Fig. 9.4. Abundance and species richness values of the Mantodea in the nine biomes of South Africa.

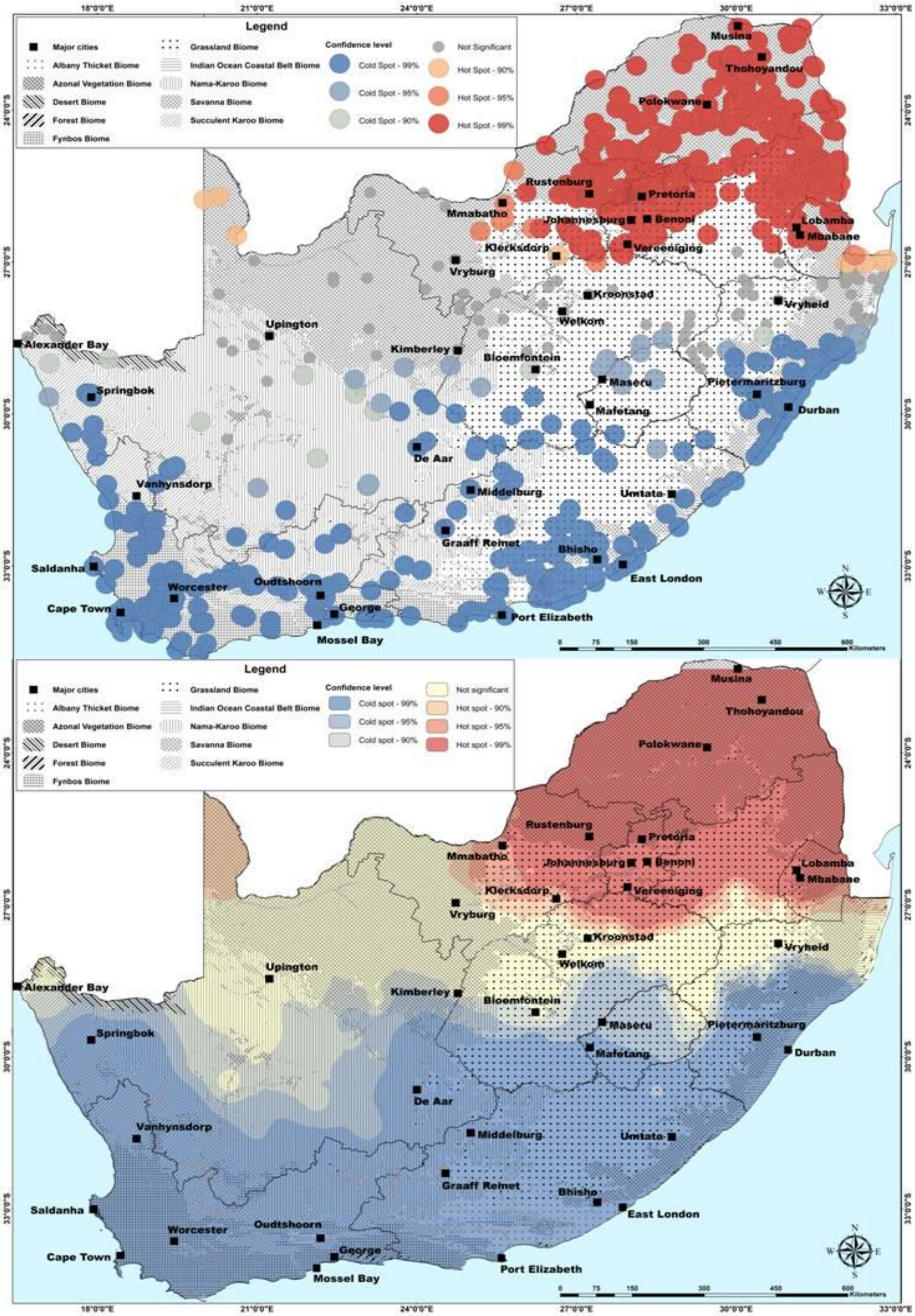


Fig. 9.5. Optimized hotspot analysis based on auto-calculated distance of data point (TOP), and the same hotspot analysis with the IDW interpolation tool applied (BOTTOM) to hotspot of Mantodea museum records. (Analyses and maps generated by Anja Erasmus)

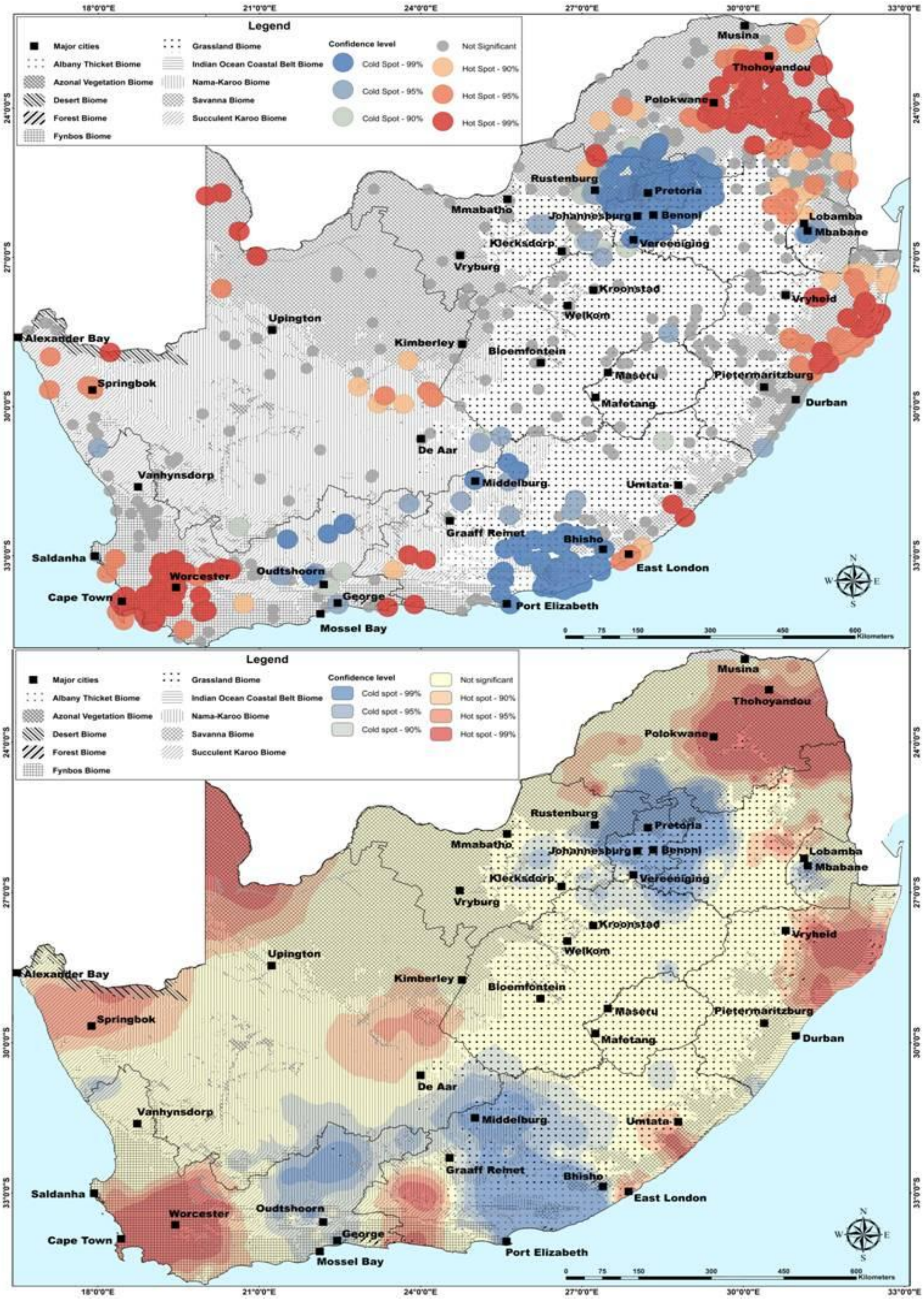


Fig. 9.6. Optimized hotspot analysis based on the frequency of species records as a ranking (TOP), and the same hotspot analysis with IDW interpolation tool applied (BOTTOM) to hotspot of Mantodea museum records (Analyses and maps generated by Anja Erasmus).

Tables

Table 9.1. Species of Mantodea that were only recorded in one particular biome in South Africa

Biomes	**Species and Author**	**Family**
Albany thicket	*Dystactula grisea* Giglio-Tos	Mantidae
Azonal vegetation	*Cilnia chopardi* Werner	Mantidae
	Galepsus bipunctatus Beier	Tarachodidae
Forest	*Ariusia conspersa* Stäl	Tarachodidae
Fynbos	*Entella nebulosa* Serville	Mantidae
IOCB	*Idolomantis diabolica* Saussure	Empusidae
	Hapalomantis orba Stäl	Iridopterygidae
	Pyrgomantis fasciata Giglio-Tos	Tarachodidae
	Solygia sulcatifrons Stäl	Mantidae
	Theopompella westwoodi Kirby	Liturgusidae
Savanna	*Idolomorpha dentifrons* Zehntner & Saussure	Empusidae
	Otomantis scutigera Bolivar	Hymenopodidae
	Oxypilus inscriptus Beier	Hymenopodidae
	Phyllocrania insignis Westwood	Hymenopodidae
	Tarachina schultzei Karny	Iridopterygidae
	Zouza radiosa Giglio-Tos	Liturgusidae
	Entella taborana Giglio-Tos	Mantidae
	Ischnomantis grandis Saussure	Mantidae
	Ligaria quadripunctata Stäl	Mantidae
	Ligariella spp. Giglio-Tos	Mantidae
	Miomantis helenae Giglio-Tos	Mantidae
	Neocilnia gracilis Beier	Mantidae
	Paramantis natalensis Stäl	Mantidae
	Polyspilota caffra Westwood	Mantidae
	Tenodera irigana Giglio-Tos	Mantidae
	Tenodera sinensis Saussure	Mantidae
	Galepsus pentheri Giglio-Tos	Tarachodidae
	Nothogalepsus planivertex Beier	Tarachodidae
	Pyrgomantis nasuta Beier	Tarachodidae
	Pyrgomantis simillima Beier	Tarachodidae
	Tarachodes dives Saussure	Tarachodidae
	Tarachodes maurus Saussure	Tarachodidae
	Tarachodes perloides Burmeister	Tarachodidae
	Hoplocorypha striata Beier	Thespidae
Succulent Karoo	*Chroicoptera vidua* Stäl	Mantidae

Table 9.2. Levene's and Brown-Forsythe test of Homogeneity, Analysis of variance (ANOVA) and Welch F ANOVA test and associated p-values indicating differences between the different biomes of South Africa for each of the diversity indices. Significance (p<0.05) indicated by an asterisk (*).

Homogeneity of data	**Species Richness**		**Abundance**	
	p	*F*	*p*	*F*
Levene's test of Homogeneity	0.000*	8.030	0.000*	16.656
Brown-Forsythe of Homogeneity	0.000*	6.902	0.000*	14.640
ANOVAs	**Species Richness**		**Abundance**	
	p	*F*	*p*	*F*
Welch F ANOVA	0.000*	10.894	0.000*	9.520
One-Way ANOVA test	0.000*	12.779	0.000*	12.093
Post Hoc test (HSD Tukey unequal N test)	**Species Richness**		**Abundance**	
	p		*p*	
Albany Thicket x Azonal vegetation	1.000		1.000	
Albany Thicket x Forest	0.999		1.000	
Albany Thicket x Fynbos	0.207		0.456	
Albany Thicket x Grassland	0.002*		0.004*	
Albany Thicket x IOCB	0.287		0.551	
Albany Thicket x Savanna	0.0001*		0.0001*	
Albany Thicket x Nama Karoo	0.854		0.959	
Albany Thicket x Succulent Karoo	1.000		1.000	
Azonal vegetation x Forest	0.999		1.000	
Azonal vegetation x Fynbos	0.168		0.482	
Azonal vegetation x Grassland	0.002*		0.005*	
Azonal vegetation x IOCB	0.237		0.577	
Azonal vegetation x Savanna	0.0001*		0.0001*	
Azonal vegetation x Nama Karoo	0.896		0.950	
Azonal vegetation x Succulent Karoo	1.000		1.000	
Forest x Fynbos	0.373		0.558	
Forest x Grassland	0.007*		0.007*	
Forest x IOCB	0.480		0.653	
Forest x Savanna	0.0001*		0.0001*	
Forest x Nama Karoo	0.672		0.918	
Forest x Succulent Karoo	0.999		0.999	
Fynbos x Grassland	0.824		0.667	
Fynbos x IOCB	1.000		1.000	
Fynbos x Savanna	0.007*		0.0009*	
Fynbos x Nama Karoo	0.003*		0.033*	
Fynbos x Succulent Karoo	0.132		0.378	
Grassland x IOCB	0.729		0.572	
Grassland x Savanna	0.375		0.198	
Grassland x Nama Karoo	0.0001*		0.0001*	
Grassland x Succulent Karoo	0.0012*		0.003*	
IOCB x Savanna	0.004*		0.0006*	
IOCB x Nama Karoo	0.005*		0.049*	
IOCB x Succulent Karoo	0.190		0.468	
Savanna x Nama Karoo	0.0001*		0.0001*	
Savanna x Succulent Karoo	0.0001*		0.0001*	
Nama Karoo x Succulent Karoo	0.931		0.979	

9.11 Supplementary Materials

S1. List of Mantodea species that occur in each of the nine biomes throughout South Africa. The two species recorded in the desert biome are only indicated by an asterisk (*).

