HUMAN NETWORKS OF TETRAPOD TRANSLOCATIONS IN THE WESTERN CAPE, SOUTH AFRICA: TRENDS AND POTENTIAL IMPACTS ON BIODIVERSITY

by

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ABSTRACT

Global trends show an increase in wildlife trade associated with the process of globalisation and increased international trade. In addition, biodiversity managers are increasingly turning to species translocations to achieve conservation goals. These human induced movements of wildlife have a number of potential impacts, one being the introduction of non-native species that may establish and become invasive. Although the underlying mechanisms are debated, it is accepted that invasive species are having detrimental effects on biodiversity worldwide. The exact nature of the wildlife trade, and the networks that facilitate it, have not been fully explored and in this thesis I aim to contribute to further understanding of this topic. I use conventional and network techniques to analyse translocation networks of tetrapods in the Western Cape province of South Africa for the period from 1999-2011. The total number and volume of species translocated annually in the Western Cape has increased significantly over the past decade. The same applies to non-native species, which have also increased significantly as a proportion of total species translocations. The network structures underlying these movements exhibit small world, scale-free properties, both of which promote the rapid propagation of negative influences, such as invasive species and pathogens, across the network. In addition, the networks for a number of taxa have grown in size and connectivity. These results suggest a high and increasing propagule pressure of non-native species in the province, with translocation networks that will facilitate rapid spread of these potentially invasive species, or other negative biodiversity impacts. There is some evidence that the Western Cape is fairly representative of broader patterns, and that human networks of tetrapod translocation have the potential to promote damage to biodiversity and cost to society worldwide.

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CHAPTER 1

LITERATURE REVIEW

There is a very broad literature covering topics relating to wildlife translocations and invasive species, which can be further broadly divided into literature specific to each biological kingdom. The subject of my research is the translocation of tetrapod species within the Western Cape province of South Africa, and for this review chapter I focus on literature relevant to tetrapod animal species.

Humans utilise and impact their environment in ways that are fundamentally different to all other naturally occurring species on earth. Human populations have already transformed most of the terrestrial biosphere and in so doing have altered, as well as created ecological patterns and processes (Ellis 2011). No ecosystem on earth is untouched by human influence, whether direct or indirect, and the complex changes being brought about by these human impacts are already being felt (Vitousek et al. 1997). Humans have altered patterns of biodiversity across the planet, and continue to do so, with large ecological and societal consequences (Chapin III et al. 2000). Despite these impacts, economies have continued to advance and through increased international trade and transport networks have broken down the geographic barriers that have historically been one determinant of the distribution of biodiversity (Brown et al. 1996; Rosenzweig 2001; Brown & Sax 2004; Hulme 2009). Although globalised development has facilitated economic growth, human societies and the interconnected economies that we have built rely on ecosystems goods and services (MEA 2005), a support structure that is increasingly threatened (Rockstrom et al. 2009).

Wildlife translocations

The human-assisted translocation of biota is one consequence of the globalised society in which we live, and is having an increasing impact on biodiversity (Elton 1958; Pimentel et al. 2001). As can be expected for such a broad subject, there are many and varied terms and definitions. Falk-Petersen et al. (2006) suggest that 'translocated' should be used to describe "human mediated movement of species within their natural range, whereas 'introduced' should be used when species are moved beyond their natural range and dispersal potential". For my purposes I will use the broader definition proposed by Bullock et al. (1996), defining translocation as the "general term for the transfer by human agency of any organism(s) from one place to another".

Wildlife translocations occur, both intentionally and unintentionally, for a number of reasons. These can be broadly divided into translocations for conservation reasons and translocation for reasons other than conservation (Bullock et al. 1996). Translocations to achieve conservation goals have been employed for decades (Griffith et al. 1989; Chipman et al. 2008) but increased rates of biodiversity loss, predicted to increase with climate change (Thomas et al. 2004), have led to a resurgence in the debate around conservation driven wildlife translocations, otherwise known as assisted migration. Conservation translocations involve introduction, re-introduction or augmentation of a species population (IUCN 1987) in order to achieve goals such as maintaining genetic diversity within small populations, establishing separate populations to reduce risk of species extinction (Griffith et al. 1989; Green & Rothstein 1998), or avoiding threats such as climate change (McLachlan et al. 2007) and human-wildlife conflict (Massei et al. 2010). Despite the increased recommendation of translocations as a conservation tool (Donlan et al. 2006; McLachlan et al. 2007; Cassey et al. 2008; Heogh-Guldberg et al. 2008; Parker 2008) the strategy has been questioned, particularly where it aims to move species beyond their native ranges (Mueller & Hellmann 2008; Ricciardi & Simberloff 2009).

Translocations for reasons other than conservation cover a broad spectrum of human wildlife utilisation, including species valued for food, sport, companionship, aesthetic purposes or biological control (White et al. 2008). Movement of animals for a number of these purposes is by no means a modern phenomenon, and the transportation of exotic animals as pets, for entertainment or for cultural purposes can be traced back to ancient societies (Hughes 2003). Species that are commonly translocated for the purposes of sport and tourism are game fish, game birds and ungulates (White et al. 2008). These species and the industries that they sustain provide a source of revenue, thus making these translocations commercially important (Green & Rothstein 1998; Gordon et al. 2004). The modern pet trade is a sector that represents a significant volume of global wildlife trade and whilst it is impossible to determine exact figures due to lack of precise monitoring, estimates put the annual magnitude of the trade at about 40 000 live primates, 4 million live birds, 640 000 live reptiles, and 350 million live tropical fish (Karesh et al. 2005), in total worth approximately US$ 20 billion each year (Karesh et al. 2007). The scale of the illegal wildlife trade is also uncertain, but the estimated value is of the order of between US$5 billion and US$20 billion per year and places the trade among the world's largest illegitimate businesses after narcotics (Wyler & Sheikh 2008). The examples of the pet trade and sport related animal translocations highlight the economic importance of many of these movements, and in turn their significance to certain sectors of society.

Unintentional animal translocations also fall under the category of translocations for reasons other than conservation, and these translocations occur via a multitude of vectors. The major pathways include movement of species as contaminants of an intentionally transported good, and unintentional movement of species as result of the transport process, known as stowaways (Hulme et al. 2008).

Movements of parasites and pathogens also fall in this category. Wildlife translocations may facilitate the spread of disease to humans as well as local wildlife populations. With regard to human health, introduced wildlife species are a potential source of parasites and zoonotic pathogens. Zoonotic pathogens are those that are transmitted naturally from wildlife to humans (Daszak et al. 2000; Karesh et al. 2005; Chomel et al. 2007; Swift et al. 2007). This risk is particularly high for the pet trade because of the close contact between translocated animal pets and their human owners (Brown 2008). There is a clear economic cost associated with these emerging infectious diseases, although these costs may be complex and difficult to predict (Daszak et al. 2000; Karesh et al. 2005; Chomel et al. 2007). The spread of disease through wildlife populations also poses a significant risk to local biodiversity and ecosystem health (Karesh et al. 2005). Introduced species may bring with them novel pathogens, regardless of the distance of translocation, and these pathogens may be devastating to a naïve population with no prior exposure to the disease (Daszak et al. 2000; Acevedo & Cassinello 2009). The threats are just as real for captive-bred species that are introduced to wild populations for conservation purposes (Daszak et al. 2000)

There are a number of genetic impacts associated with species translocations, of which hybridisation and introgression are two of the primary concerns (Ricciardi & Simberloff 2009). These effects are particularly prevalent in the case of translocations of non-native species, and I elaborate under the discussion on non-native species translocations. However, translocations can also lead to intraspecific hybridisation through the mixing of two previously geographically distinct populations of the same species (Olden et al. 2004). This mixing can lead to the loss of unique locally adapted genotypes (Green & Rothstein 1998), thus endangering local populations through increased susceptibility to threats such as disease (Olden et al. 2004). These threats are particularly pressing when conservation translocations are carried out to augment endangered species populations (Storfer 1999). It must be noted, however, that these risks should be weighed against the potential positive benefits for genetic fitness and diversity (Moritz 1999).

Wildlife translocations, particularly those for reasons other than conservation, can be associated with significant impacts on biodiversity through depletion of source populations and the question of how heavily a source population can be harvested is one that needs to be asked in some cases (Armstrong & Seddon 2007). However, the profit-driven wild animal trades, particularly the illegal components, often have little regard for sustainable harvesting with the result that the international wildlife trade is seen as a significant threat to biodiversity conservation (Sodhi et al. 2004; Schlaepfer et al. 2005; Andreone et al. 2006; Nijman & Shepherd 2007; Sutherland et al. 2009;

Luiselli et al. 2011; Nijman et al. 2011). These impacts are even more important for endangered species, which may be subject to higher prices and demand through rarity value (Courchamp et al. 2006). The collection of larger, more attractive individuals may also selectively target the fittest individuals in a wild population, thus potentially decreasing fitness in the long term (Paquette & Lapointe 2007). Despite these negative impacts, the global commercial trade in wildlife is of great socio-economic importance in many sectors of society worldwide (Cooney & Jepson 2006; Nijman 2010). Through the livelihoods that it provides, the wildlife trade may encourage conservation and sustainable utilisation of local environments (Andreone et al. 2006; Cooney & Jepson 2006; Luiselli et al. 2011).

Invasive species

The introduction of non-native species, and potential establishment of these species as invasive, is one of the specific threats associated with wildlife translocations that I focus on in this study. A non-native species is one that does not occur naturally in an area (Bullock et al. 1996), whereas an invasive species is defined as a non-native species that is producing reproductive offspring that are able to sustain self-replacing populations over several life cycles, and have the potential to spread over long distances (Pysek and Richardson 2010). The crossing of major biogeographical barriers is the first hurdle a species must overcome in the process of potentially becoming invasive (Richardson et al. 2000). Trade and translocation of wildlife around the world is largely unregulated (Schlaepfer et al. 2005), and the relative ease with which non-native species may be legally moved has made accomplishment of this first step of invasion much more likely for many (McLachlan et al. 2007).

The circumstances and mechanisms through which a non-native species may become invasive are not completely understood and thus invasions are difficult to predict (Chornesky and Randall 2003; Hellmann et al. 2008). In many cases lag times involved between the arrival of a non-native species and its establishment as invasive further limit awareness of particular threats (Ricciardi and Simberloff 2009). It is clear, however, that propagule pressure, incorporating both number of introduction events as well as the number of individuals involved in each event, is key to the establishment of invasive species (Reaser et al. 2008). In the case of non-native wildlife, translocation events may either result in intentional introductions into the wild or carry a risk of escape into the wild, and thus represent potential contributions to propagule pressure. In trying to quantify the proportion of introduced non-native species that become invasive, Williamson (1996) proposed the now widely cited tens rule. This rule predicts that ~10% of introduced species become established in their new environments, but in turn only ~10% of these established species spread and complete the process of invasion. Vertebrates, however, are of particular concern as research has shown that the rate of tetrapod species completing the transition from introduced to invasive is higher than that predicted by the tens rule (Kraus 2003; Jeschke and Strayer 2005).

Biological invasions have occurred naturally throughout history as species have shifted their ranges in response to changing environmental conditions (Vermeij 1991). What is worrying is the rate and magnitude at which these invasions are now occurring due to human influence (Hulme 2009). Intentional translocation of species provides a pathway for animal invasions, primarily through releases (both accidental and intentional) from the pet trade (Kraus 2003; Carrete and Tella 2008; Cassey et al. 2008; Hulme et al. 2008; van Wilgen et al. 2009; Perry and Farmer 2011) and translocations for other commercial purposes such as game ranching (Nentwig 2007; Lindsey et al. 2009; Spear and Chown 2009). Specifically, pathways for worldwide species introductions have been dominated by the pet trade for reptiles and amphibians; the pet trade, aesthetics, and release for game purposes for birds, and the introduction for food and game purposes for mammals (Kraus 2003). There is evidence that introductions by some of these pathways continue to rise (Kraus 2003), suggesting that tetrapod introductions and associated impacts are likely to remain a concern in the future.

The negative impacts of invasive species vary greatly, dependent on the biological characteristics of the species itself, as well as the characteristics of the environment through which it propagates (Elton 1958; Mack et al. 2000). Invasive species impact biodiversity on a range of scales. On a very broad scale, there is concern that the proliferation of invasive species across the globe is driving the homogenisation of global biodiversity (Olden and Poff 2003; Romagosa et al. 2009), whereby species introductions increase local biodiversity in the short run but overall diversity is lost in the long run as a result of local extinctions. At the population level, there is evidence that invasive species are a major cause of such local species extinctions (Wilcove et al. 1998; Mack et al. 2000; Clavero and Berthou 2005), but although this has certainly been the case in some situations the universal existence of a direct causal link has been questioned (Gurevitch and Padilla 2004). The main obstacle to clear understanding of the population level impacts of invasive species is that they often occur in already degraded environments, and so it is difficult to isolate the impact of invasive species from other factors (Brown and Sax 2004; Didham et al 2005). Population-level genetic impacts of invasive species are better understood. Invasive species have the potential to hybridise with local relatives in the invaded community. This process leads to genetic dilution and assimilation and can potentially drive local species to extinction through loss of genetic integrity (Olden et al. 2004; Ricciardi and Simberloff 2009).

At the ecosystem level, there is no doubt that invasive species have the potential to drastically alter local wildlife communities. Invasive species modify interspecific relationships, including but not limited to patterns of herbivory (Castley et al. 2001), competition (Acevedo and Cassinello 2009) and predation (Salo et al. 2007), and have the capacity to disrupt entire food webs (Ricciardi and Simberloff 2009). Through these and other effects, invasive species have the potential to disrupt ecosystem function and services (White et al. 2008).