Species	Albany Thicket	Azonal vegetation	Forest	Fynbos	Grasslands	IOCB	Savanna	Nama Karoo	Succulent Karoo	Species occurs in number of biomes
Amorphoscelidae										
Amorphoscelis tuberculata					x	x	x			3
Amorphoscelis austrogermanica		x					x			2
Amorphoscelis spp.			x				x			2
Angelidae										
Agrionopsis distanti		x	x		x	x	x			5
Agrionopsis spp.					x					1
Empusidae										
Empusa guttula		x		x	x		x	x	x	6
Empusa spinosa		x		x	x	x	x	x	x	7
Empusa spp.	x	x			x					3
Hemiempusa capensis	x		x	x	x	x	x			6
Idolomantis diabolica						x				1
Idolomorpha dentifrons							x			1
Idolomorpha spp.						x				1
Galinthiadidae										
Galinthias amoena			x			x	x			3
Galinthias spp.		x	x			x	x			4
Harpagomantis discolor			x	x	x		x		x	5
Harpagomantis spp.	x		x	x	x	x	x	x		7
Harpagomantis tricolor		x		x	x	x	x		x	6
Hymenopodidae										
Junodia sp.		x				x	x			3
Junodia strigipennis		x			x	x	x			4
Otomantis scutigera							x			1

Species	Albany Thicket	Azonal vegetation	Forest	Fynbos	Grasslands	IOCB	Savanna	Nama Karoo	Succulent Karoo	Species occurs in number of biomes
Hymenopodidae										
Otomantis spp.			x		x	x	x			4
Oxypiloidea spp.			x	x	x	x	x			5
Oxypiloidea tridens			x	x	x	x	x			5
Oxypilus capensis		x		x	x	x	x		x	6
Oxypilus inscriptus							x			1
Oxypilus spp.*		x	x	x	x		x	x		6
Oxypilus transvalensis					x		x			2
Phyllocrania insignis							x			1
Phyllocrania paradoxa	x		x		x	x	x			5
Phyllocrania spp.	x	x	x	x	x	x	x			7
Pseudocreobotra ocellata			x			x				2
Pseudocreobotra spp.	x		x		x	x	x			5
Pseudocreobotra wahlbergi	x		x	x	x	x	x			6
Sibylla pretiosa		x	x	x	x	x	x			6
Sibylla spp.			x	x	x	x	x			5
Iridopterygidae										
Bolbena minutissima							x		x	2
Hapalogymnes gymnes					x		x			2
Hapalomantis orba						x				1
Tarachina schultzei							x			1
Tarachina transvaalensis		x					x			2
Theopompella spp.						x	x			2
Theopompella westwoodi						x				1
Zouza radiosa							x			1

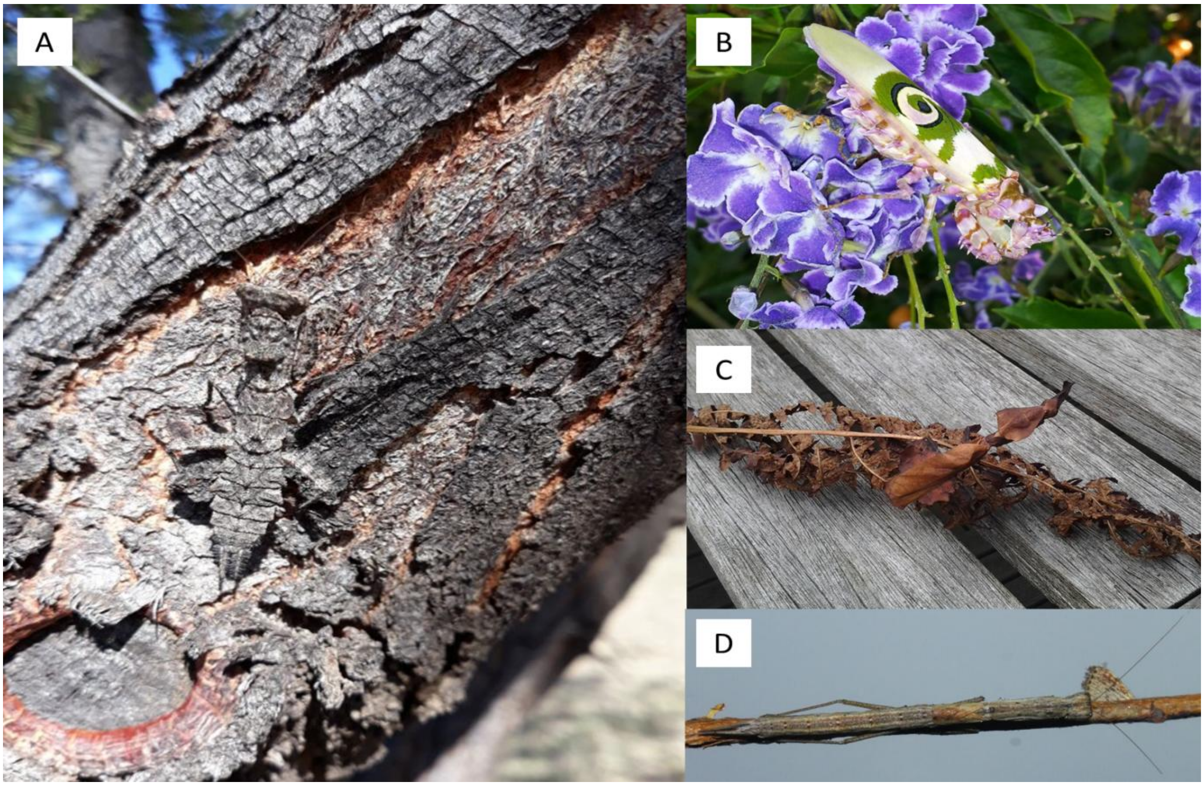
Species	Albany Thicket	Azonal vegetation	Forest	Fynbos	Grasslands	IOCB	Savanna	Nama Karoo	Succulent Karoo	Species occurs in number of biomes
Mantidae										
Ameles spp.	x				x					2
Bisanthe pulchripennis					x		x			2
Bisanthe spp.							x			1
Bolbella punctigera		x			x	x	x			4
Bolbella rhodesiaca		x			x		x			3
Chroicoptera saussurei	x				x					2
Chroicoptera vidua									x	1
Cilnia chopardi		x								1
Cilnia humeralis	x	x			x	x	x	x		6
Compsothespis anomala				x			x	x	x	4
Compsothespis natalica					x		x			2
Compsothespis spp.				x	x	x	x	x		5
Danuria spp.		x	x		x	x	x			5
Danuria thunbergi		x	x		x	x	x			5
Dystacta alticeps					x		x		x	3
Dystacta spp.	x				x	x	x			4
Dystactula grisea	x									1
Entella congica				x	x		x		x	4
Entella delalandi				x					x	2
Entella nebulosa				x						1
Entella pusilla				x	x		x			3
Entella spp.	x			x	x	x		x	x	6
Entella taborana							x			1
Entella transvaalica							x		x	2
Entelloptera rogenhoferi		x	x	x	x		x			5
Gonypetella deletrix					x		x			2
Gonypetella kilimandjarica					x					1

Species	Albany Thicket	Azonal vegetation	Forest	Fynbos	Grasslands	IOCB	Savanna	Nama Karoo	Succulent Karoo	Species occurs in number of biomes
Mantidae										
Heterochaeta occidentalis				x				x	x	3
Heterochaeta sp.		x					x	x		3
Ischnomantis fatiloqua		x	x	x	x	x	x			6
Ischnomantis grandis							x			1
Ischnomantis spp.	x		x	x	x	x	x			6
Ligaria brevicollis		x					x			2
Ligaria chopardi *		x		x	x			x	x	5
Ligaria quadrinotata					x		x			2
Ligaria quadripunctata							x			1
Ligaria spp.			x		x		x			3
Ligariella spp.							x			1
Ligariella trigonalis		x							x	2
Mantis religiosa		x	x	x	x	x	x			6
Mantis spp.					x		x			2
Miomantis aequalis					x					1
Miomantis caffra			x				x			2
Miomantis coxalis				x		x	x		x	4
Miomantis exilis	x	x		x	x	x	x		x	7
Miomantis fenestrata				x	x		x		x	4
Miomantis helenae							x			1
Miomantis natalica	x				x		x			3
Miomantis prasina					x					1
Miomantis quadripunctata		x	x		x	x	x			5
Miomantis saussurei			x			x				2
Miomantis semialata		x	x	x	x	x	x			6
Miomantis spp.	x	x	x	x	x	x	x	x	x	9
Neocilnia gracilis							x			1

Species	Albany Thicket	Azonal vegetation	Forest	Fynbos	Grasslands	IOCB	Savanna	Nama Karoo	Succulent Karoo	Species occurs in number of biomes
Mantidae										
Neodanuria bolauana	x			x			x			3
Omomantis spp.	x	x	x		x	x	x			6
Omomantis zebrata	x		x				x			3
Paramantis natalensis							x			1
Paramantis sacra				x	x		x		x	4
Paramantis spp.					x		x			2
Polyspilota aeruginosa	x		x	x	x	x	x			6
Polyspilota caffra							x			1
Polyspilota spp.	x		x		x	x	x			5
Popa spp.	x	x	x	x	x	x	x	x	x	9
Popa spurca		x	x	x	x	x	x		x	7
Rhomboderella scutata			x				x			2
Solygia sulcatifrons						x				1
Sphodromantis gastrica	x	x	x	x	x	x	x	x		8
Sphodromantis spp.			x		x		x			3
Taumantis globiceps					x		x			2
Taumantis spp.							x			1
Tenodera capitata	x						x			2
Tenodera irigana							x			1
Tenodera sinensis							x			1
Tenodera superstitiosa			x		x	x	x			4
Tarachodidae										
Antistia maculipennis		x					x			2
Antistia parva		x					x	x	x	4
Ariusia conspersa			x							1
Episcopomantis chalybea		x			x		x			3
Episcopomantis spp.					x		x	x	x	4

Species	Albany Thicket	Azonal vegetation	Forest	Fynbos	Grasslands	IOCB	Savanna	Nama Karoo	Succulent Karoo	Species occurs in number of biomes
Tarachodidae										
Galepsus bipunctatus		x								1
Galepsus capitatus		x			x		x			3
Galepsus femoratus				x			x			2
Galepsus intermedius				x	x		x			3
Galepsus lenticularis					x		x			2
Galepsus meridionalis						x	x			2
Galepsus pentheri							x			1
Galepsus spp.	x	x	x	x	x	x	x	x	x	9
Galepsus transvaalensis					x		x			2
Galepsus centralis					x					1
Nothogalepsus planivertex							x			1
Oxyelaea elegans			x				x			2
Pyrgomantis fasciata						x				1
Pyrgomantis nasuta							x			1
Pyrgomantis rhodesica					x		x			2
Pyrgomantis simillima							x			1
Pyrgomantis singularis					x		x			2
Pyrgomantis spp.	x		x	x	x	x	x			6
Tarachodes dives							x			1
Tarachodes insidiator		x	x	x	x	x	x			6
Tarachodes lucubrans		x		x			x			3
Tarachodes maurus							x			1
Tarachodes perloides							x			1
Tarachodes sanctus					x		x			2
Tarachodes spp.		x	x			x	x	x	x	6

Species	Albany Thicket	Azonal vegetation	Forest	Fynbos	Grasslands	IOCB	Savanna	Nama Karoo	Succulent Karoo	Species occurs in number of biomes
Thespidae										
Hoplocorypha fumosa					x					1
Hoplocorypha macra	x			x	x		x			4
Hoplocorypha nana		x			x		x			3
Hoplocorypha saussurii					x		x			2
Hoplocorypha spp.		x			x		x	x	x	5
Hoplocorypha striata							x			1
Hoplocoryphella grandis					x					1
Toxoderidae										
Toxodera spp.		x				x	x		x	4



S2. The camouflage abilities of a few mantid species. (A): A species of bark mantid (Mantodea: Liturgusidae) Photo by Amone’ Mouton, (B): Eyed Flower mantid, *Pseudocreobotra wahlbergi* Stäl (Mantodea: Hymenopodidae) Photo by Abigail Wolmarans, (C): Ghost mantid resembling dead leaves, *Phyllocrania paradoxa* Burmeister (Mantodea: Hymenopodidae) and a mantid usually found in grasslands (D) *Galepsus* sp. Stäl (Mantodea: Tarachodidae) Photo by Allison Sharp.

CHAPTER 10

Conclusion and recommendations

10.1 Diversity and distribution of Mantodea in South Africa

The diversity and distribution of the Mantodea in southern Africa was studied by using historic museum records from seven national insect collections in South Africa. The biology of three mantid species in that occur in the Highveld grasslands of South Africa was also studied.

Previous studies on South African Mantodea encapsulated 180 species that were reported to occur in the region, their taxonomy, as well as the potential distribution of 13 genera. This study however updated the South African checklist of species (Chapter 4) and reported that 198 species, 60 genera and 11 families occur in the region. This updated checklist also included new distribution records for one genus and 20 species. Digitized data of museum specimens were used to determine the distribution of Mantodea fauna in South Africa (Chapter 7). The database generated by these museum records is available at: http://natural-sciences.nwu.ac.za/unit-environmental-sciences-and-management/praying-mantid-mantodea-records-southern-africa. This database encapsulated 4292 specimens collected throughout southern Africa, of which 3559 were from South Africa. The remaining records (733) were collected in 12 other African countries and two Indian Ocean islands (Madagascar and Zanzibar). A total of 91 species were recorded of which fewer than 10 specimens exist among the local museum collections and for 31 of these, there was only a single specimen record (Figure 10.1). This could indicate possible endemic, scarce or even endangered species.

Chapter 8 refers to the diversity of Mantodea within each biome in South Africa. Recently, several studies have indicated a decline in insect diversity and biomass across the world. These declines are due to various factors such as habitat fragmentation and destruction, climate change and pollution (Cardoso et al. 2020; Samways et al. 2020; Hallmann et al. 2019; Habel et al. 2016). However, in order to investigate these potential threats, data on species distribution and ecology are urgently required (Karlsson et al. 2020). Data of museum specimen records were used to determine mantid diversity and species composition in the different biomes of South Africa. Results suggested that the Savanna, Grassland and Indian Ocean Coastal Belt biomes are the most diverse in terms of mantid species with 127, 87 and 57 species recorded from each of these biomes respectively. Mantid community composition differed between biomes in most cases and several species (45) were only recorded in a single biome. These results, although based on museum records that are inconsistently collected, enabled this study on a broad geographic scale to be done and therefore provide a baseline of Mantodea diversity in different biomes in South Africa.

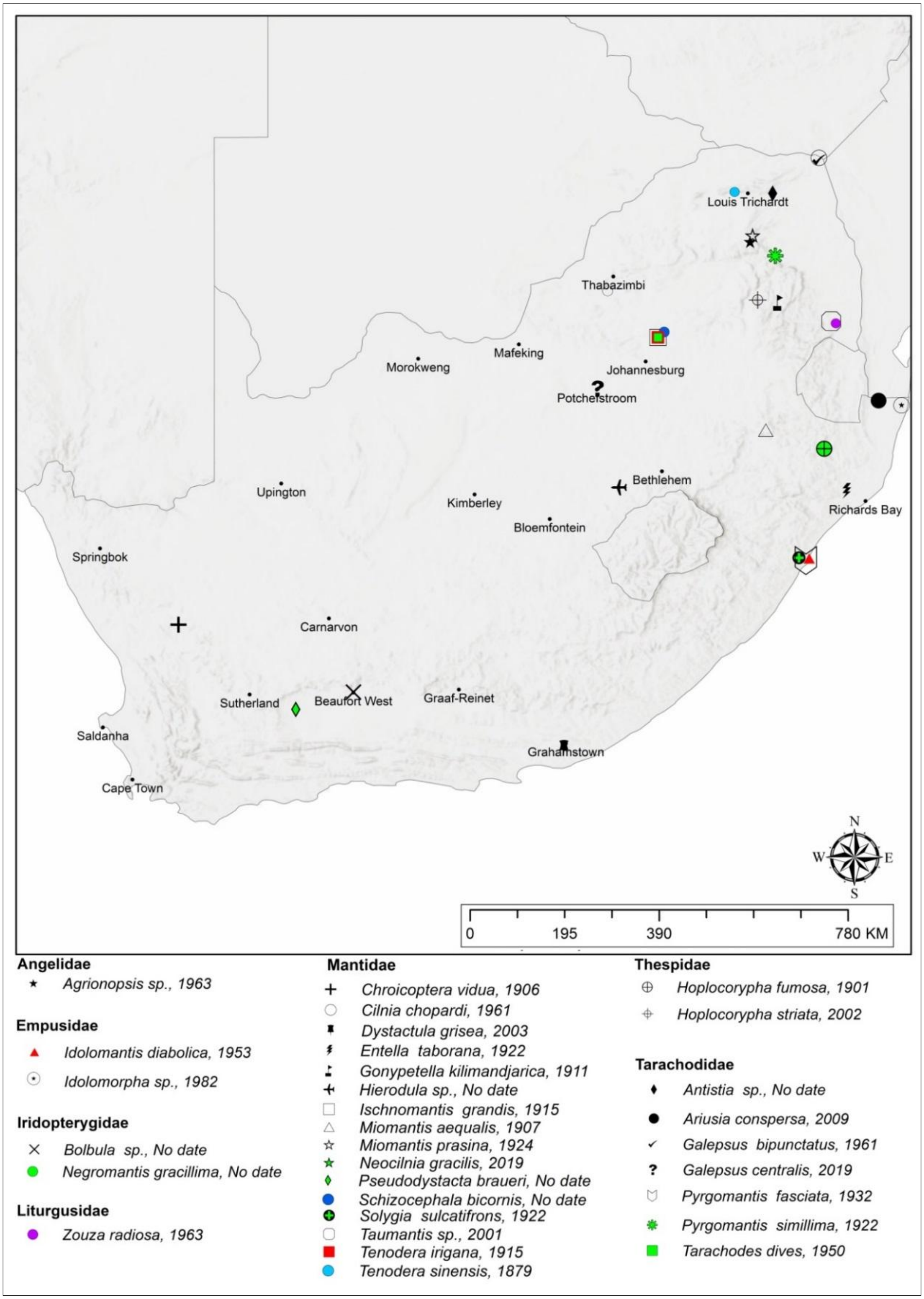


Figure 10.1. Localities and distribution records of 31 mantid species for which only one specimen exists as well as the year in which they were collected in South Africa.

Biology of three mantid species that occur in the Highveld grasslands of South Africa.

The biology of three species were investigated. These species: *Popa spurca* (Stäl) (Mantidae) (Chapter 5), *Galepsus lenticularis* Saussure (Tarachodidae) (Chapter 3) and *Harpagomantis tricolor* L. (Galinthiadidae) (Chapter 6).

Life history parameters were recorded from the time that oothecae were deposited until the nymphs that hatched became adults, mated, deposited oothecae, and died. Results indicated that various possible survival strategies are used by the different species. For example, *P. spurca* females could be "bet-hedging", which was also suggested by Maxwell (2014) for the species *Stagmomantis limbata* Hahn (Mantidae: Stagmomantinae). For *G. lenticularis* however, a survival strategy that reduces competition between nymphs of different oothecae, deposited by a single female is suggested. An extended copulation period (6 hrs) in *H. tricolor* was observed, which could be a mechanism to decrease sperm competition by other males, thus increasing the original male's chances of fathering offspring. The mean duration of the life cycles (from hatching to death) of *P. spurca*, *G. lenticularis* and *H. tricolor* were 332, 199 and 191 days respectively.

The results obtained from this study generated much needed data about South African Mantodea species and their distribution and the diversity in different biomes of South Africa. The biology of the three species that were reared under captive conditions indicated different possible survival strategies and various biological attributes which was not known about these species before. Some of the knowledge gaps regarding Mantodea were addressed and various anomalies uncovered that should be addressed in future investigations.

10.2 Recommendations

Future studies should further address the cultural values identified in this study, and investigate how these can be used to attain better insect appreciation by using Mantodea as a flagship species. Mantodea could be used as a gateway bug to increase insect appreciation. This could possibly be done by exposing people to novel and interesting aspects of mantids. Mantids are not often observed and can be regarded as 'stranger' and more 'unique' than species such as butterflies, ladybugs and dragonflies that are often referred to as flagship bugs. This could enhance the tolerance people have towards strange and "less aesthetically beautiful" creatures and perhaps create a gateway for appreciation of more and different insect species.

Various taxonomic anomalies were uncovered as well as contrasting information about species distribution. It is suggested that future investigations include molecular studies on *Harpagomantis tricolor* and *Harpagomantis discolor* to determine how molecularly similar these species/ecomorphs are. Attempts were made within this study to extract DNA from musuem specimen (aboive mentionded species), as preliminary experiments conducted indicated that DNA from old musuem specimen were vaible and could have aided in determining species and further phylogenetic investigation. However, due to unforseen circumstances and denied access to specimen this endevour was postponed beyond this study. Thus future investigations into DNA barcoding and molecular studies of musuem specimen are highly recommended. Furthermore, since no literature about this species or the original species description could be found, its distribution and taxonomical status remains unclear. These investigations could also include *Popa spurca spurca, P. spurca crassa* and *P. spurca pallida* to determine the phylogenetic structure of this genus and their distribution.

The biological attributes investigated and results obtained throughout this study can be used to assess the IUCN red list status of these three species. Furthermore, factors influencing the development of these species can be investigated i.e. increased temperature, prey diversity and potential effects of genetically modified crops on these non-target organisms.

Future investigations should also address the regions that were identified in this study to have a high diversity (Savanna, Grassland and IOCB) as well as areas which were underrepresented, such as the desert biome. The Centers of Endemism within these biomes could be ideal areas for future investigations since Mantodea community composition differed between biomes (Chapter 8) and it may be that these centers have high biodiversity and endemism rates. Investigations should also be done to determine if species that were regarded as rare, and also those of which only one specimen exist in South Africa museum collections, still occur at the sites where they were originally collected. For example, Battiston et al. (2012) indicated that *Tenodera rungsi* still occurred at the original site where it was recorded 78 years earlier in Morocco. With the latter example in mind, future investigations should focus on determining if the 31 species with only one collection record still exist in the region (Figure 10.1). Since these species could be endangered or threatened, this matter requires urgent investigation. A further 60 species only had between two and nine specimen records and should also be investigated for similar reasons.

The rate of parasitism and effect of the on mantid population dynamics by horsehair worms and other parasites (Torymidae) should also be investigated to estimate the treat that these parasitoids pose to mantid species as this could influence the threat status of several mantid species.

Studies on the ecology of the abovementioned species and others reported to be endemic, should be done to determine their threat status. The 31 “rare” species should be the priority and their associated threat status must be investigated. Of the 2400 mantid species worldwide, only 13 are listed on the IUCN red data list. There could be many more species (possibly the 31 identified in this study) that are in critical need for conservation.

South Africa has a very rich biological diversity with regards to fauna and flora and is the third most biologically diverse country in the world (Cadman et al. 2010). The eight centers of endemism and many endemic species that occur in South Africa (von Maltitz and Scholes 2006) necessitate further investigation into the Mantodea in the region.

It is important that the Mantodea receive urgent further research attention since they:

- have the potential to serve as environmental indicators of change,
- are an important functional group,
- are of extremely important cultural value, and
- should be an important element in conservation planning.

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APPENDIX A

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Instructions to Authors (excerpt) (Article 1)

Journal: Insects (MPDI)

Manuscript Submission Overview

Types of Publications

Insects has no restrictions on the length of manuscripts, provided that the text is concise and comprehensive. Full experimental details must be provided so that the results can be reproduced. *Insects* requires that authors publish all experimental controls and make full datasets available where possible (see the guidelines on Supplementary Materials and references to unpublished data).

Manuscripts submitted to *Insects* should neither been published before nor be under consideration for publication in another journal. The main article types are as follows:

- *Articles:* Original research manuscripts. The journal considers all original research manuscripts provided that the work reports scientifically sound experiments and provides a substantial amount of new information. Authors should not unnecessarily divide their work into several related manuscripts, although Short *Communications* of preliminary, but significant, results will be considered. Quality and impact of the study will be considered during peer review.
- *Reviews:* These provide concise and precise updates on the latest progress made in a given area of research. Systematic reviews should follow the PRISMA guidelines.

Manuscript Preparation

General Considerations

- **Research manuscripts** should comprise:
  - Front matter: Title, Author list, Affiliations, Abstract, Keywords
  - Research manuscript sections: Introduction, Materials and Methods, Results, Discussion, Conclusions (optional).
  - Back matter: Supplementary Materials, Acknowledgments, Author Contributions, Conflicts of Interest, References.
- **Review manuscripts** should comprise the front matter, literature review sections and the back matter. The template file can also be used to prepare the front and back matter of your review manuscript. It is not necessary to follow the remaining structure. Structured reviews and meta-analyses should use the same structure as research articles and ensure they conform to the PRISMA guidelines.
- **Graphical abstract:** Authors are encouraged to provide a graphical abstract as a self-explanatory image to appear alongside with the text abstract in the Table of Contents. Figures should be a high quality image in any common image format. Note that images displayed online will be up to 11 by 9 cm on screen and the figure should be clear at this size.
- **Abbreviations** should be defined in parentheses the first time they appear in the abstract, main text, and in figure or table captions and used consistently thereafter.
- **SI Units** (International System of Units) should be used. Imperial, US customary and other units should be converted to SI units whenever possible
- **Accession numbers** of RNA, DNA and protein sequences used in the manuscript should be provided in the Materials and Methods section. Also see the section on Deposition of Sequences and of Expression Data.
- **Research Data and supplementary materials:** Note that publication of your manuscript implies that you must make all materials, data, and protocols associated with the publication available to readers.

Disclose at the submission stage any restrictions on the availability of materials or information. Read the information about Supplementary Materials and Data Deposit for additional guidelines.

- **Guidelines and standards:** MDPI follows standards and guidelines for certain types of research. See https://www.mdpi.com/editorial_process for further information.

Front Matter

These sections should appear in all manuscript types

- **Title:** The title of your manuscript should be concise, specific and relevant. It should identify if the study reports (human or animal) trial data, or is a systematic review, meta-analysis or replication study. When gene or protein names are included, the abbreviated name rather than full name should be used.
- **Author List and Affiliations:** Authors' full first and last names must be provided. The initials of any middle names can be added. The PubMed/MEDLINE standard format is used for affiliations: complete address information including city, zip code, state/province, and country. At least one author should be designated as corresponding author, and his or her email address and other details should be included at the end of the affiliation section. Please read the criteria to qualify for authorship.
- **Abstract:** The abstract should be a total of about 200 words maximum. The abstract should be a single paragraph and should follow the style of structured abstracts, but without headings: 1) Background: Place the question addressed in a broad context and highlight the purpose of the study; 2) Methods: Describe briefly the main methods or treatments applied. Include any relevant preregistration numbers, and species and strains of any animals used. 3) Results: Summarize the article's main findings; and 4) Conclusion: Indicate the main conclusions or interpretations. The abstract should be an objective representation of the article: it must not contain results which are not presented and substantiated in the main text and should not exaggerate the main conclusions.
- **Keywords:** Three to ten pertinent keywords need to be added after the abstract. We recommend that the keywords are specific to the article, yet reasonably common within the subject discipline.