The negative impacts of invasive species are not limited to biodiversity; there are significant direct economic costs associated with biotic invasions. These costs fall into three basic categories – loss of economic output, costs of curbing invasions and the costs associated with human health impacts of invasive species (Mack et al. 2000). Recent estimates put the annual cost of all invasive species in the United States at $120 billion (Pimentel et al. 2005). The bulk of the costs of invasive species are related to management, including control, eradication, monitoring, and environmental education programs (Pysek and Richardson 2010). In the case of intentional translocation of tetrapods, there are economic incentives for individuals to import, breed and translocate non-native species. However, if an introduced species becomes invasive, the potential costs are borne by society at large and as such invasions stemming from non-native wildlife translocations constitute an economic externality (Perrings et al. 2002). Until the costs of these risks can somehow be incorporated in the actual cost to the actors involved in the translocations, there will continue to be significant economic incentives to trade and translocate non-native tetrapods.

Network analysis

A network is any collection of units potentially interacting as a system (Proulx et al. 2005) and can be defined by a group of nodes (vertices) and the relationships (edges) that link them. These networks can be described and analysed using a suite of methods known as network analysis, which forms a branch of mathematical graph theory. Complex networks can be found in many real-world systems, with examples ranging from the structure of cellular protein interactions to the layout of electricity grids (Strogatz 2001). Network analysis techniques have been widely applied in the spheres of physics and sociology, and more recently to ecology. Networks have been described in a number of fields in ecology (Bascompte 2007), including species interaction networks such as food webs (Montoya and Sole 2002; Pascual and Dunne 2006) and mutualistic relationships (Bastolla et al. 2009), spatial networks such as the spread of biological invasions (Muirhead and Macisaac 2005) and epidemiological networks describing the spread of disease (Liljeros et al. 2001).

Structure influences function (Strogatz 2001), and the main goal of network analysis is to describe the structure of complex systems in order to better understand function. Network approaches emphasise the pattern of interactions among vertices in the network rather than studying the actual attributes associated with each. In this way, network techniques are able to address heterogeneity in a complex system, and how this heterogeneity impacts the relations among actors (Bascompte 2009). Networks can capture variable amounts of detail, known as the resolution of the network, about the system that they represent (Proulx et al. 2005). Information about the edges in the network may simply be captured as an undirected binary tie between two vertices, thereby not reflecting the strength or direction of the relationship. Alternatively, an edge between two vertices may be weighted and directed, thus incorporating data on the strength and directionality of the interaction.

There has also been growing interest in understanding how the network architecture underlying complex systems contributes to their stability and functioning. It appears that real-world networks often have structural elements in common (Barabasi and Bonabeau 2003). One common variety of real-world networks is 'small world' networks (Milgram 1967). In these networks, any two nodes in the network connect to one another through only a small number of intermediate nodes, and directly connected nodes often share common neighbours. Another property common of many real-world networks is the highly skewed degree-distribution of vertices in the network, where a number of vertices have a very large number of connections while the majority only has a small number (Barabasi and Bonabeau 2003). As the number of described networks continues to grow, patterns will emerge as to how universal these and other patterns are, as well as how they relate to network function.

A number of studies use network analysis to describe elements of biodiversity as well as human impacts on biodiversity. One approach is to link landscapes and the spatial association networks of specific species. Based on network-centric methods, Bodin and Norberg (2007) propose methods to identify habitat patches that are disproportionately high in maintaining connectivity such that organisms can traverse a landscape, as well as find compartments of internally connected habitat fragments that are disconnected from others, thus isolating species populations. By using network methods to analyse habitat utilisation by bees and lemurs in Madagascar, Bodin et al. (2006) found that in a network of fragmented forest patches the location of the remaining patches was more important than their size in maintaining ecosystem processes such as crop pollination and seed dispersal. Rhodes et al. (2006) describe a scale-free network in the pattern of roosting tree usage by white-striped freetail bats (*Tadarida australis*), with consequences on the epidemiology and social life of these animals. Studies such as this can give insights into animal behavior, with implications for conservation efforts.

Network analysis has been used to provide insight into urban planning in order to achieve urban biodiversity goals. Zhang and Wang (2006) used network methods to develop planning scenarios for the ecological network of Xiamen Island (China) that would decrease landscape fragmentation and enhance connectivity. Rudd et al. (2002) conducted similar work in Greater Vancouver (Canada) and determined that at least 325 linkages were necessary to connect half of the 54 habitat nodes (green spaces) in the study area.

Network techniques have also been useful in more traditional ecological studies. Food webs have been shown to typically have short paths between species (Williams et al. 2002) but generally display a uniform degree distribution as opposed to the scale-free distributions that are commonly found in complex networks (Dunne et al. 2002a). Dunne et al. (2002b) found that although food webs are more robust to random removal of species than selective removal of species with the most trophic links, the robustness of food webs to species removal increases with connectance but appears independent of species richness. The impact on an ecosystem of species extinction thus depends on the trophic function of the species lost. Looking at networks of interaction between species, Bascompte and Jordano (2007) argue that plant-animal mutualistic networks are very heterogenous, nested and built on weak and asymmetric links among species, and that this network structure has consequences for both the coexistence of species as well as for coevolutionary processes.

Perhaps the greatest value of network techniques is that they can be applied to any system that functions as a network, allowing comparison between superficially different systems (e.g., economics and ecosystems) that may nonetheless share common organisational principles. Ecosystems have been described as complex adaptive systems (Levin 1998), characterised as systems in which properties and patterns at higher levels emerge from interactions and processes acting at lower scales that can feed back to influence the development of these interactions. Specifically, social-ecological systems are composed of multiple social and ecological variables at lower levels which are relatively separable but interact to produce outcomes at a social-ecological system level, which in turn feed back to affect these subsystems (Ostrom 2009). Wildlife translocations function as such a social-ecological network, where the elements comprising the system are social, economic and ecological. The distributions of most species are strongly influenced by people, and in order to understand and manage these human-influenced distributions we need to analyse these linked networks as a whole. Network analysis is able to introduce heterogeneity into previously homogenous theories of societies, diseases and populations (Bascompte 2009) and thus play a valuable role in the development of a more unified approach to analysing social-ecological systems (Cumming et al. 2010).

Apparently no studies have used network analysis to understand more about the characteristics of these wildlife translocation networks and how they potentially impact biodiversity. However, network analysis has been used in a number of cases to understand domestic animal movements and their potential contribution to disease spread. Ortiz-Pelaez et al. (2006) used network techniques to characterise patterns of animal movements in the early phases of the 2001 foot and mouth disease outbreak in the United Kingdom, and discovered that most of the nodes with the highest betweeness were identified as central actors in the initial spread of the disease. Bigras-Poulin et al. (2006) carried out a network analysis of the Danish cattle industry in order to identify possible disease transmission paths. They concluded that the Danish cattle trade network was scale-free with a large degree of heterogeneity.

Network analysis of the social component of these linked social-ecological systems can shed light on how humans manage natural resources and biodiversity. The structural pattern of relations of a social network has a significant impact on how actors within the network behave (Bodin & Crona 2009) and thus respond to efforts to minimise the negative impacts of wildlife translocations. Prell et al. (2009) showed that network analysis could be used to inform stakeholder analysis in a case study from the Peak District National Park in the United Kingdom. By using network analysis, they were able to identify which individuals played more central roles in the network and this information could guide stakeholder selection. In the context of a wildlife translocation network, network analysis can identify the more influential members of the network and potentially show where intervention and monitoring may be most effective.

In this thesis I begin with a basic analysis of trends in volume and composition of the wildlife trade in the Western Cape over the past decade in order to understand more about the nature of trade. I then use network analysis to analyse how these translocation networks have evolved and how the elements of the translocations described may impact biodiversity.

CHAPTER 2

TRENDS IN TETRAPOD TRANSLOCATIONS IN THE WESTERN CAPE, SOUTH AFRICA

INTRODUCTION

Wildlife translocations are carried out in South Africa for all of the reasons outlined in Chapter One. Translocations for conservation purposes are frequently undertaken, particularly in the case of endangered species such as Cape mountain zebra (*Equus zebra zebra*) and wild dog (*Lyacon pictus*) (Gusset et al 2008; Smith et al. 2008). With regard to translocations other than for conservation, the game industry and the pet trade are two major contributors to the movement of wildlife in South Africa.

The activities associated with the game industry can be broadly divided into hunting (Damm 2005), eco-tourism (Van der Merwe and Saayman 2003), production of meat (Hoffman 2007), and the breeding of rare species (Lloyd 2000), all of which are commercially important. The industry has grown substantially over the last three decades (NAMC 2006) and it is estimated that up to 70 000 animals are translocated annually within South Africa (du Toit 2007). The pet trade in South Africa is relatively young (van Wilgen et al. 2008) but growing rapidly (van Wilgen et al. 2009). In some cases, for example reptiles, keeping and collecting indigenous species is illegal and so trade is dominated by non-native species (van Wilgen et al. 2009), with implications for potential invasive species introductions. There are indications that pet species are being captive bred on a large scale (van Wilgen et al 2008; van

Wilgen et al 2009), however, harvesting of indigenous wild populations has become a threat to certain species (Baard and de Villiers 2000). Historically, wildlife translocations have been a vector for the introduction of non-native species tetrapod species to South Africa (Richardson et al. 2003; Peacock et al. 2007; Spear and Chown 2009), and South Africa has in turn been the source of non-native introductions elsewhere (Weldon et al. 2007).

International trade in animals is monitored by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and this has a direct impact on trade in certain species. However, the number of controlled species is limited and once a non-native tetrapod has been imported into South Africa, there are very few controls to restrict their spread throughout the country (Richardson et al. 2003). The National Environmental Management: Biodiversity Act (no. 10 of 2004) and the associated Threatened or Protected Species Regulations (TOPS) aimed to address this problem, and the government has introduced legislation directed at controlling and regulating the introduction and translocation of wildlife, including non-native species (van Wilgen et al. 2009). The national situation is complicated by the fact that each province in South Africa has its own legislation with different requirements relating to wildlife translocations (van Wilgen et al. 2008). In general, record keeping is poor, making it difficult to monitor wildlife movements and assess their potential impacts (van Wilgen et al. 2008).

The situation is better in the Western Cape province, where controls are in place and a permit system allows for recording of species being moved. Wildlife trade and translocations in the Western Cape are broadly governed by the Nature Conservation

Ordinance of the Western Cape Province (Ordinance No. 19 of 1974) (Lloyd 2000). According to section 44(1)(a) of the Ordinance, a permit is needed to import into, export from or transport through the Western Cape any wild animal, defined as any live vertebrate or invertebrate animal belonging to a non-domestic species and including any such animal which is kept or has been born in captivity. A permit for the transport of birds only applies to those species listed as protected or endangered in terms of the Ordinance. The Ordinance prohibits the release of a non-native animal without a permit (Lloyd 2000).

In this chapter I analyse permits issued for the intentional translation of tetrapods within the Western Cape province of South Africa, for the period from 1999 to 2011. Given the impacts of wildlife translocations (see Chapter One), with particular emphasis on the potential for introduction of non-native species, I aim to quantify trends in the composition of wildlife translocations according to class, native/non-native status, and conservation status of the species being moved. Many of the conservation agencies in South Africa have limited knowledge of the alien species being kept in captivity and transported within their provinces (Van Wilgen et al. 2008), and this work aims to make the Western Cape the first step in addressing this. In addition, Van Wilgen et al. (2009) suggest that South Africa may provide a fairly good sample of species in the worldwide trade, and although my study only focuses on a very local scale, the results may contribute to a better understanding of global trends and highlight areas of further investigation.

METHODS

I obtained data documenting the translocation of tetrapods from translocation permits issued by Cape Nature, the agency responsible for biodiversity management in the Western Cape province of South Africa. Cape Nature has nine provincial offices spread throughout the Western Cape, and a head office located in Cape Town. Translocation permits were collated covered the period from 1999 to 2011. Prior to 2004 all offices had authorisation to issue translocation permits directly, but referred the majority of permits to the head office for approval. From 2004 onwards a central issuance system and database was established at the head office, although some of the regional offices continued to issue small numbers of permits. From 2009 no permits were issued by any regional offices, barring a very few special cases. From October to November 2011 I visited and collected data from five of the regional offices, as well as the head office. The other offices were not visited due to time constraints and the data is thus a sample. Translocation permits were available either electronically from head office or were obtained by going through archived files in the regional offices, and I captured the data in a standard format. The number of permits collected from each office is shown in Table 1 (see Appendix 1 for more detail).

Table 1. Permit sources and excluded records for tetrapod translocation permits issued from 1999-2011.

	Excluded records	Tetrapod permits	**Total**
Boland	56	517	573
George	21	96	117
Head office	506	9249	9755
Hermanus	3	84	87
Oudtshoorn	52	221	273
Riversdale		7	7
Total	638	10174	10812

Each permit records details concerning the origin and destination of the translocation, the species and number translocated, as well as any additional information that may be specific to that translocation. The focus of the study is on tetrapod translocations within the Western Cape, and so all permits are for movements to and from locations within the province. A number of permits were excluded, for various reasons. My intention with this study is to analyse the translocations of wildlife from one location to another, and so any movements that were temporary or resulted in a return to the point of origin were excluded. These included translocations for veterinary visits, exhibition purposes, film shoots and temporary movements to holiday houses. Also left out of the analysis were permits for the translocation of animal products, such as skins and blood samples. A number of permits were cancelled, replaced, or accidentally repeated after issuance, and these were also left out of the analysis. Lastly, any permits in which the species could not be positively identified to species level, as well as those concerning movements of domestic bred species and hybrids, were removed as the focus of this analysis is on naturally occurring species.