Research Manuscript Sections

- **Introduction:** The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance, including specific hypotheses being tested. The current state of the research field should be reviewed carefully and key publications cited. Please highlight controversial and diverging hypotheses when necessary. Finally, briefly mention the main aim of the workand highlight the main conclusions. Keep the introduction comprehensible to scientists working outside the topic of the paper.
- **Materials and Methods:** They should be described with sufficient detail to allow others to replicate and build on published results. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited. Give the name and version of any software used and make clear whether computer code used is available. Include any pre-registration codes.
- **Results:** Provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.
- **Discussion:** Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible and limitations of the work highlighted. Future research directions may also be mentioned. This section may be combined with Results.
- **Conclusions:** This section is mandatory, and should provide readers with a brief summary of the main achievements/results of your work.

Back Matter

- **Supplementary Materials:** Describe any supplementary material published online alongside the manuscript (figure, tables, video, spreadsheets, etc.). Please indicate the name and title of each element as follows Figure S1: title, Table S1: title, etc.
- **Acknowledgments:** All sources of funding of the study should be disclosed. Clearly indicate grants that you have received in support of your research work and if you received funds to cover publication costs. Note that some funders will not refund article processing charges (APC) if the funder and grant number are not clearly and correctly identified in the paper. Funding information can be entered separately into the submission system by the authors during submission of their manuscript. Such funding information, if available, will be deposited to FundRef if the manuscript is finally published.
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  For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, X.X. and Y.Y.; Methodology, X.X.; Software, X.X.; Validation, X.X., Y.Y. and Z.Z.; Formal Analysis, X.X.; Investigation, X.X.; Resources, X.X.; Data Curation, X.X.; Writing – Original Draft Preparation, X.X.; Writing – Review & Editing, X.X.; Visualization, X.X.; Supervision, X.X.; Project Administration, X.X.; Funding Acquisition, Y.Y.", please turn to the CRediT taxonomy for the term explanation. For more background on CRediT, see here. "**Authorship must include and be limited to those who have contributed substantially to the work. Please read the section concerning the criteria to qualify for authorship carefully**".
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- **References:** References must be numbered in order of appearance in the text (including table captions and figure legends) and listed individually at the end of the manuscript. We recommend preparing the references with a bibliography software package, such as EndNote, ReferenceManager or Zotero to avoid typing mistakes and duplicated references. We encourage citations to data, computer code and other citable research material. If available online, you may use reference style 9. below.
- Citations and References in Supplementary files are permitted provided that they also appear in the main text and in the reference list.

In the text, reference numbers should be placed in square brackets [ ], and placed before the punctuation; for example [1], [1–3] or [1,3]. For embedded citations in the text with pagination, use both parentheses and brackets to indicate the reference number and page numbers; for example [5] (p. 10). or [6] (pp. 101–105).

References should be described as follows, depending on the type of work:

- Journal Articles:

1. Author 1, A.B.; Author 2, C.D. Title of the article. *Abbreviated Journal Name* **Year**, *Volume*, page range.

- Books and Book Chapters:

2. Author 1, A.; Author 2, B. *Book Title*, 3rd ed.; Publisher: Publisher Location, Country, Year; pp. 154–196.
3. Author 1, A.; Author 2, B. Title of the chapter. In *Book Title*, 2nd ed.; Editor 1, A., Editor 2, B., Eds.; Publisher: Publisher Location, Country, Year; Volume 3, pp. 154–196.

- Unpublished work, submitted work, personal communication:

4. Author 1, A.B.; Author 2, C. Title of Unpublished Work. status (unpublished; manuscript in preparation).
5. Author 1, A.B.; Author 2, C. Title of Unpublished Work. *Abbreviated Journal Name* stage of publication (under review; accepted; in press).
6. Author 1, A.B. (University, City, State, Country); Author 2, C. (Institute, City, State, Country). Personal communication, Year.

- Conference Proceedings:

7. Author 1, A.B.; Author 2, C.D.; Author 3, E.F. Title of Presentation. In *Title of the Collected Work* (if available), Proceedings of the Name of the Conference, Location of Conference, Country, Date of Conference; Editor 1, Editor 2, Eds. (if available); Publisher: City, Country, Year (if available); Abstract Number (optional), Pagination (optional).

- Thesis:

8. Author 1, A.B. Title of Thesis. Level of Thesis, Degree-Granting University, Location of University, Date of Completion.

- Websites:

9. Title of Site. Available online: URL (accessed on Day Month Year).

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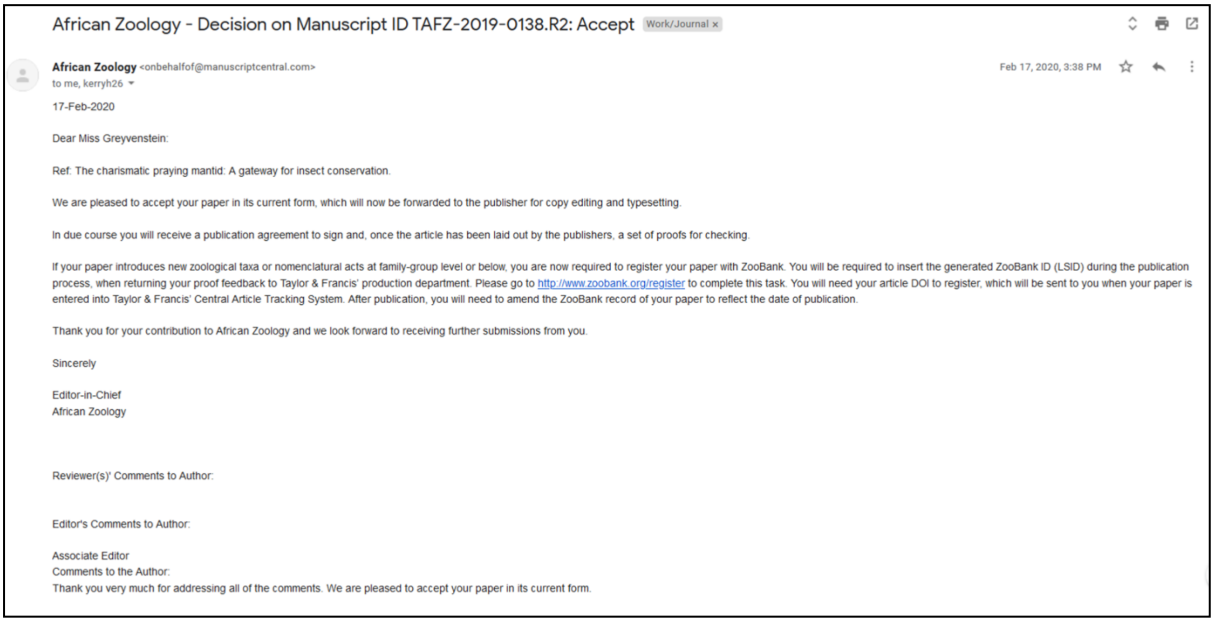
See the Reference List and Citations Guide for more detailed information.

Preparing Figures, Schemes and Tables

- File for Figures and Schemes must be provided during submission in a single zip archive and at a sufficiently high resolution (minimum 1000 pixels width/height, or a resolution of 300 dpi or higher). Common formats are accepted, however, TIFF, JPEG, EPS and PDF are preferred.
- All Figures, Schemes and Tables should be inserted into the main text close to their first citation and must be numbered following their number of appearance (Figure 1, Scheme I, Figure 2, Scheme II, Table 1, *etc.*).
- All Figures, Schemes and Tables should have a short explanatory title and caption.
- All table columns should have an explanatory heading. To facilitate the copy-editing of larger tables, smaller fonts may be used, but no less than 8 pt. in size. Authors should use the Table option of Microsoft Word to create tables.
- Authors are encouraged to prepare figures and schemes in color (RGB at 8-bit per channel). There is no additional cost for publishing full color graphics.

Appendix B

Proof of Acceptance (Article 2)



African Zoology - Decision on Manuscript ID TAFZ-2019-0138.R2: Accept

African Zoology <onbehalfof@manuscriptcentral.com>
to me, kerryh26

Feb 17, 2020, 3:38 PM

17-Feb-2020

Dear Miss Greyvenstein:

Ref: The charismatic praying mantid: A gateway for insect conservation.

We are pleased to accept your paper in its current form, which will now be forwarded to the publisher for copy editing and typesetting.

In due course you will receive a publication agreement to sign and, once the article has been laid out by the publishers, a set of proofs for checking.

If your paper introduces new zoological taxa or nomenclatural acts at family-group level or below, you are now required to register your paper with ZooBank. You will be required to insert the generated ZooBank ID (LSID) during the publication process, when returning your proof feedback to Taylor & Francis' production department. Please go to http://www.zoobank.org/register to complete this task. You will need your article DOI to register, which will be sent to you when your paper is entered into Taylor & Francis' Central Article Tracking System. After publication, you will need to amend the ZooBank record of your paper to reflect the date of publication.

Thank you for your contribution to African Zoology and we look forward to receiving further submissions from you.

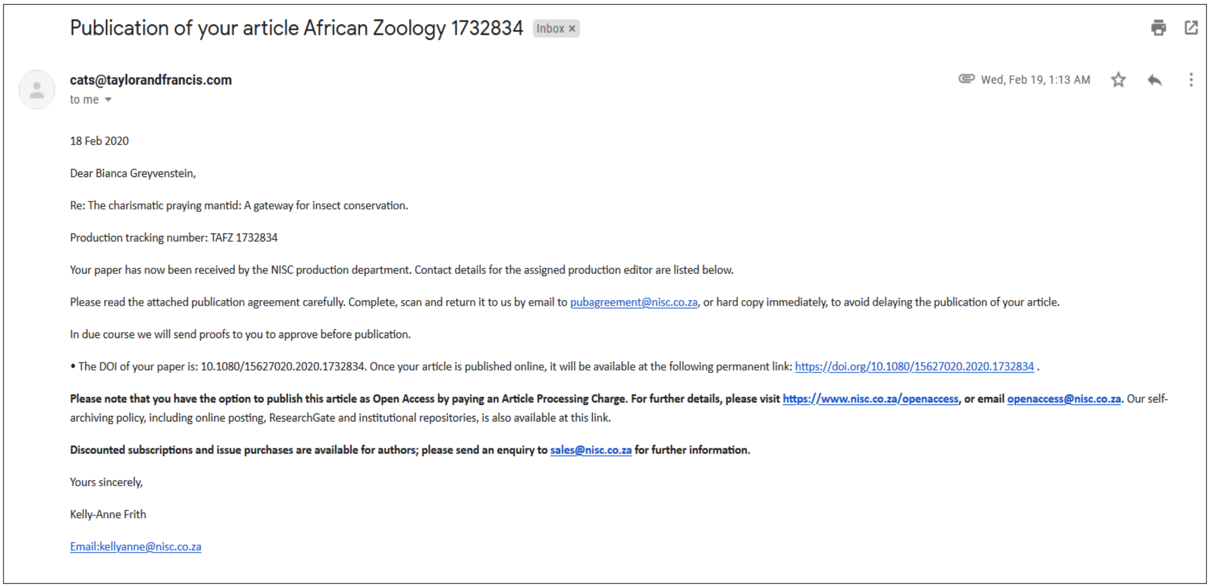
Sincerely

Editor-in-Chief
African Zoology

Reviewer(s)' Comments to Author:

Editor's Comments to Author:

Associate Editor
Comments to the Author:
Thank you very much for addressing all of the comments. We are pleased to accept your paper in its current form.



Publication of your article African Zoology 1732834

cats@taylorandfrancis.com
to me

Wed, Feb 19, 1:13 AM

18 Feb 2020

Dear Bianca Greyvenstein,

Re: The charismatic praying mantid: A gateway for insect conservation.

Production tracking number: TAFZ 1732834

Your paper has now been received by the NISC production department. Contact details for the assigned production editor are listed below.

Please read the attached publication agreement carefully. Complete, scan and return it to us by email to pubagreement@nisc.co.za, or hard copy immediately, to avoid delaying the publication of your article.

In due course we will send proofs to you to approve before publication.

- The DOI of your paper is: 10.1080/15627020.2020.1732834. Once your article is published online, it will be available at the following permanent link: https://doi.org/10.1080/15627020.2020.1732834 .

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Discounted subscriptions and issue purchases are available for authors; please send an enquiry to sales@nisc.co.za for further information.

Yours sincerely,

Kelly-Anne Frith

Email:kellyanne@nisc.co.za

Instructions to Authors (excerpt) (Article 2)

Journal: *AFRICAN ZOOLOGY (Taylor & Francis)*

Instructions to Authors

African Zoology publishes original scientific contributions that focus principally on African fauna in terrestrial, freshwater, and marine ecosystems. Research from other regions that advances practical and theoretical aspects of zoology will be considered. Rigorous question-driven research in all aspects of zoology will take precedence over descriptive research. The journal publishes full-length papers (5 000 to 7 500 words), critical reviews (up to 10 000 words), short communications (2 500 words), letters to the editors and book reviews. Contributions based on purely observational, descriptive or anecdotal data will not be considered.

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Research ethics policy: Authors are to clearly state, with reference number, in the methods and materials section that they accept and acknowledge that appropriate permits and ethical clearance for research on live vertebrates and higher invertebrates (cephalopods and decapods) or use of 'human subjects' (eg. participants in surveys) were sought and approved by the authorising body responsible for such permits and ethical clearance certificates. Details of collection permits from appropriate local/national authorities are required if collections are within nature conservation areas, including marine habitats. If the submission is from a country where no such permitting and clearance is required, a statement to this effect must be included. Irrespective of the availability of the permits and clearances, the editorial team of African Zoology reserves the right to reject papers on ethical grounds should valid concerns emerge from the contents of the research paper.

Submission: Manuscript submissions should be made online at the *African Zoology* ScholarOne Manuscripts site at **http://mc.manuscriptcentral.com/tafz**. New users should first create an account. Once a user is logged onto the site, submissions should be made via the Author Centre. Manuscripts must adhere to the format criteria described below, and papers failing to do so will be returned to authors to be corrected before being reviewed.

Manuscript presentation: Submitted manuscripts should contain the following sections, each in separate files:

Title page: The title (max. 20 words) should be a concise description of the article content. Author names must appear **only** on the title page. This page should also include each author's names (full first name and surname), each author's full institutional affiliation, the e-mail address of the designated corresponding author.

Abstract: The abstract is a concise statement of the scope of the work, the principal findings and the conclusions and should not exceed 250 words. It should not contain references. Below the abstract, up to eight additional keywords or phrases (which are not already given in the title) should be listed in alphabetical order. Short communications also require brief abstracts (max. 200 words).

Main text: Papers should be structured around Introduction, Methods, Results and Discussion sections, where appropriate for the subject matter.

Format – Manuscripts should be prepared in MSWord. The headings and text should be presented in 12-point Arial or Calibri font. The text should use 1.5 line spacing, with no extra line spacing between paragraphs, and should not include text columns, creative formatting or additional fonts. Headings should be sentence case format and never numbered. There should be no more than three heading levels. Primary headings should be presented in **bold**, secondary headings in ***bold and italics***, and tertiary headings in *italics*. Avoid footnotes. Tables and figures (graphs, photographs or scanned images) should not be part of the text but prepared as separate file but please include a list of figure captions at the end of the manuscript.

Editorial style – Manuscripts should be written in clear English (UK spelling). Consult the Oxford English Dictionary for spelling, capitalisation, hyphenation and abbreviation conventions. Consult a copy of the journal for general style conventions. The guideline document **Presenting Mathematical and Statistical Data,** available from the Journal's Instructions to Authors webpage*, clarifies conventions for this aspect of data presentation. Statistics in text should include sufficient information and permit the reader to corroborate the analysis, therefore report the full test statistic. Authors are urged to accurately disclose measures of variability, uncertainty, measurement error, etc. Unusual statistical procedures need to be explained in sufficient detail, including references if appropriate, for the reader to reconstruct the analysis.

Naming conventions – Scientific names should be given in full in the text when first mentioned. Authors should consult taxonomic authorities such as the *Bulletin of Zoological Nomenclature*, the *International Code of Zoological Nomenclature* and the *Nomenclator Zoologicus*. Taxonomic authorities should follow the name of the taxon without intervening punctuation and should not be abbreviated. If the year is added, a comma must separate the author's name and year. All species collected in the course of the study should include a species concept, for example: *Pygospio elegans* Claparède, 1863 sec. Day (1967), where sec. is the abbreviation of the Latin *secundum*, meaning 'according to', and Day (1967) represents the source of the concept or method of identification. When multiple species are named, this information should be tabulated. These identifications should be considered part of the results. Methods of identification (names of taxonomists or identifiers and identification manuals, keys or monographs) must be listed in the methodology and cited in the reference list. Please see editorial (https://doi.org/10.1080/15627020.2018.1532138). For taxonomic descriptions, authors must register new scientific names in ZooBank (http://zoobank.org). Please insert the accession number(s) after the keywords in your manuscript.

Example:

This article is registered in ZooBank under: urn:lsid:zoobank.org:pub:
69A163E0-822D-4 BC5-B230-ED5F1586E513
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Pseudopolydora eriyali: urn:lsid:zoobank.org:act:A63B4F2A-4D72-4FEE-A37F-E2EFC0FADE27

Voucher specimens – Authors of taxonomic works should deposit voucher specimens in an established permanent collection. This collection should be cited in the publication. All nucleic acid sequences should be placed in Genbank and accession numbers included in the manuscript.

Referencing: Multiple citations in the text must be separated by semicolons and cited chronologically in the form (Whitfield 1998, 2005; Gibson and Davis 2012). If there is more than one citation with the same publication year, these should be listed alphabetically. If previously published work is quoted directly, the citation must include the author, year of publication, and page number as in (Pringle 2013, p. 63). If more than two authors are cited in a reference, use only the name of the first author followed by 'et al'. For presenting the full list of references at the end of the manuscript, please consult our guide **Reference Exemplars for Authors** available at the Journal's Instructions to Authors page*. The reference list should be in alphabetical order by first author, and include all the authors of a given reference (do not use 'et al.' in the list); likewise, use full journal titles. URLs may be cited only for references that are not available in print (such as a webpage) or ones that link to hard-to-find sources (e.g. municipal document), and these URLs must be up-to-date at the time of submission. Include DOIs only for articles without complete bibliographic details, such as articles published online early and not paginated and assigned to a volume or issue.

Example reference list:

Allanson BR, Baird D, Heydorn AE. 1999. Perspectives. In: Allanson BR, Baird D (eds), *Estuaries of South Africa*. Cambridge: Cambridge University Press. pp 321–327.

IUCN (International Union for Conservation of Nature). 2012. *2012 IUCN Red List of threatened species*. Available at http://www.iucnredlist.org [accessed 18 January 2013].

Vergara P, Aguirre JI, Fernández-Cruz M. 2007. Arrival date, age and breeding success in White Stork *Ciconia ciconia*. *Journal of Avian Biology* 38: 573–579.

Tables and Figures: Tables and figures should contain only information directly relevant to the content of the paper. Each table and figure should be numbered (arabic numerals), must include a full, stand-alone caption, and each must be sequentially mentioned in the text. Highly stylised formatting should be avoided. Tables may use thin, horizontal lines but should not include cells with shading. Authors must ensure that their figures conform to the style of the journal. Pay particular attention to line thickness, font and figure proportions, taking into account the Journal's printed page size (210 x 275 mm). Costs of redrawing figures may be charged. Please refer to **Figure Guidelines for Authors: format, style and technical considerations** available from the Journal's Instructions to Authors webpage*. For digital photographs or scanned images the resolution should be at least 300 dpi for colour or greyscale artwork and a minimum of 600 dpi for black line drawings. These can be saved (in order of preference) in PSD, JPEG, PDF or EPS format. Graphs, charts or maps can be saved in AI, PDF or EPS format. MS Office files (Word, Powerpoint, Excel) are also acceptable but DO NOT EMBED Excel graphs or Powerpoint slides in a MS Word document, rather send the original Excel or Powerpoint files. More detailed technical information is given in **Figure Guidelines for Authors**.

Page Charges: *African Zoology* levies the following page charges: South African and African contributors – R150 per page (ex VAT); international contributors - US$25 per page. Non-essential colour pages will be charged at R900 (ex VAT) per page for African contributors and US$150 per page for contributors from elsewhere. Authors who do not receive subsidies from their institutions or do not have access to publication funding will be eligible to apply to the publisher for a full waiver, excluding colour charges.

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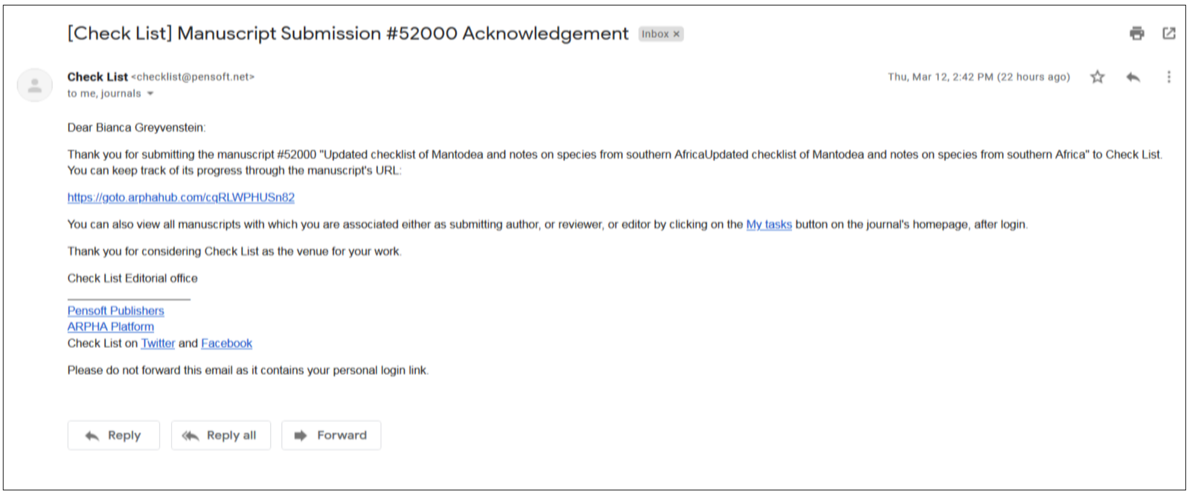
APPENDIX C

Proof of submission (Article 3)



[Check List] Manuscript Submission #52000 Acknowledgement

Check List <checklist@pensoft.net>
to me, journals
Thu, Mar 12, 2:42 PM (22 hours ago)

Dear Bianca Greyvenstein:

Thank you for submitting the manuscript #52000 "Updated checklist of Mantodea and notes on species from southern AfricaUpdated checklist of Mantodea and notes on species from southern Africa" to Check List. You can keep track of its progress through the manuscript's URL:

https://goto.arphahub.com/cqRLWPHUSn82

You can also view all manuscripts with which you are associated either as submitting author, or reviewer, or editor by clicking on the My tasks button on the journal's homepage, after login.

Thank you for considering Check List as the venue for your work.

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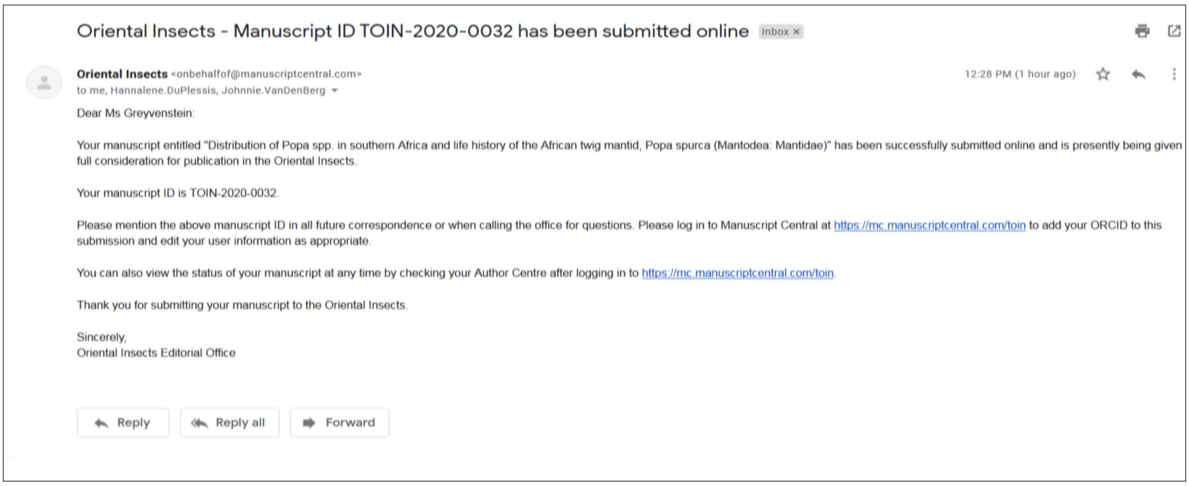
Proof of submission (Article 4)



Oriental Insects - Manuscript ID TOIN-2020-0032 has been submitted online

Oriental Insects <onbehalfof@manuscriptcentral.com>
to me, Hannalene.DuPlessis, Johnnie.VanDenBerg
12:28 PM (1 hour ago)

Dear Ms Greyvenstein:

Your manuscript entitled "Distribution of Popa spp. in southern Africa and life history of the African twig mantid, Popa spurca (Mantodea: Mantidae)" has been successfully submitted online and is presently being given full consideration for publication in the Oriental Insects.

Your manuscript ID is TOIN-2020-0032.

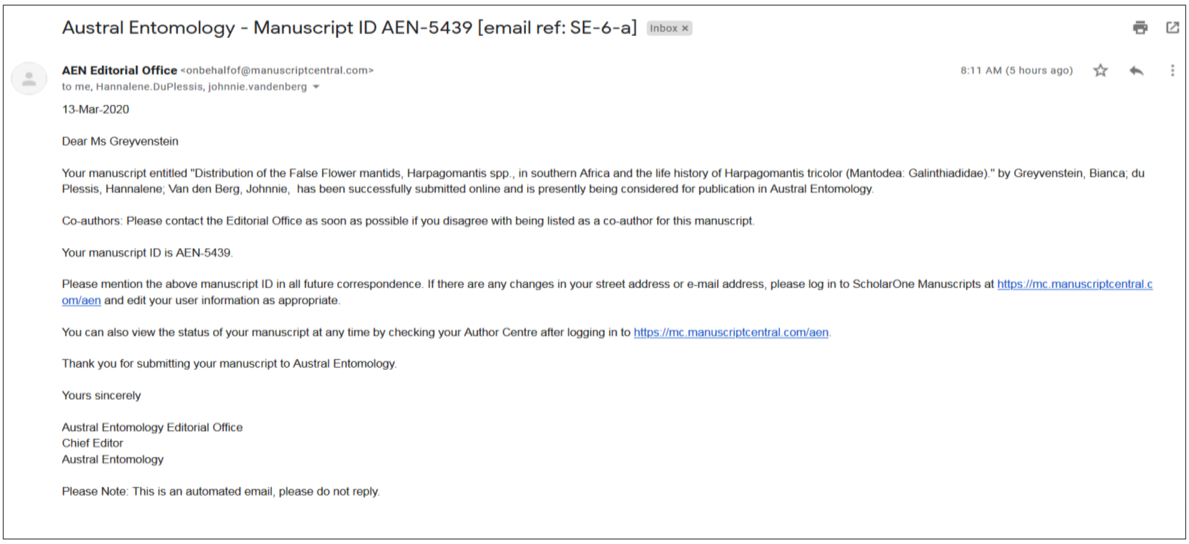
Please mention the above manuscript ID in all future correspondence or when calling the office for questions. Please log in to Manuscript Central at https://mc.manuscriptcentral.com/toin to add your ORCID to this submission and edit your user information as appropriate.