A single permit may be issued for the translocation of more than one species and so there are a greater number of species translocation records in my database than there are permits. Permits are valid for one month, except in special cases, and the year of issuance, as opposed to the year of expiry, was used to generate the annual breakdown of permits. In order to get an indicator of each species' conservation status, I used the IUCN Red List of Threatened Species (IUCN 2011) to classify the species according to extinction risk. A number of the species in my analysis had not been evaluated by the IUCN and these are designated as 'not evaluated' (NE). For the species that had been assessed, species names were updated to conform to taxonomy as used by the

IUCN red list. IUCN assessed species were also classified as native/non-native to South Africa dependent on the species native ranges provided by the IUCN. For species not assessed by the IUCN, alternative sources were used to update taxonomy and determine native ranges of reptiles (Marais 2004; Alexander and Marais 2007), mammals (Skinner and Chimimba 2005; Wilson and Reeder 2005) and birds (Hockey et al. 2005). All amphibian species in the analysis had been assessed by the IUCN.

I performed four sets of analyses using this compiled database. The first objective was to assess whether there were noticeable trends in the volume and number of species being translocated within the Western Cape. I grouped tetrapod species by class, and calculated total annual volumes and numbers of species being moved. I ran linear regressions of these variables against time, using base functions in R statistical software (R Development Core Team 2011) to identify any significant trends. The same tasks were performed for the relative proportions of volume and species number per class to test for trends in the composition of translocations.

Simple species richness does not take into account how the relative volumes of each species are distributed across the total number of species moved each year. The Shannon index (*H*) is a measure of biodiversity that takes into account both the species richness and proportional volume of each species within a sample in order to evaluate heterogeneity in the community. In this case I applied the index to the annual ‘population’ of wildlife translocations as opposed to a particular ecosystem.

The index was calculated as follows:

$$H = -\sum_{i=1}^{S} P_i * lnP_i \tag{1}$$

Where: S = Total number of species in the sample

P_i = Proportional volume of S made up of the ith species

Shannon's equitability index (E_H) was also calculated for each annual sample of species. This value is a measure of how evenly the number of individuals of each species in a sample is distributed and is calculated by:

$$E_H = \frac{H}{H_{max}} = \frac{H}{lnS} \tag{2}$$

Where: H_{max} = Maximum possible Shannon Index (H) for a given sample size.

In the third set of analyses I focussed on the conservation status of the translocated species. I calculated the proportion of all species translocated from 1999 to 2011 that was comprised by animals in each of the specific IUCN threat categories. In order to determine trends over time, I grouped all species that were assessed by the IUCN as threatened in any way into one category, 'IUCN listed'. Once again I used linear regression in R to detect trends.

The final component of the analysis was aimed at identification of trends in the annual composition of native vs. non-native species translocated within the Western

Cape. In order to determine the number of non-native species involved, as well as the potential propagule pressure associated with wildlife translocations, I investigated both the proportion of non-natives species in the annual data and the annual volume of non-native species translocations.

There are a number of caveats regarding this dataset that must be identified at the outset. First, these data reflect permits that were issued for a wildlife translocation and there is no guarantee that the translocation was actually carried out, potentially artificially inflating the number of translocations. There is also no way of knowing which permits refer to the same individual being moved a number of times and so I have assumed that all translocations are of different individuals. Second, I only have data on legal translocations for which a permit was issued. The illegal trade and translocation of wildlife in South Africa is significant (Warchol et al. 2003) and whether through intentional illegal trade or ignorance on behalf of owners, wildlife translocations without permits are not accounted for in this study. This may include effects of increasing permit compliance. Unfortunately there is no way quantify these errors and so the assumption made for this study is that permits issued are representative of all wildlife translocations and permit compliance is constant. Third, the number of permits that were issued but for which records have been lost was unknown. This is primarily a problem in the case of records from the smaller provincial offices, as the majority of their records are kept in hard copy. Lastly, I classified all species as native or non-native to South Africa as a whole. Because of this coarse scale of analysis, species that are extralimital to the Western Cape were treated as native, thus underestimating the trade in species not native to the province.

RESULTS

For the period from 1999 to 2011, 10174 permits were issued for the translocation of a total of 50 508 tetrapods within the Western Cape, representing 4 classes and 508 species (Appendix 2). The classes represented in translocations were amphibia, aves, reptilia and mammalia (Table 2).

Table 2. Total wildlife translocations, by species class, within the Western Cape province from 1999 to 2011.

Class	Total number of species	Total volume translocated
Amphibia	9	399
Aves	264	4254
Mammalia	78	23911
Reptilia	157	21944

Mammals dominated the volume of translocations with 47.3% of the total, followed by reptiles (43.3%), birds (8.4%) and amphibians (0.8%) (Figure 1).

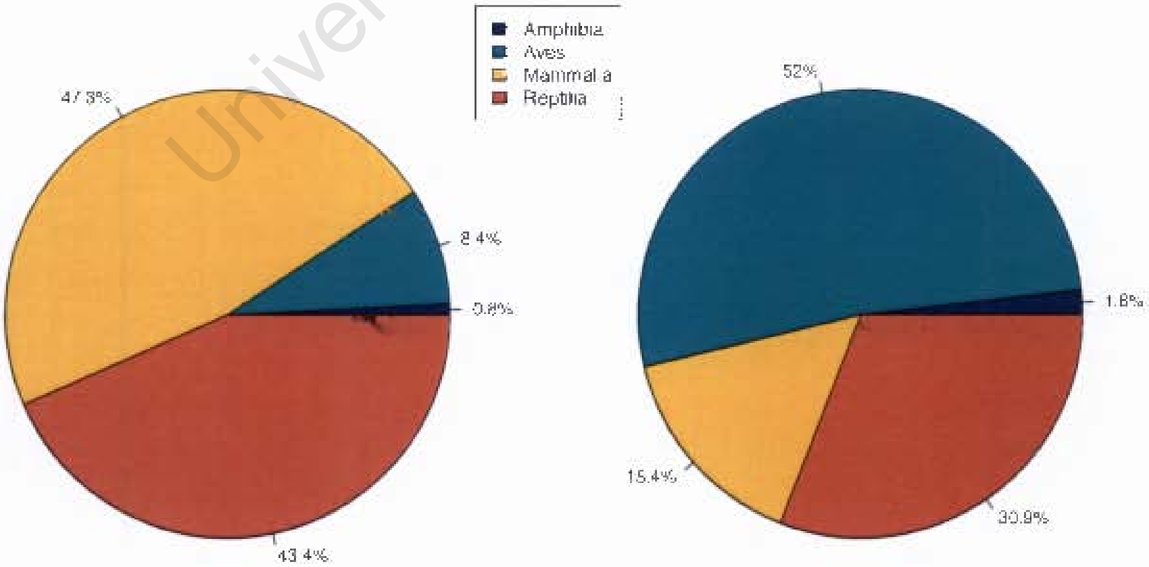

Figure 1. Proportion by species class of total volume (left) and total number of species (right) translocated in the Western Cape from 1999 to 2011.

With respect to the number of species translocated from 1999 to 2011, birds comprise the majority with 52% of the total, followed by reptiles (30.9%), mammals (15.4%) and amphibians (1.8%). The change in total annual volume of all species translocations is shown in Figure 2, and there is a highly significant increase from 1999 to 2011 ($P<0.001$, df=11). A summary of all results is shown in Table 3.

Table 3. Summary of results detailing trends in various components of wildlife translocations taking place within the Western Cape from 1999 to 2011. Only significant P values are reported, df =11 and n = 13 years in all cases.

Variable	Trend	Adjusted R^2	P value
Number of species			
Total	Increase	0.670	<0.001
Amphibia	None		
Aves	Increase	0.432	0.009
Mammalia	None		
Reptilia	Increase	0.865	<0.001
Non-native	Increase	0.727	<0.001
IUCN listed	Increase	0.587	0.001
Volume of trade			
Total	Increase	0.808	<0.001
Amphibia	None		
Aves	Increase	0.325	0.025
Mammalia	Increase	0.786	<0.001
Reptilia	Increase	0.749	<0.001
Non-native	Increase	0.749	<0.001
IUCN listed	Increase	0.611	0.001
Proportional number of species			
Amphibia	None		
Aves	None		
Mammalia	Decrease	0.334	0.023
Reptilia	None		
Exotic	Increase	0.529	0.003
IUCN listed	None		
Proportional volume of trade			
Amphibia	None		
Aves	Decrease	0.436	0.008
Mammalia	Increase	0.264	0.042
Reptilia	None		
Exotic	None		
IUCN listed	None		

Over the period 1999-2011 there was no significant increase in volume of amphibians translocated, however, significant increases in volume were detected for birds, mammals and reptiles (Table 3). Trends were more varied for the annual proportional composition of total volume; amphibians and reptiles showed no significant change in proportional contribution to annual volume, whilst mammals showed a significant increase and birds showed a significant decrease (Table 3).

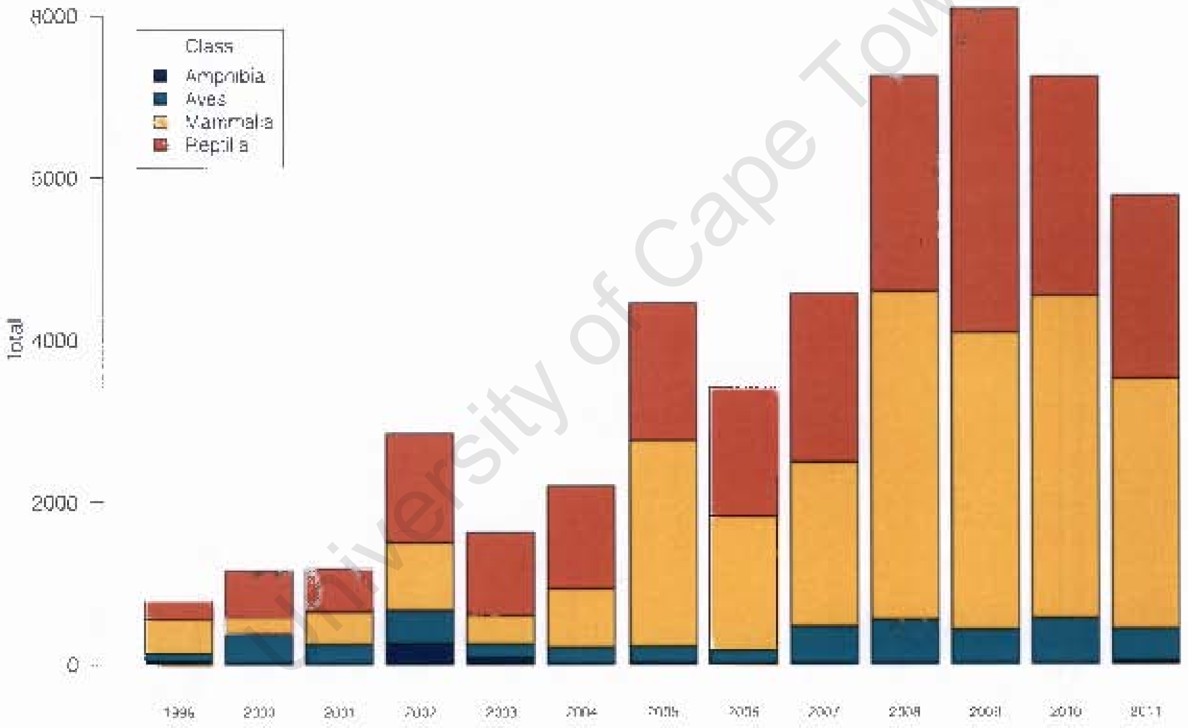

Figure 2. Annual volume of translocations within the Western Cape.

Annual translocated species richness for all tetrapod taxa shows a significant increase (P<0.001, df=11) from 1999 to 2011 (Figure 3).

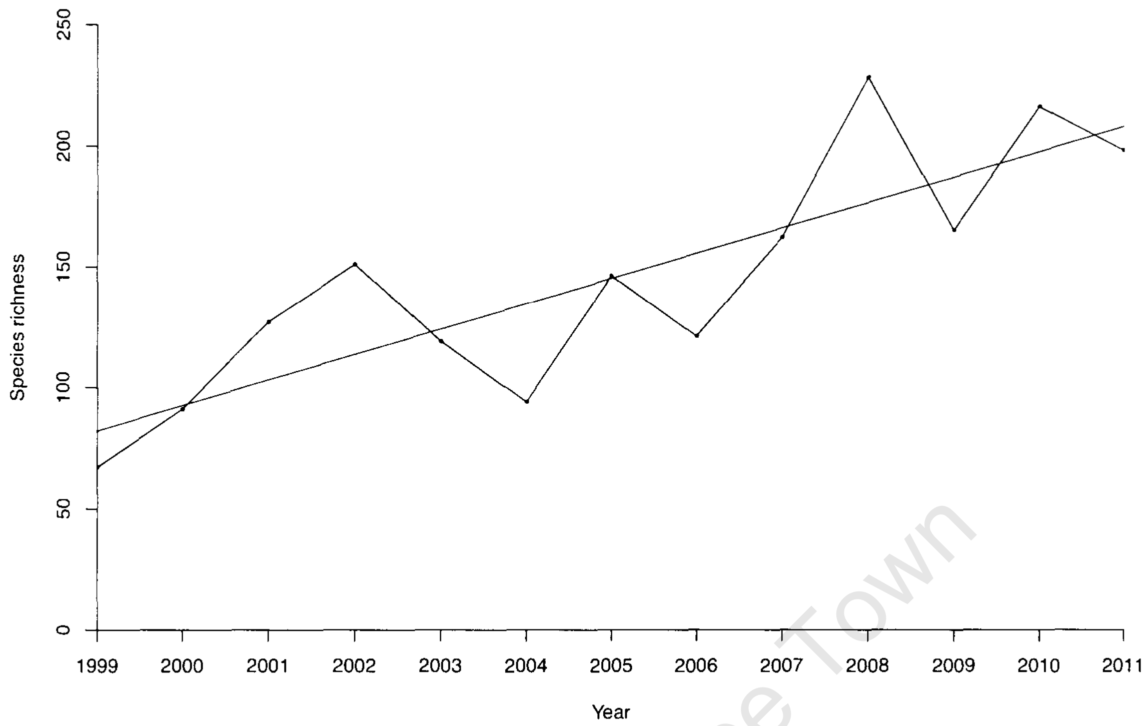

Figure 3. Total number of species translocated annually in the Western Cape

I found no significant trend in the number of species of amphibians and mammals translocated annually, however, there were significant increases in the annual species richness of birds ($P<0.01$, df=11) and reptiles ($P<0.001$, df=11). With regard to proportional contributions of each class to the total number of species translocated annually, amphibian, birds and reptiles showed no significant change whilst the proportional contribution of mammals to total species richness showed a significant decrease ($P<0.05$, df=11). The Shannon index of diversity, calculated for each year, showed no significant change between 1999 and 2011. However, there was a significant decrease ($P<0.01$, df=11) in annual Shannon equitability over time.