You can also view the status of your manuscript at any time by checking your Author Centre after logging in to https://mc.manuscriptcentral.com/toin.

Thank you for submitting your manuscript to the Oriental Insects.

Sincerely,
Oriental Insects Editorial Office

Proof of submission (Article 5)



Austral Entomology - Manuscript ID AEN-5439 [email ref: SE-6-a]

AEN Editorial Office <onbehalfof@manuscriptcentral.com>
to me, Hannalene.DuPlessis, johnnie.vandenberg
8:11 AM (5 hours ago)

13-Mar-2020

Dear Ms Greyvenstein

Your manuscript entitled "Distribution of the False Flower mantids, Harpagomantis spp., in southern Africa and the life history of Harpagomantis tricolor (Mantodea: Galinthiadidae)." by Greyvenstein, Bianca; du Plessis, Hannalene; Van den Berg, Johnnie, has been successfully submitted online and is presently being considered for publication in Austral Entomology.

Co-authors: Please contact the Editorial Office as soon as possible if you disagree with being listed as a co-author for this manuscript.

Your manuscript ID is AEN-5439.

Please mention the above manuscript ID in all future correspondence. If there are any changes in your street address or e-mail address, please log in to ScholarOne Manuscripts at https://mc.manuscriptcentral.com/aen and edit your user information as appropriate.

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Thank you for submitting your manuscript to Austral Entomology.

Yours sincerely

Austral Entomology Editorial Office
Chief Editor
Austral Entomology

Please Note: This is an automated email, please do not reply.

Instructions to Authors (excerpt) (Article 3)

Journal: Check List (Pensoft)

Authors' Guidelines

Main text

Manuscript Types, Templates, Spacing, Fonts, and Page Numbering

The three main types of published articles are:

- **Distribution summary** of a supraspecific taxon (e.g. family, genus) in a broad geographic area (e.g., hemisphere, country, biome), as a review of the distribution of a taxon in the given area.
- **Annotated list of Species**, of a given taxon in a strict geographic area, with comments and illustrations on the identifications, based on original data.
- **Notes on the Geographic Distribution**, reporting new records of one or more species while providing a complete overview on the known distribution of the treated taxa.

Title

The title should be in a sentence case (only scientific, English common names, and geographic or personal names should be with a first capital letter, i.e. *Elater ferrugineus* L., Cuban Greater Funnel-eared Bat, Germany), and should include an accurate, clear, and concise description of the reported work, avoiding abbreviations. The higher taxa within the title should be separated with commas and not with a semicolon or colon, e.g.: (Coleoptera, Elateridae, Elaterini). Include authority (and year for animals) of publication of species- or genus-level taxa.

Authors and Affiliations

Provide the complete names of all authors as they should appear in the published work. One of the authors should be designated as the corresponding author. It is the corresponding author's responsibility to ensure that the author list, and the individual contributions to the study are accurate and complete. If the article has been submitted on behalf of a consortium, all consortium members and their affiliations should be listed after the Acknowledgements section.

Authors' affiliations must include the full mailing addresses for correspondence, including e.g., institutional affiliation (e.g. university, institute), street address or post office box number, city, state/province (when applicable), and country.

Abstract

Up to 150 words for ALS and DS; up to 90 words for NGD. In-text literature citations should not be present. Avoid acronyms and abbreviations, but explain these if needed. Include authority (and year for animals) of publication of species- or genus-level taxa.

Keywords

Up to seven (7) keywords, in alphabetical order and separated by commas, should be included in the text following the abstract. Key words must be different than what already appears in the title.

Body Text

Use American or British English, but be consistent. Keep the whole text left-aligned. All lines must be numbered consecutively on the left margin of the page. Write with precision, clarity, and economy, and whenever appropriate in active voice and first person. Avoid the use of parenthetical comments. Do not use italics or bold for emphasis. This journal discourages the use of quotation marks except for direct quotations, words defined by the author, and words used in unusual contexts. Quotations should be embedded in the text and enclosed in double quotation marks ("). Single quotation marks are to be used only for a quotation that occurs within another quotation.

Headings and subheadings

Main headings: The body text should be subdivided into six main sections. Use appropriate template (see above) and the following mandatory headings: **Introduction**, **Methods**, **Results**, **Discussion**, **Acknowledgements**, **References**. These headings need to be in bold font on a separate line and start with a first capital letter. Please do not number headings or subheadings.

- **Introduction** − The motivation or purpose of your research should appear in the Introduction, providing some of the historical basis for those questions. Be concise.
- **Methods** − A clear description of your experimental design and sampling procedures are especially important. Include protocols for specimen collection, permits for collection, and specialized methods for identification. If you list a product (e.g., animal food, analytical device), supply the name and location of the manufacturer. Give the model number for equipment used. Explicitly indicate where the voucher specimens were deposited (give acronyms for collections but not the details of records and vouchers). Supply complete citations, including author or editor, title, year, publisher, and version number, for computer software mentioned in your article.
- **Results** − Results should be stated concisely and without interpretation. Do not present Methods or Discussion here!
  For an NGD with 1 species (optional), add species name and other taxonomic information. For an NGD with more than 1 species, minimally include the name of the species here (other taxonomic information optional). For NGDs, this section should include a subsection called "**New records**" (or similar: Materials examined, for example). List each of your new records here. Call this section Materials examined if this is more suitable. Call this subsection "Materials examined" if more appropriate. Include any additional results, as separate paragraphs, that do not easily fit in the above list of new records, e.g. observational notes that are more easily presented in sentence form. Include a subsection called "**Identification**"; this will show how your recognized the species. You may prepare a full description, but more important is that you compare and contrast your specimens to the species that you claim it to be and with similar or related taxa. You might also add results of molecular analysis here. If your NGD includes two or more species, repeat for each.
  For an ALS or DS, results follow the same pattern as for NGD (but see Taxa Treatment in these Guidelines). You can optionally add other subsections: e.g. Distribution, Remarks, Taxonomic remarks, Habitat, etc., for each species. Please give each section a subheading in bold font.
- **Discussion** − Focus on the rigorously supported aspects of your study. Carefully differentiate the results of your study from data obtained from other sources. Interpret your results, relate them to the results of previous research, and discuss the implications of your results or interpretations. In case of new records, previous research consists in all previously known records for that given species—cite, comment and discuss them, highlighting why your new data is relevant. Clearly summarize the importance of your new record(s): e.g. distance and direction from nearest previous records, occurrence in a country, state, biome, etc.
  Point out results that do not support speculations or the findings of previous research, or that are counterintuitive. You may choose to include a subsection in which you pursue new ideas suggested by your research, compare and contrast your research with findings from other

systems or other disciplines, pose new questions that are suggested by the results of your study, and suggest ways of answering these new questions.

- **Acknowledgements** – Include people/organizations who provided help, guidance, or financial assistance. Consider acknowledging the reviewers, even when anonymous.
- **Authors' Contributions** – Include if there are 2 or more authors. Briefly describe authors' roles in the study, using initials to identify authors.
- **References** − The list of References should be included after the final section of the main article body. Authors are requested to include links to online sources of articles, especially DOIs (digital online identifiers), whenever possible!
- **Appendix** – Rarely, there is a need for an appendix. Materials examined should be presented in Results. However, for example, the background data for producing a distributional map might be presented as an appendix (or as supplemental data).

- **Supplemental Data** – If you plan to include supplemental data (separate file published online), include a statement that supplemental data is available and a brief description of the data.

Subordinate headings

Subordinate headings (e.g. **New records**, **Identification**), should be left-justified, bold, and in a regular sentence case. All subordinate headings should be on the same line as the subordinate text.

Capitals

First capital letters should be used only in the beginning of a sentence, in proper names, English common names of species, and in headings and subheadings, as well as to indicate tables, graphs and figure(s) within the text. (German-language text, such as titles of books, require all nouns to be capitalized.) Scientific names should be written according to their specific nomenclatural code. Software programs should be written with capital letters (e.g., ANOVA, MANOVA, PAUP).

Italicization/Underlining

Scientific names of species and genera and symbols for variables and constants (except for Greek letters), such as *p, F, U, T, N, r,* but not for SD (standard deviation), SE (standard error), DF (degrees of freedom) and NS (non significant) should be italicized. These symbols in illustrations and equations should be in italics to match the text. Italics should not be used for emphasis, and not in abbreviations such as e.g., i.e., et al., etc., cf. Underlining of any text is not acceptable.

Abbreviations/Contractions

Abbreviations should be followed by "." (full stop or period; for instance: i.e., e.g., cf., etc.). Contractions are not followed by a "."; that is, you shouldn't add a full stop at the end of abbreviated words if the last letter of the abbreviation is the same as the last letter of the full word. Figs, ca (circa), Eds, Dr, and Mr are examples. All SI and similar units, for instance mm, cm, m, s, L, should be written without full stop.

On the use of dashes

(1) Hyphens are used to link words such as personal names, some prefixes and compound adjectives (the last of which vary depending on the style manual in use).

(2) En-dash or en-rule (the length of an 'n') is used to link spans. In the context of our journal en-dash should be used to link numerals, sizes, dates and page numbers (e.g., 1977–1981; figs 5–7; pp. 237–258); geographic or name associations (Murray–Darling River; a Federal–State agreement); and character states combinations such as long–pubescent or red–purple.

(3) Em-dash or em-rule (the length of an 'm') should be used rarely for introducing a subordinate clause in the text that is often used much as we use parentheses; in contrast to parentheses an em-dash can be used alone. Check List typically uses the em-dash to separate names from references in synonym lists when the reference is a subsequent use of the name (i.e. not the original description).

En-dashes and em-dashes should not be spaced.

Appendices and Supplementary files

An appendix is preferrable to Supplementary files because the Appendix is part of the published PDF and downloaded as a single file. Supplementary files are detached files that must be downloaded separately. Identify tables in appendices as Table A1, A2, etc. and figures as Figure A1, A2, etc.

Larger datasets can be uploaded separately as Supplementary Files. Tabular data provided as supplementary files can be uploaded as an Excel spreadsheet (.xls), as an OpenOffice spreadsheets (.ods) or comma separated values file (.csv). As with all uploaded files, please use the standard file extensions.

References

Please format the references properly. Your manuscript may be returned if references are incomplete or not well formatted. It is desirable to add a DOI (digital object identifier) for either the full-text or title and abstract of the article as an addition to traditional volume and page numbers. Please use the following style for the reference list (or download the *Pensoft EndNote style*—reference lists created with Endnote may require minor corrections): here

Published Papers

Polaszek A, Alonso-Zarazaga M, Bouchet P, Brothers DJ, Evenhuis NL, Krell FT, Lyal CHC, Minelli A, Pyle RL, Robinson N, Thompson FC, van Tol J (2005) ZooBank: the open-access register for zoological taxonomy: technical discussion paper. Bulletin of Zoological Nomenclature 62: 210–220.

With DOI

Martel C, Salas M (2018) *Telipogon jucusbambae* (Orchidaceae), the rediscovery of a marvelous *Telipogon* from Peru. Check List 14 (1): 189–193. https://doi.org/10.15560/14.1.189

Accepted, In Press Papers

Same as above, but "(in press)" appears instead the year in parentheses.

Book chapters

Mayr E (2000) The biological species concept. In: Wheeler QD, Meier R (Eds) Species concepts and phylogenetic theory: a debate. Columbia University Press, New York, 17–29.

Books

Goix N, Klimaszewski J (2007) Catalogue of Aleocharine rove beetles of Canada and Alaska. Pensoft Publishers, Sofia/Moscow, 166 pp.

Note for book titles: In English, capitalize the first word and proper nouns only; in German, capitalize all nouns; in other languages, capitalize where required, using minimal capitalizaiton.

Book with institutional author

International Commission on Zoological Nomenclature (1999) International Code of Zoological Nomenclature. 4th edition. The International Trust for Zoological Nomenclature, London, xxiv + 306 pp.

PhD/Master thesis

Gould SJ (1967) Pleistocene and Recent history of the subgenus *Poecilozonites* (*Poecilozonites*) (Gastropoda: Pulmonata) in Bermuda: an evolutionary microcosm. PhD dissertation, Columbia University, New York, 444 pp.

Online publication (not journal articles)

Australian Invasive Species Program (2015) http://www.environment.gov.au/biodiversity/invasive/weeds/index.html. Accessed on: 2015-8-25.

GISP (2005) América do Sul Invadida: a crescente ameaça das espécies exóticas invasoras. Global Invasive Species Programme, Cape Town, 80 pp. http://www.institutohorus.org.br/download/gispSAmericapo.pdf. Accessed on: 2013-10-27.

Ordering references: All references should be ordered alphabetically.

If the references have **the same first author and a varying number of co-authors,** the ordering should be based on the number of co-authors starting with the lowest as follows:

Smith J (2018) Article Title. Journal Name 1: 1-10. https://doi.org/...

Smith J, Gunderson A (2017) Article Title. Journal Name 1: 10-20. https://doi.org/...

Smith J, Gunderson A, Brock B (2015) Article Title. Journal Name 1: 20-30. https://doi.org/...

In the occasion of **more than one article from the same first author** within any of the categories above, the references should be ordered chronologically.

If both the **first author and year of publication match** within the categories above, the references are distinguished by adding the letters 'a', 'b', 'c', etc. after the year of publication and this marking is followed in the in-text citations, respectively.

Use square brackets [ ] to distinguish data that has been interpreted by the author e.g., coordinates interpreted from a locality, or translations of label data:

Instructions to Authors (excerpt) (Article 4)

Journal: Oriental Insects (Taylor & Francis)

Instructions for authors

Thank you for choosing to submit your paper to us. These instructions will ensure we have everything required so your paper can move through peer review, production and publication smoothly. Please take the time to read and follow them as closely as possible, as doing so will ensure your paper matches the journal's requirements.

About the Journal

Oriental Insects is an international, peer-reviewed journal publishing high-quality, original research. Please see the journal's Aims & Scope for information about its focus and peer-review policy.

Please note that this journal only publishes manuscripts in English.

Oriental Insects accepts the following types of article: original articles, review articles.

Peer Review

Taylor & Francis is committed to peer-review integrity and upholding the highest standards of review. Once your paper has been assessed for suitability by the editor, it will then be single blind peer reviewed by independent, anonymous expert referees. Find out more about what to expect during peer review and read our guidance on publishing ethics.

Preparing Your Paper

Structure

Your paper should be compiled in the following order: title page; abstract; keywords; main text introduction, materials and methods, results, discussion; acknowledgments; declaration of interest statement; references; appendices (as appropriate); table(s) with caption(s) (on individual pages); figures; figure captions (as a list).

Word Limits

Please include a word count for your paper. There are no word limits for papers in this journal.

Style Guidelines

Please refer to these quick style guidelines when preparing your paper, rather than any published articles or a sample copy.

- Please use British (-ise) spelling style consistently throughout your manuscript.
- Please use single quotation marks, except where 'a quotation is "within" a quotation'. Please note that long quotations should be indented without quotation marks.
- Section headings should be concise and numbered sequentially, using a decimal system for subsections.
- Authors are strongly encouraged to include an ORCiD with their manuscript submission or revision. For more information on how to register for an ORCiD click here.

- If necessary you will be prompted to register your paper with ZooBank at proof stage in order to validate electronic publication of your article. Individual new taxa need not be registered before publication; this can be done subsequently should you wish. After publication, you will need to amend your ZooBank record of your paper to reflect the date of publication. **Zoobank ID -** For papers introducing new zoological taxa at family-group level or below. No heading. Indented left and right. Full url (including http://www).
  http://www.zoobank.org/urn:lsid:zoobank.org:pub:unique-alpha-numeric-id
- The subheading *Comments* is preferred over Remarks. Please change the latter to the former if used.
- If some of the above headings are missing that is fine, but please ensure the headings that are present adhere to the above order.
- In *Material examined* subsections m should be used for male and f for female (i.e. don't use ?and ? symbols).
- Text *Type species:* should always be set in italics.
- All subheadings in species descriptions should have text continuing below.

When a paper uses a 'Key' to the species, please don't break this section of text with figures or tables – these should be placed after the Key section ends. Each line should be adjusted to the right (dots between the last word and species name must be multiplied to equal adjustment of all lines to the right). Generic name should be abbreviated and the author and a year omitted so not *"Musca domestica* Linnaeus, 1758" but *"M. domestica"*
Left margin of a key should not be indented. The Arabic numerals indicating thesis and dashes "-" indicating antithesis should start evenly under each other

Monographs:
Oriental Insects accepts monograph submissions. Monographs should follow the same sections and format as Research Articles, with the distinction that there is no limit for the number of words. Monographs will be subject to an article fee on acceptance payable by the authors, which will be quoted on an individual article basis according to the number of pages (usually minimum of £1,000).

References

Please use this reference guide when preparing your paper with the following amendments:

- **Journal titles must be written in full (not abbreviated).**
- In whole book references (not book chapter references) reports, etc., the total pages of the book/report should be given at the end of the reference, e.g.: Schott J, Priest J. 2002. Leading antenatal classes: a practical guide. 2nd ed. Boston (MA): Books for Midwives. 275 pp.
- Formally unpublished works as dissertations or reports should rather not be included in the references.

Checklist: What to Include

1. **Author details.** All authors of a manuscript should include their full name and affiliation on the cover page of the manuscript. Where available, please also include ORCiDs and social media handles (Facebook, Twitter or LinkedIn). One author will need to be identified as the corresponding author, with their email address normally displayed in the article PDF (depending on the journal) and the online article. Authors' affiliations are the affiliations where the research was conducted. If any of the named co-authors moves affiliation during

the peer-review process, the new affiliation can be given as a footnote. Please note that no changes to affiliation can be made after your paper is accepted. Read more on authorship.

2. Should contain an unstructured abstract of 200 words.
3. You can opt to include a **video abstract** with your article. Find out how these can help your work reach a wider audience, and what to think about when filming.
4. No more than 5 **keywords**. Read making your article more discoverable, including information on choosing a title and search engine optimization.
5. **Funding details.** Please supply all details required by your funding and grant-awarding bodies as follows:
   For single agency grants
   This work was supported by the [Funding Agency] under Grant [number xxxx].
   For multiple agency grants
   This work was supported by the [Funding Agency #1] under Grant [number xxxx]; [Funding Agency #2] under Grant [number xxxx]; and [Funding Agency #3] under Grant [number xxxx].
6. **Disclosure statement.** This is to acknowledge any financial interest or benefit that has arisen from the direct applications of your research. Further guidance on what is a conflict of interest and how to disclose it.
7. **Data availability statement.** If there is a data set associated with the paper, please provide information about where the data supporting the results or analyses presented in the paper can be found. Where applicable, this should include the hyperlink, DOI or other persistent identifier associated with the data set(s). Templates are also available to support authors.
8. **Data deposition.** If you choose to share or make the data underlying the study open, please deposit your data in a recognized data repository prior to or at the time of submission. You will be asked to provide the DOI, pre-reserved DOI, or other persistent identifier for the data set.
9. **Supplemental online material.** Supplemental material can be a video, dataset, fileset, sound file or anything which supports (and is pertinent to) your paper. We publish supplemental material online via Figshare. Find out more about supplemental material and how to submit it with your article.
10. **Figures.** Figures should be high quality (1200 dpi for line art, 600 dpi for grayscale and 300 dpi for colour, at the correct size). Figures should be supplied in one of our preferred file formats: EPS, PS, JPEG, GIF, or Microsoft Word (DOC or DOCX). For information relating to other file types, please consult our Submission of electronic artwork document.
    - Within the text figures must be cited as (Fig. 1A) or (Fig. 1A-C) or (Fig. 1A-C, E) or (Figs 1A-B, 2A)
    - In figure captions, figure parts (if present) should be labelled:

      Figure 1A-C. Male genitalia of a species. A, xxxxxxxx; B, yyyyyyyy; C, zzzzzzzz.

      (i.e. no parentheses around figure part labels (or similar) should be used). The scale bar indicator should always be an en dash, not an equals sign (i.e. Scale bar – 1 mm).
11. **Tables.** Tables should present new information rather than duplicating what is in the text. Readers should be able to interpret the table without reference to the text. Please supply editable files.
12. **Equations.** If you are submitting your manuscript as a Word document, please ensure that equations are editable. More information about mathematical symbols and equations.
13. **Units.** Please use SI units (non-italicized).

Instructions to Authors (excerpt) (Article 5)

Journal: Austral Entomology (Wiley Online Library)

1. SUBMISSION

Thank you for your interest in *Austral Entomology*. Please read the complete Author Guidelines carefully prior to submission. Note that submission implies that the content has not been published or submitted for publication elsewhere except as a brief abstract in the proceedings of a scientific meeting or symposium, or presented in a non-peer reviewed journal.

2. AIMS AND SCOPE

Austral Entomology is a scientific journal of entomology for the Southern Hemisphere. It publishes Original Articles that are peer-reviewed research papers from the study of the behaviour, biology, biosystematics, conservation biology, ecology, evolution, forensic and medical entomology, molecular biology, public health, urban entomology, physiology and the use and control of insects, arachnids and myriapods. The journal also publishes Reviews on research and theory or commentaries on current areas of research, innovation or rapid development likely to be of broad interest – these may be submitted or invited. Book Reviews will also be considered provided the works are of global significance. Manuscripts from authors in the Northern Hemisphere are encouraged provided that the research has relevance to or broad readership within the Southern Hemisphere. All submissions are peer-reviewed by at least two referees expert in the field of the submitted paper. Special issues are encouraged; please contact the Chief Editor for further information.

Austral Entomology is the official publication of the **Australian Entomological Society**, an incorporated non-profit Australian company limited by guarantee. Membership of the Society is open to any person interested in entomology in its broadest sense. Application forms are available from the Australian Entomological Society website (**http://www.austentsoc.org.au/**).

3. MANUSCRIPT CATEGORIES AND REQUIREMENTS

Austral Entomology publishes the following article types:

- Original Articles
- Reviews
- Book Reviews
- Editorials
- Symposium Overviews

Original Articles

Original Articles are peer-reviewed research papers from the study of the behaviour, biology, biosystematics, conservation biology, ecology, evolution, forensic and medical entomology, molecular biology, public health, urban entomology, physiology and the use and control of insects, arachnids and myriapods.

Please click on this link for further details on how Original Articles should be formatted: **Template for Original Articles**.

4. PREPARING YOUR MANUSCRIPT

You are strongly encouraged to download and follow the structure outlined in the templates for Original Articles and Taxonomic Articles. Use of these templates will make it much easier for you to prepare your paper in a manner conforming to the journal's requirements.

Style and Formatting

For submission, the manuscript should preferably be submitted as a single file, with the figures embedded as low resolution files. Tables and figures should be inserted at the end of the manuscript. Name the manuscript file as: **authorname.doc**.

- Submissions should be typed in 12 pt Times New Roman and have 1.5 line spacing.
- All margins should be set to 2.5 cm.
- The first paragraph under each heading is not indented; indent following paragraphs, with no blank line between paragraphs.
- Ensure that all mark-up (‘Track Changes’) done during manuscript preparation is removed (‘Accept All Changes’ on Reviewing Toolbar) so that reviewers have a clean copy on which to insert suggested changes and comments.

Abbreviations and Units

SI units (metre, kilogram etc.), as outlined in the latest edition of *Units, Symbols and Abbreviations: A Guide for Medical and Scientific Editors and Authors* (Royal Society of Medicine Press, London), should be used wherever possible. Give statistics and measurements in figures; that is, 10 mm, except where the number begins the sentence. When the number does not refer to a unit measurement, it is spelt out, except where the number is greater than nine. Use only standard abbreviations. Shorten the word ‘Figure’ to Fig. unless starting a sentence.

The journal uses Australian spelling and authors should therefore set the Language in MS Word to English (Australia) (accessible under the Tools menu in MS Word) and follow the latest edition of the Macquarie Dictionary. Manuscripts that do not conform to this requirement and the following format will be returned to the author prior to review for correction.

Parts of the Manuscript

Title page

The title page should contain:
(i) an informative title that contains the major key words. The title should contain the scientific name of the insect, with the order and family placed in parentheses;
(ii) the full names of the authors;
(iii) the author's institutional affiliations at which the work was carried out;
(iv) a short running title of less than 50 characters including spaces.
(iv) the email address of the author to whom correspondence about the manuscript should be sent.

Abstract

All manuscripts must include a brief but informative abstract intelligible without reference to the main text. It should not exceed 350 words and should describe the scope of the work and the main findings. Both common and scientific names of the insect should be included. Authorities to species names are not required except for taxonomic papers. References to scientific literature must not be included. Use the passive voice in the Abstract. DO NOT use the uninformative phrase ‘Results are discussed.’

Key Words

Up to 10 additional key words should be provided below the Abstract.

Main Text Sections

- *Introduction:* This section should include sufficient background information to set the work in context. The aims and goals of the manuscript should be clearly stated. The introduction should not contain findings or conclusions.

- *Materials and Methods:* This should be concise but provide sufficient detail to allow the work to be repeated by others.

- *Results:* This should be presented in a logical sequence in the text, tables and figures; repetitive presentation of the same data in different forms is not permissible. The results should not contain material appropriate to the Discussion.

- *Discussion:* This should consider the results in relation to any hypotheses advanced in the Introduction and place the study in the context of other work.

Acknowledgements

The source of financial grants and other funding must be acknowledged, including a frank declaration of the author's industrial links and affiliations. Financial and technical assistance may be acknowledged here. If tables or figures have been reproduced from another source, or copyright is not held by any of the authors, then written permission from the copyright holder must be mentioned in the Acknowledgements.

Ethical Considerations

Research permits

When the research is carried out in areas for which research permits are required (e.g. nature reserves or National Parks), or when it deals with organisms for which collection or import/export permits are required (e.g. protected species), the authors must clearly state these permits in the Acknowledgements.

Human/Animal Ethics

Where research is carried out involving humans or materials of human origin (e.g. blood sera, DNA), or involves the use of animals, the permit number and issuing body must be included in the Acknowledgements.