In the next component of the analysis I focussed on the conservation statuses of the species that were translocated within the Western Cape between 1999 and 2011. 17.3% of the species had not been assessed by the IUCN. The majority of translocated tetrapods were classified as least concern (LC), with smaller proportions representing each IUCN threat level (Figure 4).

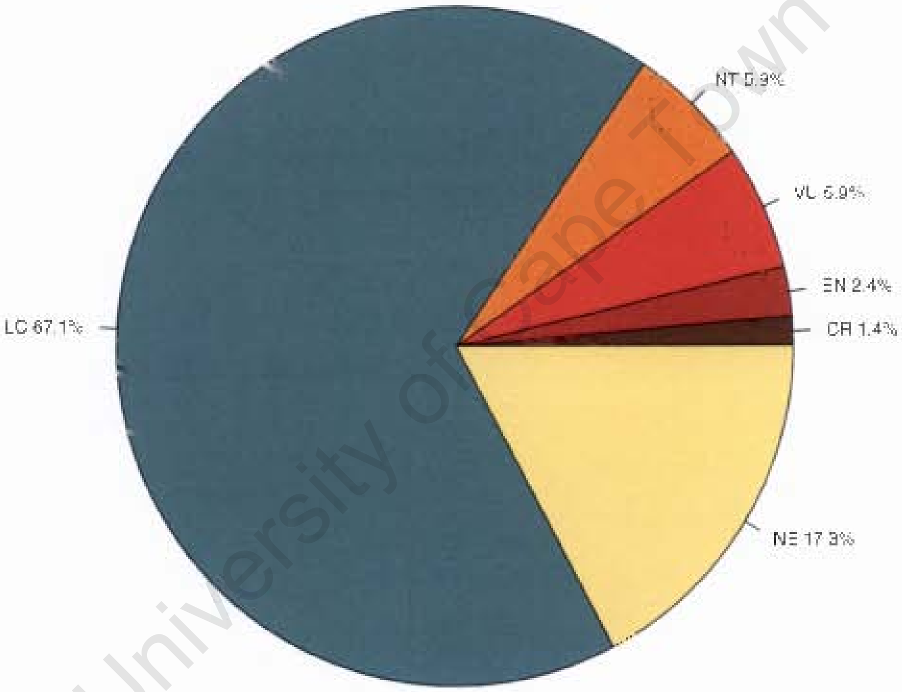

Figure 4. Classification of all species translocated in the Western Cape from 1999-2011 according to IUCN conservation status (CR=Critically endangered, EN=Endangered, VU=Vulnerable, NT=Near threatened, LC=Least concern, NE=Not evaluated).

From 1999 to 2011 there was a significant increase in number ($P<0.001$, df=11) and volume ($P<0.01$, df=11) of IUCN listed species translocated within the Western Cape. However, there was no significant change in the proportional contribution of IUCN listed species to either the annual volume or annual number of species translocated (Figure 5).

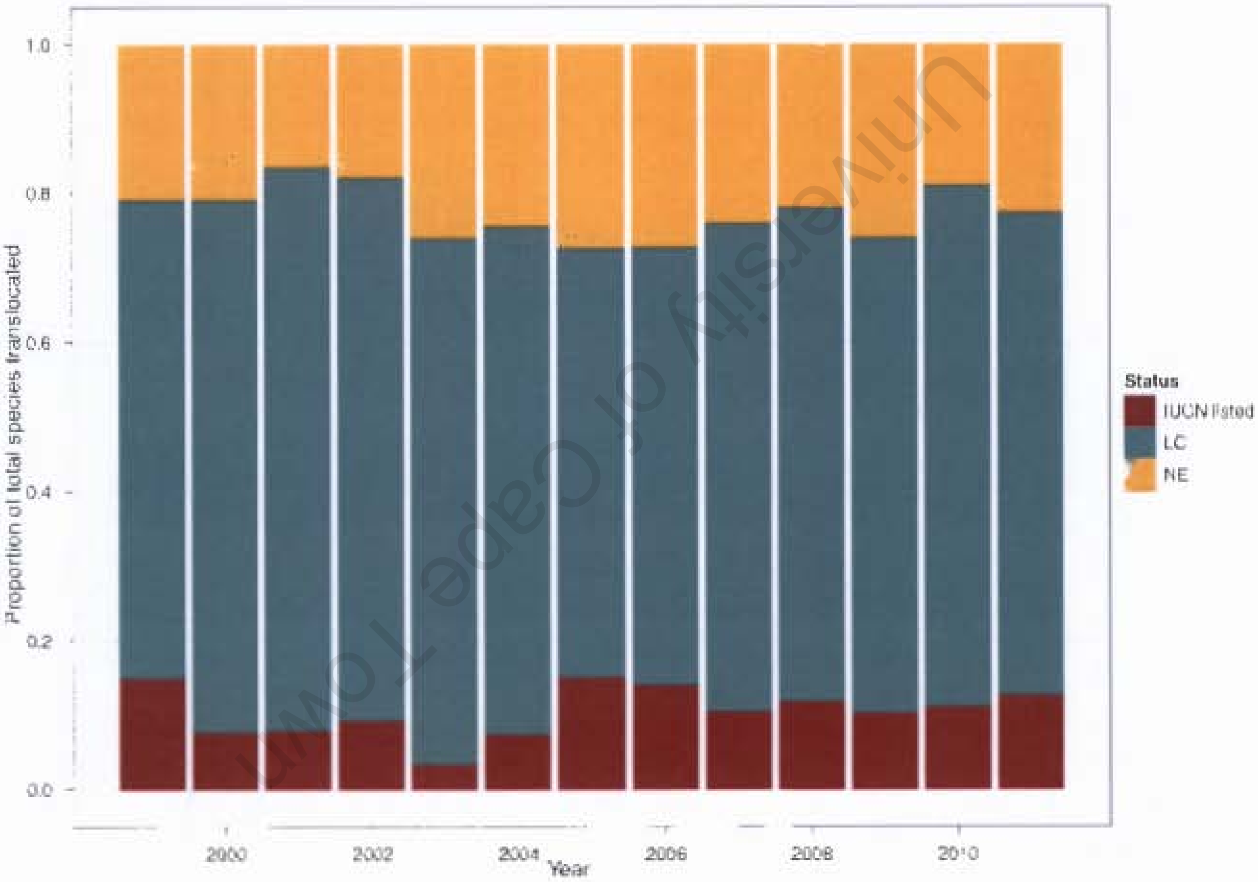

Figure 5. Proportional contribution of conservation status categories to the total number of species translocated annually in the Western Cape from 1999-2011 (IUCN listed – CR+EN+VU+NT).

Significant trends were detected in the translocations of non-native species within the Western Cape. There were highly significant increases in both the total volume ($P<0.001$, df=11) and total number ($P<0.001$, df=11) of non-native species (Figure 6).

There has been no significant change in the proportional volume of non-native species translocated. However, there has been a significant increase ($P<0.01$, df=11) in the proportion of non-native species making up the total annual number of translocated species.

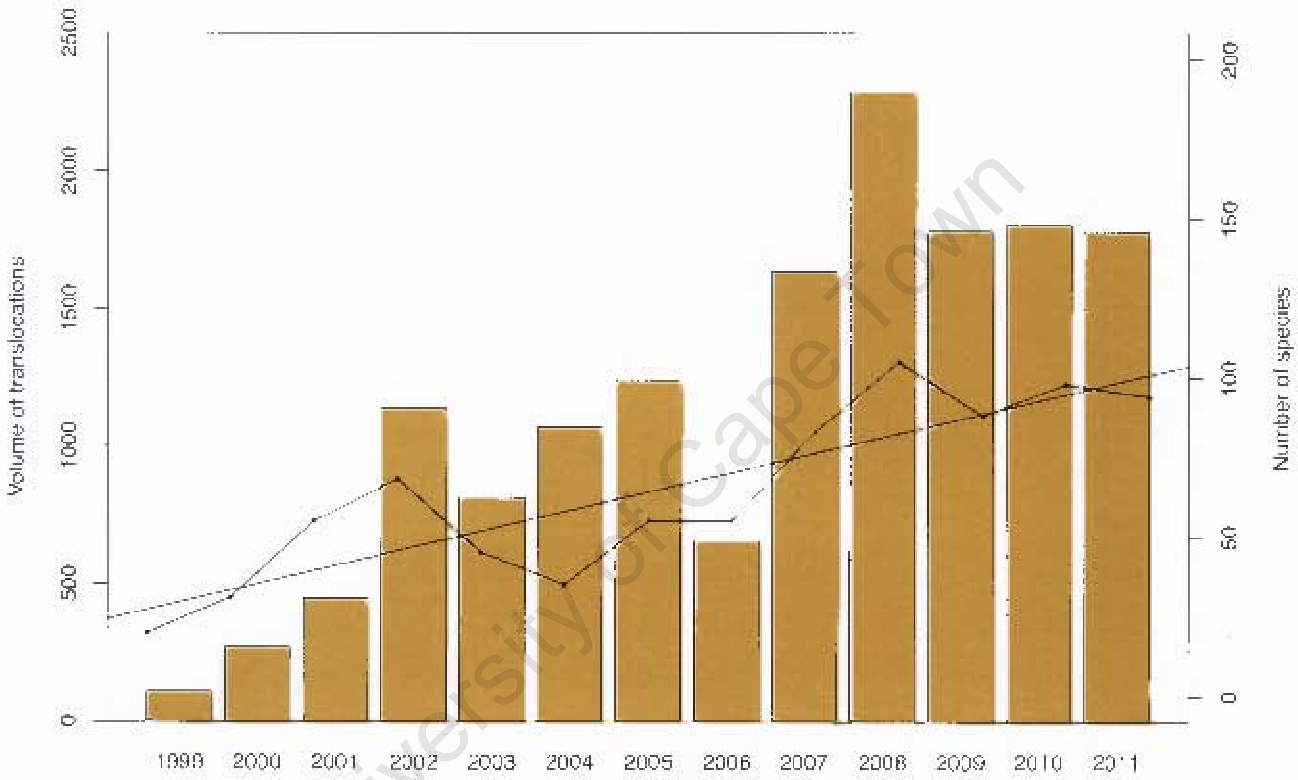

Figure 6. Volume (bars) and total number (line) of non-native species translocated within the Western Cape from 1999-2011. The straight line is the best-fit linear regression for the number of non-native species translocated over the time period.

DISCUSSION

The results of my analysis clearly show that the number of tetrapod species, as well as the volume of individual animals, translocated annually in the Western Cape has risen steadily from 1999 to 2011. Amphibians comprise a marginal proportion of both number and volume of species translocated, and are left out of the discussion from this point. Mammals comprise a large proportion of total volume of translocations but a relatively small proportion of the total number of species, whereas the opposite is true for birds. This indicates that there are relatively large volumes of a small number of mammal species being translocated, whereas there are relatively small volumes of a large number of bird species being moved. The proportional contributions of each class to the total number of species translocated in the Western Cape is not dissimilar to findings by Soorae et al. (2008) detailing the composition of the trade in wildlife for pets in the United Arab Emirates, suggesting that the basic trends observed in the Western Cape may be similar to those observed elsewhere across the globe.

The bulk of the mammal species are either primates likely destined for the pet trade or ungulates for the game ranching industry. The large number of bird species translocations likely represents the diversity in the aviary trade (Richardson et al. 2003). Reptiles are a large component of both the total volume and total number of species translocated, and the majority of these animals are most likely part of the pet reptile trade. The increasing number of wildlife translocations in the Western Cape increases the probability of occurrence of associated negative impacts, described in Chapter One, particularly the spread of disease and genetic pollution.

The respective annual translocation volumes of each tetrapod class showed a significant increase from 1999 to 2011. This was paralleled by significant increases in the number of bird and reptile species being translocated. There was, however, no significant increase in the number of mammals species translocated over the time period. This suggests that the bird and reptile trades are increasing in scope, but that the mammal pet trade and game ranching industry are both saturated with species with no significant demand or potential for translocation of any other mammal species, at this time. The decrease in proportional contribution of mammals to total species number, as well as an increase in the proportional volume of trade, further highlight that mammal translocations in the province are characterised by large volumes of a fewer species, and are becoming comparatively less important in terms of numbers of species but relatively more important in terms of volumes moved. These increased mammal volumes being moved are most likely a result of the rapid growth seen in the game ranching industry in the Western Cape over the last decade, with least 37 species presently utilised by humans for ecotourism, hunting and live sales (van Hoving 2011). The significant decrease in proportional volume of birds indicates that birds are becoming relatively less important in the total annual volume of wildlife translocations.

Interestingly, the increase in total annual volume and number of species translocated was not matched by a significant change in the Shannon index of biodiversity (*H*). If the distribution of individuals among the number of species in a community were to remain constant, the addition of extra species to the community would result in an increase in *H*. However, as individuals are spread less evenly among the species in a community, *H* will decrease, and it is this effect that is balancing the addition of species to the annual translocation networks in the Western Cape, with the result that there is no significant trend in *H.* This shows that even with the addition of new species, the volume of tetrapod translocations is increasingly skewed to a smaller number of species. This is affirmed by the significant negative trend in the Shannon equitability index, which is a measure of evenness in a community, from 1999 to 2011. There was an increase in the number of bird and reptile species translocated annually from 1999 to 2011, but no significant increase in the number of mammal species, which represent the greatest proportion of total annual volume. Thus the additions of reptiles and bird species with lower numbers of individuals translocated was not balanced by addition of mammal species with higher volumes being translocated.