Conflict of Interest

The journal requires that all authors disclose any potential sources of conflict of interest. Any interest or relationship, financial or otherwise, which might be perceived as influencing an author's objectivity is considered a potential source of conflict of interest. These must be disclosed when directly relevant or indirectly related to the work that the authors describe in their manuscript. Potential sources of conflict of interest include but are not limited to patent or stock ownership, membership of a company board of directors, membership of an advisory board or committee for a company, the testing of a commercial product paid or sponsored by the manufacturer, distributor or seller of that product, and consultancy for or receipt of speaker's fees from a company, or paid travel to present the information at a conference. The existence of a conflict of interest does not preclude publication in this journal. It is the responsibility of the corresponding author to review this policy with all authors and to collectively list on the front page of the manuscript and in the manuscript (under the Acknowledgments), ALL pertinent commercial and other relationships. You are also required to state if no conflict of interests exist.

References

The Harvard (author, date) system of referencing is used.

- In the text give the author's name followed by the year in parentheses: Sago (2000).
- When reference is made to a work by three or more authors, the first name followed by *et al.* should be used: Powles *et al.* (1998).
- Within parentheses, groups of references should be cited in chronological order.
- Personal communication, unpublished data and publications from informal meetings are not to be listed in the reference list but should be listed in full in the text (e.g. A. Smith, 2000, unpublished data).
- Titles of journals should be given in full.
- If several manuscripts by the same author(s) and from the same year are cited, a, b, c etc. should be put after the year of publication.
- 'In press' should only be used to cite manuscripts actually accepted for publication in a journal. Citations such as 'manuscript in preparation' or 'manuscript submitted' are not permitted. Data from such manuscripts can only be mentioned in the text as 'unpublished data'.
- Pre-print publications are to be cited as websites, not cited as published papers because they have not been peer reviewed.
- References should be listed in alphabetical order at the end of the manuscript.
- Cite the names of all authors when there are six or fewer; when seven or more cite the first three plus *et al.*
- Authors are responsible for the accuracy of the references.
- References can be formatted using the **EndNote style** for AEN. Please click **AEN EndNote style** to access the style.

References should be listed in the following form:

Journal articles
North RC & Shelton AM. 1996. Ecology of Thysanoptera within cabbage fields. *Environmental Entomology* **15**, 520–526.

Books
Eberhard WG. 1985. *Sexual Selection and Animal Genitalia*. Harvard University Press, Harvard.

Chapters in books
Bray RA. 1994. The leucaena psyllid. In: *Forage Tree Legumes in Tropical Agriculture* (eds RC Gutteridge & HM Shelton) pp. 283–291. CAB International, Oxford.

Website
Bureau of Meteorology. 2014. Southern Oscillation Index Archives – 1876 to present. Available from: http://www.bom.gov.au/climate/current/soihtm1.shtml [Accessed 5 March 2014]

Tables

Tables must be constructed using the 'Table' function of your word processor and must not have the Enter key used in any cell. Tables should be self-contained and complement, but not duplicate, information contained in the text. Tables should be numbered consecutively in Arabic numerals. Each table should be presented on a separate page at the end of the text with a comprehensive but concise legend above the table. Tables should be double-spaced and vertical lines should not be used to separate columns. Column headings should be brief, with units of measurement in parentheses; all abbreviations should be defined in footnotes. Use superscript letters (not numbers) for footnotes and keep footnotes to a minimum. *, **, *** should be reserved for *P*-values. The table and its legend/footnotes should be understandable without reference to the text.

Figure Legends

Legends should be concise but comprehensive – the figure and its legend must be understandable without reference to the text. Include definitions of any symbols used and define/explain all abbreviations and units of measurement.

Figures

Only scientifically necessary illustrations should be included. Magnifications should be indicated using a scale bar on the illustration. Figures should be cited in consecutive order in the text.

Preparing Figures: Although we encourage authors to send us the highest-quality figures possible, for peer-review purposes we are happy to accept a wide variety of formats, sizes, and resolutions. Please note that it is preferable that line figures (e.g. graphs and charts) are supplied in black and white so that they are legible if printed by a reader in black and white.

Click here for the basic figure requirements for figures submitted with manuscripts for initial peer review, as well as the more detailed post-acceptance figure requirements.

Supporting Information

Supporting information is information that is complementary to the article but that provides greater depth and background. It is hosted online, and appears without editing or typesetting. It may include appendices, tables, figures, videos, datasets, etc. **Click here** for Wiley’s FAQs on supporting information.

Note, if data, scripts or other artefacts used to generate the analyses presented in the paper are available via a publicly available data repository, authors should include a reference to the location of the material within their paper.

Wiley Author Resources

Wiley Editing Services offers expert help with English Language Editing, as well as translation, manuscript formatting, figure illustration, figure formatting, and graphical abstract design – so you can submit your manuscript with confidence. Also, check out our resources for Preparing Your Article for general guidance about writing and preparing your manuscript. In particular, authors may benefit from referring to Wiley’s best practice tips on **Writing for Search Engine Optimization.**

APPENDIX D

Instructions to Authors (excerpt) (Article 6)

Journal: Insect Diversity and Conservation (Wiley Online Library)

Editorial Policy

Papers submitted to *Insect Conservation and Diversity* should be original research papers on aspects pertaining mainly to aspects of insect conservation and diversity. Papers concerning other arthropods will also be considered. Major reviews, minor reviews, techniques and methodology papers, short communications, commentaries, and thought- provoking forum-type articles on any aspect of insect conservation and/or diversity ranging from policy matters to conjecture based on a solid science base are all welcomed.

Types of Manuscript

Original Article

A report of research addressing a specific research question, including the methods used, the results of the research, and conclusions drawn from the research. Papers should be in clear concise English and should not normally exceed 7,000 words of text (excluding abstract and references), but longer papers of particular merit may be considered. Papers should be novel and of wide general interest to entomologists and ecologists, with a particular focus on insect diversity and/or insect conservation.

Short Communication

Short research reports that would not normally exceed 3,000 words. Manuscripts submitted as Short Communications should be novel and of wide general interest to entomologists. The type of material submitted as a Short Communication is flexible, with manuscripts describing (for example) natural history observations, or preliminary empirical or experimental findings of particular merit. A Short Communication should be a concise report of an independent line of research, which does not require a detailed, full-length paper.

Short, species-specific articles addressing or focusing on specific management of conservation issues of species of particular conservation interest may also be submitted as Short Communications.

Major Review

These should be a systematic review of the published literature addressing a specific research theme, including an exhaustive search of the literature to date (with or without a quantitative meta-analysis). In rare cases a more narrative review discussing a particular topic may be considered with appropriate justification. Word limits can be negotiated with the Editors based on the merits of the subject area, but would not normally exceed 12,000 words.

Minor Review

A short review of a highly topical subject area, usually covering the most recent literature on fast moving and important topics that merit rapid consideration and publication. These should not normally exceed 8,000 words.

Techniques & Methodology

We encourage Techniques and Methodology articles that describe, develop and test new methods or techniques in relevant fields of insect conservation and diversity. Manuscript formatting and style should follow the standard for Original Articles described above.

Forum & Policy

Essays on new ideas and perspectives that will appeal to a wide entomological audience. Policy forum essays are particularly encouraged, addressing political, social or management aspects of conservation entomology. These should not normally exceed 8,000 words.

Comment

We encourage constructive responses to recent papers in the journal, or highly topical articles in other journals. The aim should be to stimulate debate and new avenues for research enquiry, with the aim of clarifying and synthesizing competing hypotheses in controversial areas of broad entomological or ecological interest. Commentary articles would not normally exceed 3,000 words, except by negotiation with the Editors.

References

Authors must use the Harvard (author-date) system. The reference list should be in alphabetical order according to the author surnames. All authors' names and the full title of the article must be included. Journal and periodical titles should be given in full.

Only articles which have been published or accepted for publication may be included in the reference list. In the text, unpublished studies should be referred to as such, or as personal communication with the author's surname and initials. It is the author's responsibility to obtain permission from their colleagues to include their work as personal communication.

In the running text, citations should be made as per the following examples. For up to two authors, give the surnames separated by '&'. For more than two authors, give the surname of the first author followed by '*et al.*'

As part of the sentence: Fox (2013), or Stork & Hammond (2013), or Didham *et al*. (2013).

When in parentheses: (Didham *et al*., 2013; Fox, 2013; Stork & Hammond, 2013).

If the reference would require the same author abbreviation but different years: Leather *et al*. (2008, 2011) or (Leather *et al*., 2008, 2011).

1. ***Journal articles***

Fuller, R.J., Oliver, T.H. & Leather, S.R. (2008) Forest management effects on carabid beetle communities in coniferous and broadleaved forests: implications for conservation. *Insect Conservation and Diversity*, **1**, 242-252.

1. ***From books, or other non-serial publications***

Samways, M.J. (2005) Insect Diversity Conservation. Cambridge University Press, Cambridge, UK.

1. ***From reference book contributions***

Hunter, M.D. (1994) The search for pattern in pest outbreaks. *Individuals, Populations and Patterns in Ecology* (ed. by Foottit, R.G. & Adler, P.H.), pp. 443-448. Intercept, Andover, UK.

1. ***Work which has been accepted for publication***

Leather, S.R. (In press) Editorial. *Insect Conservation and Diversity*.

1. ***From websites***

Insect Conservation and Diversity (2014) *Insect Conservation and Diversity Author Guidelines*. <http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1752-4598/homepage/ForAuthors.html> 2nd April 2014.

Instructions to Authors (excerpt) (Article 7)

Journal: Journal of Insect Conservation (Springer)

Manuscript Submission

Manuscript Submission

Submission of a manuscript implies: that the work described has not been published before; that it is not under consideration for publication anywhere else; that its publication has been approved by all co-authors, if any, as well as by the responsible authorities – tacitly or explicitly – at the institute where the work has been carried out. The publisher will not be held legally responsible should there be any claims for compensation.

Title Page

Please use this **template title page** for providing the following information.

The title page should include:

- The name(s) of the author(s)
- A concise and informative title
- The affiliation(s) of the author(s), i.e. institution, (department), city, (state), country
- A clear indication and an active e-mail address of the corresponding author
- If available, the 16-digit ORCID of the author(s)

If address information is provided with the affiliation(s) it will also be published.

For authors that are (temporarily) unaffiliated we will only capture their city and country of residence, not their e-mail address unless specifically requested.

Abstract

Please provide an abstract of 150 to 250 words. The abstract should not contain any undefined abbreviations or unspecified references.

For life science journals only (when applicable)

Trial registration number and date of registration

Trial registration number, date of registration followed by “retrospectively registered”

Keywords

Please provide 4 to 6 keywords which can be used for indexing purposes.

Declarations

All manuscripts must contain the following sections under the heading 'Declarations'.

If any of the sections are not relevant to your manuscript, please include the heading and write 'Not applicable' for that section.

To be used for non-life science journals

Funding (information that explains whether and by whom the research was supported)

Conflicts of interest/Competing interests (include appropriate disclosures)

Availability of data and material (data transparency)

Code availability (software application or custom code)

Authors' contributions (optional: please review the submission guidelines from the journal whether statements are mandatory)

To be used for life science journals + articles with biological applications

Funding (information that explains whether and by whom the research was supported)

Conflicts of interest/Competing interests (include appropriate disclosures)

Ethics approval (include appropriate approvals or waivers)

Consent to participate (include appropriate statements)

Consent for publication (include appropriate statements)

Availability of data and material (data transparency)

Code availability (software application or custom code)

Authors' contributions (optional: please review the submission guidelines from the journal whether statements are mandatory)

Please see the relevant sections in the submission guidelines for further information as well as various examples of wording. Please revise/customize the sample statements according to your own needs.

Reference list

The list of references should only include works that are cited in the text and that have been published or accepted for publication. Personal communications and unpublished works should only be mentioned in the text. Do not use footnotes or endnotes as a substitute for a reference list.

Reference list entries should be alphabetized by the last names of the first author of each work. Order multi-author publications of the same first author alphabetically with respect to second, third, etc. author. Publications of exactly the same author(s) must be ordered chronologically.

- Journal article

  Gamelin FX, Baquet G, Berthoin S, Thevenet D, Nourry C, Nottin S, Bosquet L (2009) Effect of high intensity intermittent training on heart rate variability in prepubescent children. Eur J Appl Physiol 105:731-738. https://doi.org/10.1007/s00421-008-0955-8

  Ideally, the names of all authors should be provided, but the usage of “et al” in long author lists will also be accepted:

  Smith J, Jones M Jr, Houghton L et al (1999) Future of health insurance. N Engl J Med 965:325–329

- Article by DOI

  Slifka MK, Whitton JL (2000) Clinical implications of dysregulated cytokine production. J Mol Med. https://doi.org/10.1007/s001090000086

- Book

  South J, Blass B (2001) The future of modern genomics. Blackwell, London

- Book chapter

  Brown B, Aaron M (2001) The politics of nature. In: Smith J (ed) The rise of modern genomics, 3rd edn. Wiley, New York, pp 230-257

- Online document

  Cartwright J (2007) Big stars have weather too. IOP Publishing PhysicsWeb. http://physicsweb.org/articles/news/11/6/16/1. Accessed 26 June 2007

- Dissertation

  Trent JW (1975) Experimental acute renal failure. Dissertation, University of California

Always use the standard abbreviation of a journal’s name according to the ISSN List of Title Word Abbreviations, see

ISSN LTWA

If you are unsure, please use the full journal title.

For authors using EndNote, Springer provides an output style that supports the formatting of in-text citations and reference list.

Appendix E

Declaration of language editing

Language editing statement

To whom this may concern,

I, Prof. Johnnie Van den Berg, hereby declare that the thesis titled: “Distribution of Mantodea in South Africa and biological studies of selected species” by Bianca Greyvenstein has been edited for language correctness and spelling by some of the supervisors. No changes were made to the academic content or structure of this work.

J van den Berg

Prof. Johnnie Van den Berg Date: 12 March 2020