The range of species translocated in the Western Cape from 1999 to 2011 does include a proportion of species (15.6%) listed by the IUCN as threatened to some degree. The impacts of these translocations on the wild populations of the respective threatened species depends very much on whether or not they are wild harvested, and whether or not the individuals are translocated to augment wild populations. At least in the case of non-native reptile species, it appears that the majority translocated in South Africa are captive bred (van Wilgen et al. 2008), limiting the impact on source populations. In the case of threatened native species, threats of genetic and pathogen pollution of wild individuals are a concern (Ricciardi and Simberloff 2009). Although both the number and volume of IUCN listed species translocated annually has increased significantly from 1999 to 2011, the relative proportions have not changed significantly, demonstrating that there has not been an increased relative demand for translocation of threatened species within the Western Cape. This is positive from a conservation perspective.

There has been a significant increase in both the number and volume of non-native species translocated within the Western Cape from 1999 to 2011. In addition, there has been a significant increase in the proportional contribution of non-native species to the total number of species translocated annually. If the number of translocations is assumed to be a function of the number and volume of species in the province, a not unreasonable assumption, then these results describe a potentially concerning pattern; the total number of individuals, as well as the total number of species, of non-native species is increasing annually in the Western Cape, and non-native species are becoming relatively more common in translocations, suggesting that this increase in number and volume of non-native species may be accelerating. The presence of this increased non-native species richness and biomass in the Western Cape represents an increase in probability of either escape or intentional release of species, and thus a potential increase in propagule pressure, known to be a key factor influencing establishment and impact of invasive species (Reaser et al. 2008). Thus these trends represent an increasing threat of biotic invasions associated with wildlife translocations in the Western Cape.

The increases in non-native species richness are primarily a reflection of the increases in non-native bird and reptile species, and this suggests that patterns of demand in the pet and aviary trade are driving the influx of non-native species, as reported by Kraus (2003). Van Wilgen et al. (2009) found evidence of 275 non-native reptiles in South Africa and although there haven't been any cases of non-native reptiles establishing as invasives in South Africa, the same authors note that the trade is still fairly young and growing fast. My results confirm this, particularly regarding the growth of the wildlife industries. I found a total of 100 non-native reptiles in my sample and although this is almost certainly an underrepresentation of the number of non-native reptiles in the province, it would appear that species richness in the wildlife trades does scale up with area.

Translocations take place on provincial, national and global scales, and although my results reflect the finest of these three scales, the broad findings are in line with those from other studies, lending further evidence for the findings that translocations of wildlife, and non-native species for the pet trade in particular, are increasing across the world (Nentwig 2007; Carette and Tella 2008; Nijman 2010), with significant potential impacts on biodiversity.

Locally, invasive non-native species, including fauna and flora, pose one of the gravest threats to South Africa's biodiversity (Wynberg 2002) and the threat is increasing (van Wilgen et al. 2008). There are a number of controls and programs in place to tackle invasive flora but the lack of unified policy and controls across South Africa appear to indicate less concern regarding the threat posed by non-native tetrapods. This may be partly a result of the commercial value of many of these species, and the lobbies that exist within the pet and wild game trades. However, based on the current magnitude of the threat, as well as the increasing trends of non-native species, the recommendation of van Wilgen et al. (2008) for the implementation of standard countrywide policies to monitor and control the translocation of non-native tetrapods seems important. Given the socio-economic importance of these species, these policies need to involve as much stakeholder involvement as possible, as well as include education programs for those involved in the trade and translocation of non-native species. As has happened in the Western Cape, efficient permit schemes implemented across the country would allow for better monitoring of wildlife translocations, allowing authorities to better understand and predict potential threats. In addition, restrictions on trade in all wild-caught species appear necessary. This would reduce pressure on source populations of wild-harvested species and mitigate the potential invasion and spread of pathogens, as both of these risks are diminished in captive bred species (Carette and Tella 2008).

CHAPTER 3

NETWORK ANALYSIS OF TETRAPOD TRANSLOCATION NETWORKS IN THE WESTERN CAPE, SOUTH AFRICA

INTRODUCTION

Network approaches provide a useful way to describe complex systems and analyse the consequences of heterogeneity within these systems for their functioning and dynamics. Wildlife translocations provide a complex system for the application and testing of network analysis techniques, where the origin and destination points function as the nodes and the physical translocations of animals act as the links within the network. This type of network integrates both human and biological components, the interactions between which are important for conservation. Wildlife translocations represent a case in which humans are not only having a direct impact on biodiversity, but that same biodiversity is facilitating links between people and generating social structures. In certain cases, wildlife translocations may represent a threat to biodiversity (Chapter One), and so these translocations should be managed to reduce this threat as far as possible. Structure affects function (Strogatz 2001); the power of the network technique is in the ability to describe this structure of complex systems.

In Chapter Two I have provided an understanding of the wildlife trade in the Western Cape, particularly with regard to composition. However, it is important to know how the networks that facilitate these movements either amplify or reduce the threat of these translocations to biodiversity. In this chapter I present a network analysis of the tetrapod translocation networks within the Western Cape province of South Africa from 1999 to 2011. These translocations form both spatial and social networks; my focus here is on the social. Networks have a variety of structural characteristics, based primarily on the distribution of the connections between the individual nodes, which play a large role in how the network functions. My objectives with this component of the study are to describe and compare a number of these structural characteristics, as well as trends, in the translocation networks of birds, reptiles and mammals within the province. The results are important for describing how these networks have evolved over time, particularly in response to the growth of the industry as shown in Chapter Two. The structural characteristics of the networks can also provide indications as to how influences propagate through the individual networks. These influences may include diverse elements such as genes, pathogens, invasive species or simply information, all of which are important from a conservation perspective. Based on the results in Chapter Two one of my focuses is on the translocation of non-native species and how network structure can affect the potential for the rate and extent of spread of these species throughout the network.

Characterising the structure of the different wildlife translocation networks is also of interest in itself. There is an increasing interest in cross-comparisons between different network types (Montoya et al. 2006), and the use of network analysis in this case represents a novel application of the technique. Finally, local translocation networks such as that for the Western Cape are embedded in regional and international translocation networks, and an analysis of the local dynamics of such systems may aid understanding at a broader level. The results may also have relevance insofar as they are potentially applicable to wildlife translocation networks in other parts of the world.

METHODS

All analyses presented here were performed on the same database as described in Chapter Two, with some modifications outlined below. The translocation network is bounded by the provincial limits of the Western Cape province of South Africa. For this network analysis I was interested in the translocation networks of particular tetrapod classes and not in quantifying number and volume of individual species. For this reason I included all translocations for which the animal could be identified to class level. Unlike the analysis in Chapter Two, this incorporated permits issued for hybrid and domestic bred species. In addition to permits excluded for reasons described in Chapter Two, I excluded all permits that did not specify the direction of the translocation, any permits that were circular (i.e., the origin and destination were the same), and any permits for which there wasn't information on either the origin or destination property. There were only 12 permits issued for the translocation of amphibians, not enough to generate a meaningful network, and thus amphibians were also excluded. Based on these criteria, I included 10 169 permits out of the total of 10 812. All the dataset caveats mentioned in Chapter Two still hold true in this component of the study.

The term 'property' is used here to describe a location that is either the origin or the destination of each wildlife translocation, and I assume that one property represents one social actor in the network. There were inconsistencies in the dataset, especially with the spelling of property names. If there were two similar property names, I cross-referenced using the owner's name and South African identity number where possible. If property names were very similar and the owner was the same then I equated the property names. If there was any doubt as to whether or not two properties were the same or not then I assumed that they were different. In the cases where one permit was issued for the translocation of a number of different species, the permit was treated as representing just a single translocation link for each class represented by the species on the permit.

A discrete translocation network was thus described for each tetrapod class in terms of a directed graph $G(V, E)$ consisting of a finite set V of vertices (nodes), representing the origin and destination properties in the network, and a finite set E of edges (links), representing wildlife translocations, with a defined interaction direction between each pair of vertices (Table 4). The strength of tie between two nodes is defined by the weight of the edge connecting them. I weighted the edges not by the volume of animals comprising each translocation but by the number of translocations between two particular nodes.

Table 4. Dimensions of Western Cape wildlife translocation network graphs for the period 1999-2011.

Network	Vertices	Edges
Bird	589	913
Mammal	1226	2086
Reptile	3944	7224

For the network analysis I used the 'igraph' package in R statistical software (Csardi and Nepusz 2006). I used a number of network measures (Table 5) to describe the networks in two different ways. In the first part of the analysis I subdivided the networks into annual components in order to generate annual network statistics, and thus be able to explore how the structure of each network was evolving. I used linear regressions in R to test for significant trends in these annual measures. I was also interested in relationships between the evolving network structure and the trends in

Table 5. Network statistics generated for each translocation network

Network statistic	Definition	Relevance
Average degree	Average number of connections per node across the network	Describes how interconnected is each network, and thus it's vulnerability to negative influences
Average path length	The average number of steps along the shortest paths for all possible pairs of network nodes	Estimate of the efficiency with which a non-native species or disease may be translocated across the network
Clustering co-efficient	Quantifies how well connected are the neighbours of a vertex	Indicating whether or not vertices form tightly connected groups with high density of ties
Density	The proportion of all possible ties that are actually realised in the network	Allows insight into speed and efficiency with which elements such as non-native species and diseases can propagate through the network
Directed diameter	Maximal directed distance between any two nodes in the network	Indication of the 'size' of the network, the largest number of steps a species would need to go through to get from one side of the network to the other
Indegree	Measures the number of inbound connections associated with each node	Indicator of how frequently a node is a receiver of a wildlife translocation
Outdegree	Measure the number of outbound connections associated with each node	Indicator of how frequently a node is a source of a wildlife translocation
Reciprocity	Extent to which network ties are reciprocated	Indication of the proportion of translocations that reciprocated. Indicates to what extent people are 'swapping' animals

the number of species being moved within the networks, and again used linear regression in R to test these. In the second component of the analysis my aim was to investigate and compare the structure of the complete networks for each class, and so I analysed each network as a whole, including all vertices and edges from 1999 to 2011. In order to determine what proportions of the vertices of each network were acting as sources and sinks of translocations, I described a very basic cumulative degree distribution focusing only on whether a node either had an in and out degree of zero, one, or greater than one. My reasoning here was that if a node was the source of only one translocation, there is a chance that it was a unique event, however, if a node was the source of more than one translocation then there is a far greater likelihood that the node may be functioning as a more consistent source of wildlife translocations.

The goal of the third section of my analysis was to describe the structural properties of each network in order to first make some predictions as to how their functional characteristics may impact biodiversity, and second to compare them with other real world networks. To test structural properties, I compared the characteristics of each network with what would be expected from a random graph, created using the Erdos-Renyi Model (Erdos and Renyi 1959), composed of the same number of vertices and edges. Specifically, I tested whether the translocation networks were demonstrating so-called ‘small-world’ properties (Chapter One) by comparing the clustering co-efficient and average path length of each translocation network with that of its random counterpart. I wanted to get some indication of whether the networks were scale-free, and so applied a power law fit to the connectivity relative frequency distribution of each network, using R statistical software. This method uses maximum likelihood estimation (MLE) to estimate the power law exponent for a straight line fitted to a log-log plot. In a scale-free network the probability that a randomly selected node has k links (ie. degree k) follows the log distribution $P(k) \sim k^{-\gamma}$, where γ is the degree exponent (Barabasi and Albert 1999).

RESULTS

The size and connectivity of the mammal and reptile translocation networks within the Western Cape increased significantly from 1999 to 2011 (Table 6, Figure 7). The bird translocation network, however, showed no significant trends in any of the network measures. For the mammal translocation network there was a significant increase in all measures except for density, which showed a significant decrease, and cluster co-efficient which showed no significant trend. For the reptile network, there were significant increases in all statistics except density and reciprocity, which showed significant decreases, and cluster co-efficient, which showed no trend.

Table 6. Trends in annual network statistics for mammal and reptile translocation networks in the Western Cape from 1999 to 2011. 'Inc.' represents increasing trend and 'Dec.' represents declining trend. The first value in each bracket is the gradient of the best-fit regression and the second value is the R^2. Non-significant P values not reported.

Network measure	Mammals	Reptiles
Average path length	Inc. (0.062; 0.49)	Inc. (0.157; 0.54)
Cluster co-efficient		
Density	Dec. (-0.0001; 0.65)	Dec. (-0.001; 0.60)
Directed diameter	Inc. (0.181; 0.34)	Inc. (0.396; 0.41)
Edges	Inc. (21.94; 0.80)	Inc. (73.99; 0.74)
Mean degree	Inc. (0.049; 0.41)	Inc. (0.06; 0.42)
Reciprocity	Inc. (0.001; 0.32)	Dec. (-0.002; 0.58)
Vertices	Inc. (18.643; 0.83)	Inc. (51.4; 0.78)

Figure 7. Selected network statistics for translocation networks of tetrapod classes from 1999 to 2011.

I wanted to test whether there was a direct relationship between network size, here measured as the number of nodes in the network, and the number of species being moved in the respective network. Using node count as the explanatory variable, and the number of species translocated as the dependent variable, linear regression demonstrated a highly significant positive relationship between node count and number of species translocated in both the mammal ($P<0.01$, $df=11$, $n=13$, $R^2=0.51$) and reptile ($P<0.001$, $df=11$, $n=13$, $R^2=0.84$) translocation networks.

Network level statistics, calculated for the entire translocation network of each tetrapod class from 1999 to 2011 (Figure 8), allow comparison of basic network architecture between the three different networks (Table 7), and the results indicate structural differences between the three networks.

Table 7. Network level statistics for tetrapod class translocation networks in the Western Cape, including all translocations from 1999 to 2011.

	Birds	Mammals	Reptiles
Average path length	4.069	5.16	3.639
Cluster co-efficient	0.026	0.016	0.004
Density	0.003	0.001	0.001
Directed diameter	9	14	11
Mean degree	3.1	3.403	3.663
Reciprocity	0.046	0.033	0.059

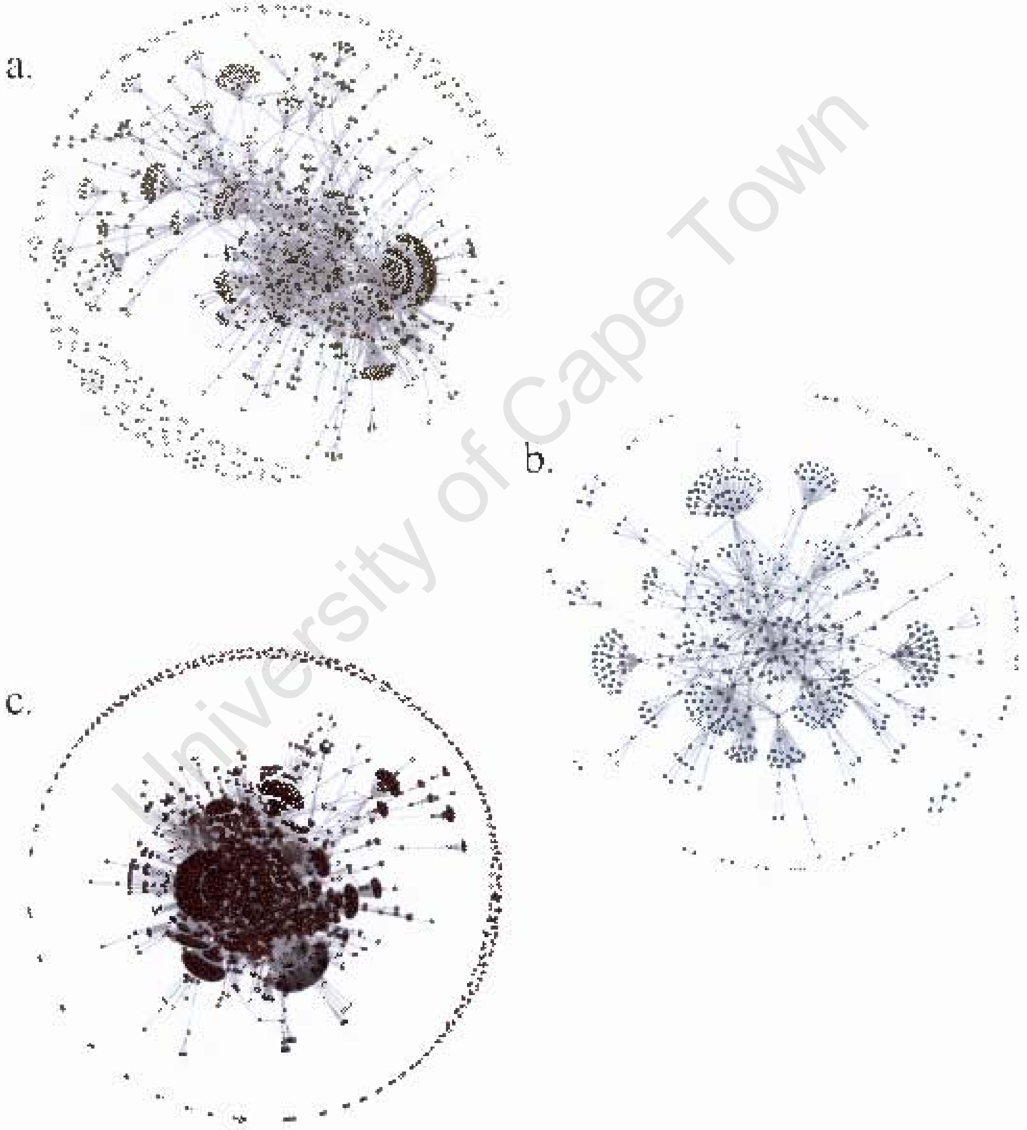

Figure 8. Network visualisations (Fruchterman Reingold layout) for tetrapod class translocation network in the Western Cape from 1999 to 2011. (a. Mammals, b. Birds, c. Reptiles). The layout has no specific dimensions, but is based on a forced-directed algorithm for node positioning.

The in and out degree distribution of the networks varied (Table 8). The mammal translocation network had the highest proportion of nodes with a positive outdegree ('sending' nodes), followed by birds and reptiles. The proportion of nodes with an outdegree of greater than one was low for reptiles compared to birds and mammals, which had similar proportions of this class of node. The proportion of nodes with an indegree ('receiving' nodes) greater than zero was much higher than the proportion of nodes with an outdegree of greater than zero, and was lowest for mammals and highest for repiles. There is a big drop from the proportion of nodes with an outdegree greater than zero to an outdegree greater than one, and mammals are left with the highest proportion of nodes in this class.

Table 8. Cumulative proportions of nodes, classed according to the magnitudes of indegrees and outdegrees, for each of the wildlife translocation networks as a whole from 1999 to 2011.

	Birds	Mammals	Reptiles
Outdegree			
> 0	0.28	0.37	0.23
> 1	0.14	0.17	0.08
In degree			
> 0	0.87	0.80	0.91
> 1	0.21	0.31	0.26

The final component of the analysis was an assessment of the architecture of each of the translocation networks relative to a random graph of the same *V* and *E* dimensions. The test for whether a network exhibits 'small world' properties takes into account the clustering co-efficient (*Cl*) and average shortest path length (*D*) (Table 9), where a small world network is one that is more highly clustered than expected from a random counterpart graph, and the average shortest paths are shorter than expected from this same random graph. In each of the cases of wildlife translocation networks in the Western Cape, the clustering co-efficient can be seen to be at least three times greater than expected of a similar random network, and the average shortest path length is in all cases considerably shorter than expected from the corresponding random graph. All three networks thus meet the criteria for having small world properties.

Table 9. Clustering co-efficient (*Cl*) and average shortest path (*D*) measures for each wildlife translocation network in the Western Cape, compared to measures expected from counterpart random graphs of the same respective dimensions *V, E.*

	Cl	**Cl**$_{Random}$	**D**	**D**$_{Random}$	Cl/CL$_{Random}$
Birds	0.024	0.0063	4.07	10.94	3.90
Mammals	0.016	0.003	5.16	10.96	5.33
Reptiles	0.004	0.0006	3.64	12.25	6.66

The degree distribution of the mammal and reptile translocation networks approximates that of a scale-free network (Figure 9), whilst the degree distribution of the bird translocation network appears to follow a truncated power law distribution. For values of degree (k) >20, the cumulative distributions of the number of translocation links decays as a power law with exponents, $\alpha = 2.35$ for birds, $\alpha = 2.32$ for the mammal translocation network and $\alpha = 1.93$ for the reptile translocation network, consistent with power law dependence in the tails of the distribution (Liljeros et al. 2001).

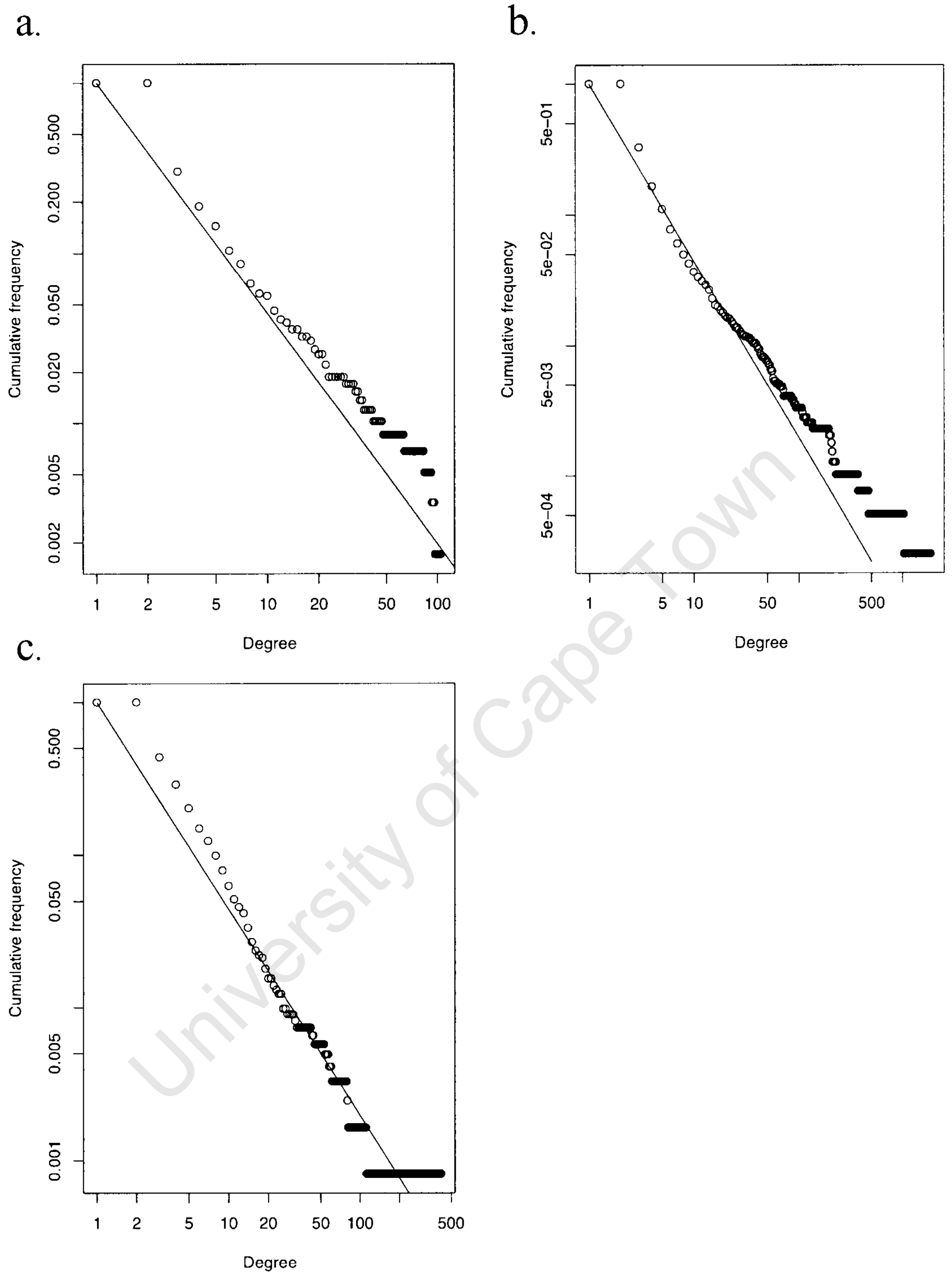

Figure 9. Cumulative degree frequency distributions for the translocation networks of birds (a), reptiles (b) and mammals (c) in the Western Cape from 1999 to 2011, with slopes of Maximum Likelihood Estimation fitted lines shown.

DISCUSSION

My results demonstrate some interesting trends in both static and dynamic elements of translocation networks in the Western Cape. In particular, the mammal and reptile translocation networks are getting larger and more connected. The bird translocation network is not showing any significant changes. The mammal network is the largest from a network perspective, and the reptile network is the most highly connected network. All the networks have a much lower proportion of nodes with a positive outdegree than nodes with a positive indegree.

Dynamic network perspective

There were no significant structural trends detected in the bird translocation network for the period from 1999 to 2011. This industry appears fairly stable, with a consistent annual number of actors and translocations, even if the actual actors change from year to year. Despite its relative stability, there was an increase in the annual number and volume of bird species traded over the same time period (Chapter Two), suggesting that the volume and number of species comprising each avian translocation event has increased.

The opposite was true however, for mammals and reptiles, with significant increases in the number of vertices (actors) and edges (translocations) in both of the networks from 1999 to 2011. Given these trends, the significant relationships between the number of vertices and the number of species being translocated in the network was particularly worrying, as it suggests that as the number of actors in the network continues to increase so will the number of species, including non-native and potentially invasive species. There is likely some threshold for annual species richness in wildlife translocations for a given area, but all indications are that the Western Cape has not yet reached that point. The effort of control is proportional to the size of the industry and so expanding networks increase the probability of non-compliance with legislation.

There was also a significant increase in directed network diameter, which is the longest directed short path from one side of the network to the other. This measure can increase either through node additions to the network, or with a decrease in density, both of which were observed here, making interpretation difficult. Average path length increased in both networks, which is the opposite of what is predicted through the "shrinking diameters" effect that has been observed in some social and information networks over time (Leskovec et al. 2005). An increasing average path length represents a 'slowing' of the rate with which non-native species and other influences, such as pathogens and parasites, can spread through a network.

Mean degree is a measure of connectance in the network, and showed significant increases in both networks. This is in line with "densification" effects that have been observed in some growing networks (Leskovec et al. 2005). Mean degree increases are important as they indicate a more connected graph that can facilitate the more extensive movement of non-native species and other negative impacts. This can be particularly important given the lag times commonly experienced between the arrival of a non-native species and its establishment as invasive (Ricciardi and Simberloff 2008). In a highly connected network, by the time a non-native species is identified as an invasive threat, it may already have spread throughout the network. However, it is not only negative impacts that spread more readily through better-connected networks. Educational information as to the harmful impacts of certain non-native species, for instance, will propagate faster through a more highly connected network. Networks with more connections may be more robust and better able to respond quickly and effectively to new threats or information (Hanneman and Riddle 2005). More connected human populations are able to better mobilise resources to respond to threats such as new invasive species.

In the cases of the mammal and reptile translocation networks for the Western Cape, density itself showed significant decreases in both cases, supporting a proposed universal rule of network organisation (Laurienti et al. 2010), that in all naturally occurring self-organised networks there is an inverse relationship between network size and connection density. The presence of this relationship in my data confirms that there is no bias in the sampling of network structure (Laurienti et al. 2010). Another of the measures conforming to well-known properties of networks is the clustering co-efficient, which is generally independent of network size (Albert & Barabasi 2002) and appeared to be so here.

Overall, the mammal and reptile translocation networks appeared to be evolving similarly as the respective wildlife translocation industries grow. The one network measure for which the trends diverge is reciprocity, which showed a significant increase in the mammal translocation network and a significant decrease in the reptile translocation network. Reciprocity simply reflects the proportion of translocations that are reciprocated. The increasing reciprocity observed in the mammal network indicates that with time there were greater numbers of nodes that were participating in some sort of exchange of mammals, as opposed to a simple one-way movement. The decreasing reciprocity of the reptile network indicates that growth in the network was dominated by one-way, unreciprocated ties. As many of the mammal translocations were of game species, the sources of wildlife in the mammal translocation network can be expected to be less dominated by a small number of nodes, and it is likely that many actors are acting as suppliers of mammals, increasing the chances of wildlife exchange and reciprocal ties. The reptile industry however, seems to be characterised by a smaller number of retailers representing the primary sources of reptiles in the network, linked to a large number of reptile pet owners by unreciprocated, once-off links representing reptile purchases. The increasing reciprocity in the mammal translocation network may have impacts for genetic exchange among populations, particularly if nodes are reciprocating with the same species, and a larger proportion of reciprocated exchange is likely to result in at least a degree of homogenisation of the gene pool.

Static network perspective

Based on the relevance of each one of these network measures to the potential spread of negative impacts, and invasive species in particular, it is possible to take a comparative static view of vulnerability of the networks to negative influences by removing the time component and treating all translocations as one discrete network for each class. Despite having the lowest density, the reptile translocation network is the most connected with the highest mean degree and shortest average path length. Although the mammal translocation network has an intermediate mean degree; low density, a long average path length and the largest diameter indicate that this network is likely the least connected. Thus the threat of the rapid spread of an invasive species is greatest for reptiles and least for mammals, with birds somewhere in between. The reptile network also displays the lowest clustering co-efficient, indicating that potential influences are less likely to be contained in one component of the network. The bird network, on the other hand, is more highly clustered and so there is potential that threats may be easier to isolate by containing one component of the network.

There appeared to be basic differences in the degree distribution among the three networks. These differences match what would be expected. Given that trade for the pet and aviary markets dominates the reptile and bird translocation networks, one would expect a smaller number of nodes involved in retailing and a large proportion of nodes merely functioning as receivers of wildlife through the transactions. The mammal translocation network is slightly different in that a large proportion was comprised of ungulates being translocated as part of the game ranching trade, and I would expect to see higher proportions of nodes acting as both sources and receivers of translocations. Table 8 shows this to be the case, with a much larger proportion of vertices having a positive outdegree in the mammal translocation network than the other two. The reptile network had a very low proportion of nodes that are acting as sources of translocations on a repeated basis, indicating that the supply of reptiles is dominated by a comparatively small proportion of the actors. In all three networks, there are much higher proportions of nodes with a positive indegree than a positive outdegree, indicating that the majority of nodes in each network all function of receivers of wildlife at some point, even if they don't function as suppliers. This also makes logical sense, as even nodes that are breeding wildlife would need to acquire breeding individuals from time to time. Overall, these figures suggest that the translocation of all tetrapod classes would be more easily controlled on the supply rather than the demand side, as there are fewer nodes on the supply side.

Small world and scale free properties

All three networks exhibited small world and scale-free properties. The degree distribution of the bird translocation network may be better described as a truncated power law distribution (Bascompte and Jordano 2007) but it is scale-free over much of the range. The most basic explanation for truncated power law distributions is small size effects, which would potentially be a rational explanation in this case. A large sample on a broader scale would determine if the bird translocation networks follow a truncated power law for larger numbers of vertices. The slopes of the lines fitted to the degree distribution plots varied from -1.93 to -2.35. The values for the bird and mammal network fall within the range similar to other networks (Albert and Barabasi 2002) but the value of -1.93 for reptiles is slightly lower than other common networks.

The structural characteristics associated with small world and scale-free properties have a number of implications for network functioning. The popular mechanism for explaining the formation of scale-free networks is that of preferential attachment (Barabasi and Albert 1999), where additional nodes joining the network attach preferentially to existing nodes in proportion the node degree, thus highly connected nodes become even more so. This leads to the highly skewed node degree distribution as observed in the wildlife translocation networks, where certain nodes function as highly connected hubs. Scale-free, small world networks propagate influences very efficiently (Watts and Strogatz 1998), and in the context of invasions this means that an invasive species could potentially spread very quickly and easily in these wildlife translocation networks. This structure also results in networks that are very stable and resilient to the random deletion of nodes (Barabasi and Bonabeau 2003). However, this same structural property makes the networks very vulnerable to 'attacks' on the hubs. Thus, the same structural characteristics that may result in rapid spread of invasive species through a wildlife translocation network may also provide an opportunity for effective control with limited resources.

Recommendations

Some basic recommendations stemming from this analysis are that first, efforts to control the spread of non-native species can be more effectively controlled on the supply side. This small number of wildlife suppliers act as hubs in the networks, and are the most logical point to focus intervention on. Frequent monitoring of these nodes may provide the best way for managers to keep their fingers on the pulse of these wildlife translocation networks. Intervention need not only be in the form of restrictive control, which is often the source of conflict and can be more destructive for the situation in the long run. Because of the relative importance and influence of these nodes, particularly for birds and reptiles, information that they provide (e.g., educational materials) could reach a maximum number of people in the network with the minimum effort. Education at the supply hubs would present a way of potentially altering demand.

CHAPTER 4

SYNTHESIS

Conclusions

The global extent of wildlife translocations has expanded drastically as a result of globalisation, and demand for wildlife continues to grow, driven particularly by the exotic pet trade. These translocations are having impacts on both source populations and on the biodiversity of the areas to which tranlocations are happening. The scale of wildlife translocations in South Africa is increasing due to increased demand in both the game industry and the expanding wild pet trade, particularly in reptiles.

The volume and number of species being translocated within the Western Cape annually has increased dramatically since 1999 and despite a slight drop over the last 2 years, there is no indication that this increasing trend will not continue into the future. Of particular importance is the potential for wildlife translocations to introduce non-native and invasive species. My analysis shows a significant increase from 1999 to present in both number and volume of non-native species involved in translocations in the Western Cape. Importantly, there has also been a significant increase in proportion of non-native species relative to the total number of species translocated annually, suggesting that for whatever reason, non-native species are becoming more popular in the Western Cape. This trend is likely to continue as the pet trade continues to expand and game ranchers seek to stock commercially valuable extralimital species on their properties. All of these trends contribute to increased propagule pressure, in the form of increased introduction volumes and an increased number of introduction events, which is a key factor in the establishment and transition of a non-native species to an invasive one.

The system of wildlife translocations in the Western Cape can be represented as a linked social-ecological network where the nodes in the network represent human actors and the links between them represented translocations of biodiversity. The underlying structure of these networks has implications for how rapidly influences, such as the spread of invasive species, may propagate through the network as well as where the most effective intervention points are. The networks for mammal and reptile translocations have both changed significantly as they have grown. The network of reptile translocations is the most connected network, followed by birds, then mammals. Invasive species thus have greater capacity for spread in the reptile translocation network than the mammal translocation network. The bulk of invasive species are reptiles and birds and so this correlation between propagule pressure and network connectivity is worrying from the perspective of invasive spread. All three of the networks were found to show scale-free, small world properties, both of which potentially facilitate the rapid propagation of invasive species, parasites, and pathogens throughout the network. The threat of introduction of invasive species in the Western Cape is growing annually, and if an invasive does become embedded in the translocation system, these networks may facilitate rapid spread. However, these same structural characteristics open up opportunity for intervention at strategic hubs in the network, where maximum influence can be gained.

Study limitations

There were a number of caveats with regard to the data itself, all of which I identified and briefly discussed in the methods section of Chapter \ Two. Time constraints kept me from collecting all of the data available for the Western Cape, but I was able to include the majority of records and the robustness of the results suggests that the inclusion of the small amount of missing data would not change any of the trends reported here.

Future research

The demonstrated success of the network technique in analysing wildlife translocations in the Western Cape will hopefully inspire similar analyses of other wildlife translocation networks in different areas and at different scales. Interregional and international comparisons are important because a large amount of wildlife translocations happen on these scales, with potential for intercontinental invasions.

In any similar future research, the inclusion of socio-economic attributes for each node in the network would allow for powerful conclusions to be drawn about the ways in which these attributes configure the structure of the biodiversity translocation networks. The methods used here could also be expanded to apply to spatial data detailing translocations, potentially facilitating the construction of models that may predict how far a particular species may travel in a translocation network, and thus by how far it may potentially expand its range.

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Appendix 1. Data sources for translocation permits for tetrapod translocations in the Western Cape from 1999 to 2011.

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
Boland														
Excluded records			7	24	9	6	1	1	5	3				
Translocation permits			34	247	103	36	27	18	42	10				
George														
Excluded records									12	6		3		
Translocation permits					2				63	30		1		
Head office database														
Excluded records	59	72	96	71	60	35	39	19	15	17	13	7	3	
Translocation permits	130	149	266	478	414	673	712	388	817	1463	1319	1262	1178	
Hermanus														
Excluded records		1	1		1									
Translocation permits	2	6	6	9	11	11	10	16	8	5				
Oudtshoorn														
Excluded records				2		7	30	10	3					
Translocation permits	1	3	1	2	8	14	93	38	61					
Riversdale														
Excluded records														
Translocation permits			1	2	2	1	1							
Total excluded records	59	73	104	97	70	48	70	30	35	26	13	10	3	**638**
Total translocation permits	133	158	308	738	540	735	843	460	991	1508	1319	1263	1178	**10174**

Appendix 2. Species list of tetrapods translocated in the Western Cape from 1999 to 2011, including the total number translocated.

Common name	Scientific name	Volume translocated
Amphibia		
African bullfrog	*Pyxicephalus adspersus*	18
African clawed frog	*Xenopus laevis*	350
Axolotl	*Ambystoma mexicanum*	Not recorded
Cape river frog	*Afrana fuscigula*	1
Green & black poison dart frog	*Dendrobates auratus*	3
Natal tree frog	*Leptopelis natalensis*	22
Painted reed frog	*Hyperolius mamoratus*	1
Ranger's toad	*Bufo rangeri*	2
Sand toad	*Bufo angusticeps*	2
Aves		
African firefinch	*Lagonosticta rubricata*	8
African goshawk	*Accipiter tachiro*	1
African penguin	*Spheniscus demersus*	7
American wigeon	*Anas americana*	4
Argentine bluebilled duck	*Oxyura vittata*	2
Bahama pintail duck	*Anas bahamensis*	25
Baikal teal	*Anas formosa*	4
Bald ibis	*Geronticus calvus*	1
Bali myna	*Leucopsar rothschildi*	3
Barheaded goose	*Anser indicus*	13
Barn owl	*Tyto alba*	33
Barnacle goose	*Branta leucopsis*	12
Bengal eagle owl	*Bubo bengalensis*	8
Black and white casqued hornbill	*Bycanistes subcylindricus*	2
Black capped lory	*Lorius lory*	2
Black crow	*Corvus capensis*	2
Black duck	*Anas sparsa*	6
Black shouldered kite	*Elanus axillaris*	1
Black sparrowhawk	*Accipiter melanoleucus*	3
Black swan	*Cygnus atratus*	217
Black throated canary	*Serinus atrogularis*	8
Black vulture	*Coragyps atratus*	2
Black widow finch	*Vidua funerea*	3
Black-cheeked waxbill	*Estrilda erythronotos*	41
Black-crowned night heron	*Nycticorax nycticorax*	1
Black-headed canary	*Serinus alario*	21
Blacknecked swan	*Cygnus melancoryphus*	20
Blue and gold macaw	*Ara ararauna*	6
Blue bellied roller	*Coracias cyanogaster*	1
Blue crane	*Grus paradisea*	48
Blue fronted parrot	*Amazona aestiva*	8
Blue magpie	*Urocissa erythrorhyncha*	1
Blue quail	*Coturnix chinensis*	12
Blue waxbill	*Uraeginthus angolensis*	54

Blue winged mountain-tanager	*Anisognathus somptuosus*	2
Blue winged teal	*Anas discors*	7
Blue-throated macaw	*Ara glaucogularis*	2
Booted eagle	*Hieraaetus pennatus*	1
Brazilian teal	*Amazonetta brasiliensis*	4
Brimstone canary	*Serinus sulphuratus*	4
Bronze mannikin	*Lonchura cucullata*	8
Brown pelican	*Pelecanus occidentalis*	4
Brown-headed parrot	*Poicephalus cryptoxanthus*	196
Burrowing owl	*Athene cunicularia*	3
Cackling goose	*Branta hutchinsii*	6
Canada goose	*Branta canadensis*	38
Canvasback	*Aythya valisineria*	4
Cape canary	*Serinus canicollis*	21
Cape cormorant	*Phalacrocorax capensis*	1
Cape eagle owl	*Bubo capensis*	6
Cape glossy starling	*Lamprotornis nitens*	4
Cape parrot	*Poicephalus robustus*	109
Cape shoveler	*Anas smithii*	22
Cape siskin	*Serinus totta*	2
Cape teal	*Anas capensis*	4
Cape vulture	*Gyps coprotheres*	3
Cape weaver	*Ploceus capensis*	13
Carolina wood duck	*Aix sponsa*	197
Chestnut teal	*Anas castanea*	9
Chiloe wigeon	*Anas sibilatrix*	14
Cinnamon dove	*Aplopelia larvata*	11
Cinnamon teal	*Anas cyanoptera*	2
Comb duck	*Sarkidiornis melanotos*	9
Common goldeneye	*Bucephala clangula*	2
Common moorhen	*Gallinula chloropus*	15
Common quail	*Coturnix coturnix*	7
Common shelduck	*Tadorna tadorna*	23
Common waxbill	*Estrilda astrild*	24
Coscoroba swan	*Coscoroba coscoroba*	11
Crested guineafowl	*Guttera pucherani*	3
Crowned cormorant	*Phalacrocorax coronatus*	1
Crowned crane	*Balearica regulorum*	15
Crowned eagle	*Harpyhaliaetus coronatus*	1
Crowned hornbill	*Tockus alboterminatus*	1
Cuban parrot	*Amazona leucocephala*	2
Cut throat finch	*Amadina fasciata*	26
Demoiselle crane	*Grus virgo*	6
Double wattled (southern) cassowary	*Casuarius casuarius*	2
Ducorps's cockatoo	*Cacatua ducorpsii*	2
Eclectus parrot	*Eclectus roratus*	2
Egyptian goose	*Alopochen aegyptiaca*	4
Emu	*Dromaius novaehollandiae*	7
Eurasian scops owl	*Otus scops*	1
Eurasian wigeon	*Anas penelope*	2
European eagle owl	*Bubo bubo*	3
European honey buzzard	*Pernis apivorus*	1
Falcated teal	*Anas falcata*	1

Ferruginous duck	*Aythya nyroca*	2
Ferruginous pygmy owl	*Glaucidium brasilianum*	4
Fischer's turaco	*Tauraco fischeri*	2
Forest buzzard	*Buteo trizonatus*	2
Forest canary	*Serinus scotops*	5
Fulvous whistling duck	*Dendrocygna bicolor*	74
Gadwall	*Anas strepera*	1
Glossy ibis	*Plegadis falcinellus*	4
Goffin's cockatoo	*Cacatua goffiniana*	37
Golden parakeet	*Guaruba gurouba*	4
Golden pheasant	*Chrysolophus pictus*	12
Golden-breasted bunting	*Emberiza flaviventris*	2
Golden-breasted starling	*Cosmopsarus regius*	2
Great cormorant	*Phalacrocorax carbo*	1
Great green macaw	*Ara ambiguus*	8
Greater flamingo	*Phoenicopterus roseus*	33
Greater hill mynah	*Gracula religiosa*	2
Greater kestrel	*Falco rupicoloides*	2
Green pigeon	*Treron calvus*	8
Green winged teal	*Anas crecca*	2
Green-crested turaco	*Tauraco persa*	8
Green-spotted dove	*Turtur chalcospilos*	35
Grey heron	*Ardea cinerea*	2
Grey-headed parrot	*Poicephalus fuscicollis*	16
Greyheaded sparrow	*Passer griseus*	3
Guinea turaco	*Tauraco persa*	2
Hadeda ibis	*Bostrychia hagedash*	14
Harlequin quail	*Coturnix delegorguei*	5
Harris hawk	*Parabuteo unicinctus*	3
Hawaiian goose	*Branta sandvicensis*	20
Helmeted guinea fowl	*Numida meleagris*	104
Hooded merganser	*Lophodytes cucullatus*	4
Hottentot teal	*Anas hottentota*	28
House crow	*Corvus splendens*	5
House sparrow	*Passer domesticus*	7
Hyacinth macaw	*Anodorhynchus hyacinthinus*	4
Illigers macaw	*Propyrrhura maracana*	21
Indian peafowl	*Pavo cristatus*	19
Jackal buzzard	*Buteo rufofuscus*	10
Karoo scrub robin	*Erythropygia coryphaeus*	18
King vulture	*Sarcoramphus papa*	1
Knysna turaco	*Tauraco corythaix*	8
Lanner falcon	*Falco biarmicus*	10
Laughing dove	*Stigmatopelia senegalensis*	7
Laughing kookaburra	*Dacelo novaeguineae*	6
Lesser flamingo	*Phoeniconaias minor*	3
Lilac crowned parrot	*Amazona finschi*	2
Long tailed glossy starling	*Lamprotornis caudatus*	2
Long tailed paradise whydah	*Vidua interjecta*	2
Ludwig's bustard	*Neotis ludwigii*	1
Luzon bleeding heart	*Gallicolumba luzonica*	7
Macaroni penguins	*Eudyptes chrysolophus*	1
Mallard duck	*Anas platyrhynchos*	2

Mandarin duck	*Aix galericulata*	180
Maned goose	*Chenonetta jubata*	22
Marabou stork	*Leptoptilos crumeniferus*	3
Marbled teal	*Marmaronetta angustirostris*	12
Marsh owl	*Asio capensis*	2
Martial eagle	*Polemaetus bellicosus*	1
Masked lapwing	*Vanellus miles*	9
Melba finch	*Pytilia melba*	59
Meyers parrot	*Poicephalus meyeri*	350
Military macaw	*Ara militaris*	12
Moluccan cockatoo	*Cacatua moluccensis*	6
Mute swan	*Cygnus olor*	55
Namaqua dove	*Oena capensis*	65
Nicobar pigeon	*Caloenas nicobarica*	9
Northern bobwhite	*Colinus virginianus*	9
Northern pintail	*Anas acuta*	16
Northern shoveler	*Anas clypeata*	6
Olive thrush	*Turdus olivaceus*	4
Orange-breasted waxbill	*Amandava subflava*	20
Orinoco goose	*Neochen jubata*	12
Ostrich	*Struthio camelus*	6
Pale chanting goshawk	*Melierax canorus*	1
Palm cockatoo	*Probosciger aterrimus*	5
Paradise shelduck	*Tadorna variegata*	6
Peregrine falcon	*Falco peregrinus*	3
Philippine duck	*Anas luzonica*	13
Pied crow	*Corvus albus*	4
Pied manninkin	*Lonchura fringilloides*	3
Puna teal	*Anas puna*	7
Purple gallinule	*Porphyrio martinica*	2
Purple glossy starling	*Lamprotornis purpureus*	4
Purple-crested lourie	*Tauraco porphyreolophus*	23
Quailfinch	*Ortygospiza atricollis*	53
Radjah shelduck	*Tadorna radjah*	12
Rameron pigeon	*Columba arquatrix*	22
Red & yellow barbet	*Trachyphonus erythrocephalus*	2
Red backed mannikin	*Lonchura nigriceps*	56
Red bellied parrot	*Poicephalus rufiventris*	2
Red bishop	*Euplectes orix*	19
Red crested pochard	*Netta rufina*	16
Red headed finch	*Amadina erythrocephala*	6
Red-billed firefinch	*Lagonosticta senegala*	15
Red-billed hornbill	*Tockus erythrorhynchus*	11
Red-billed teal	*Anas erythrorhyncha*	19
Red-breasted sparrowhawk	*Accipiter rufiventris*	1
Red-eyed dove	*Streptopelia semitorquata*	4
Redbreasted goose	*Branta ruficollis*	1
Redfronted macaw	*Ara rubrogenys*	10
Redfronted parakeet	*Cyanoramphus novaezelandiae*	6
Redwinged starling	*Onychognathus morio*	2
Ring-necked duck	*Aythya collaris*	2
Ringed teal	*Callonetta leucophrys*	56
Rock dove	*Columba livia*	1

Rock kestrel	*Falco tinnunculus*	15
Rosy-billed pochard	*Netta peposaca*	11
Rosy-faced lovebird	*Agapornis roseicollis*	100
Ruddy duck	*Oxyura jamaicensis*	8
Ruddy shelduck	*Tadorna ferruginea*	10
Ruddy-headed goose	*Chloephaga rubidiceps*	2
Ruppell's parrot	*Poicephalus rueppellii*	21
Sacred ibis	*Threskiornis aethiopicus*	10
Saddle-billed stork	*Ephippiorhynchus senegalensis*	2
Saker falcon	*Falco cherrug*	2
Scalyfeathered finch	*Sporopipes squamifrons*	8
Scarlet ibis	*Eudocimus ruber*	25
Scarlet macaw	*Ara macao*	43
Secretarybird	*Sagittarius serpentarius*	11
Senegal parrot	*Poicephalus senegalus*	2
Shaft tailed wydah	*Vidua regia*	2
Sharp winged teal	*Anas flavirostris*	10
Silver pheasant	*Lophura nycthemera*	8
Silver teal	*Anas versicolor*	7
Silver-cheeked hornbill	*Bycanistes brevis*	13
Smew	*Mergellus albellus*	11
Snow goose	*Chen caerulescens*	2
South african shelduck	*Tadorna cana*	28
Southern ground hornbill	*Bucorvus cafer*	3
Southern masked weaver	*Ploceus velatus*	10
Southern pochard	*Netta erythrophthalma*	17
Spotted eagle owl	*Bubo africanus*	24
Spurwinged goose	*Plectropterus gambensis*	13
Steppe buzzard	*Buteo buteo*	1
Streaky-headed canary	*Serinus gularis*	6
Sulphur crested cockatoo	*Cacatua galerita*	21
Superb starling	*Lamprotornis superbus*	2
Swee waxbill	*Estrilda melanotis*	10
Tambourine dove	*Turtur tympanistria*	38
Thick billed weaver	*Amblyospiza albifrons*	6
Trumpeter hornbill	*Bycanistes bucinator*	1
Trumpeter swan	*Cygnus buccinator*	2
Tucamon parrot	*Amazona tucumana*	4
Turkmenian eagle owl	*Bubo bubo*	2
Umbrella cockatoo	*Cacatua alba*	3
Upland goose	*Chloephaga picta*	4
Verreauxs eagle	*Aquila verreauxii*	4
Verreauxs eagle owl	*Bubo lacteus*	8
Vinaceous amazon	*Amazona vinacea*	4
Violet-backed starling	*Cinnyricinclus leucogaster*	6
Violet-eared waxbill	*Uraeginthus granatinus*	43
Von der deckens hornbill	*Tockus deckeni*	15
Vulturine guinea fowl	*Acryllium vulturinum*	2
Waldrapp ibis	*Geronticus eremita*	10
Wandering whistling duck	*Dendrocygna arcuata*	8
Western crowned-pigeon	*Goura cristata*	3
White pelican	*Pelecanus onocrotalus*	20
White Stork	*Ciconia ciconia*	5

White throated canary	*Serinus albogularis*	4
White winged widowbird	*Euplectes albonotatus*	2
White-backed vulture	*Gyps africanus*	2
White-browed coucal	*Centropus superciliosus*	1
White-faced owl	*Otus leucotis*	8
White-faced whistling duck	*Dendrocygna viduata*	75
Whooper swan	*Cygnus cygnus*	2
Wood owl	*Strix woodfordii*	4
Yellow canary	*Serinus flaviventris*	8
Yellow-billed duck	*Anas undulata*	170
Yellow-billed hornbill	*Tockus flavirostris*	12
Yellow-billed kite	*Milvus migrans*	5
Yellow-crested cockatoo	*Cacatua sulphurea*	14
Yellow-crowned bishop	*Euplectes afer*	4
Yellow-eyed canary	*Serinus mozambicus*	2
Yellow-headed parrot	*Amazona oratrix*	8
Yellow-naped parrot	*Amazona auropalliata*	4
Yellowbilled stork	*Mycteria ibis*	3

Mammalia

Bat-eared fox	*Otocyon megalotis*	6
Black spider monkey	*Ateles paniscus*	1
Black tufted-ear marmoset	*Callithrix penicillata*	61
Black wildebeest	*Connochaetes gnou*	326
Black-backed jackal	*Canis mesomelas*	6
Blesbok	*Damaliscus pygargus phillipsi*	728
Blue duiker	*Philantomba monticola*	14
Blue wildebeest	*Connochaetes taurinus*	205
Bolivian squirrel monkey	*Saimiri boliviensis*	9
Bontebok	*Damaliscus pygargus pygargus*	1516
Brown capuchin monkey	*Cebus apella*	11
Brown hyaena	*Hyaena brunnea*	6
Brown-mantled tamarin	*Saguinus fuscicollis*	3
Buffalo	*Cyncerus caffer*	142
Bushbuck	*Tragelaphus scriptus*	23
Bushpig	*Potamochoerus porcus*	4
Cape clawless otter	*Aonyx capensis*	2
Capuchin monkey	*Cebus capucinus*	12
Caracal	*Felis caracal*	24
Chacma baboon	*Papio hamadryas ursinus*	87
Chimpanzee	*Pan troglodytes*	4
Common duiker	*Sylvicapra grimmia*	17
Common marmoset	*Callithrix jacchus jacchus*	650
Common squirrel monkey	*Saimiri sciureus*	24
Cotton-top marmoset	*Saguinus geoffroyi*	15
Cotton-top tamarin	*Saguinus oedipus oedipus*	45
Dama wallaby	*Macropus eugenii*	8
Eland	*Taurotragus oryx*	2138
Elephant	*Loxodonta africana*	3
Fallow deer	*Cervus dama dama*	202
Gemsbok	*Oryx gazella*	1874
Geoffrey marmoset	*Callithrix geoffroyi*	1
Giraffe	*Giraffa camelopardalis*	130

Greater bushbaby	*Otolemur crassicaudatus*	1
Grey rhebok	*Pelea capreolus*	101
Ground squirrel	*Xerus inauris*	1
Grysbok	*Raphicerus melanotis*	99
Hamadryas baboon	*Papio hamadryas hamadryas*	4
Hippopotamus	*Hippopotamus amphibius*	4
Honey badger	*Mellivora capensis*	1
Impala	*Aepyceros melampus*	107
Klipspringer	*Oreotragus oretragus*	16
Kudu	*Tragelaphus strepsiceros*	811
Large spotted genet	*Genetta tigrina*	5
Leopard	*Panthera pardus*	2
Lion	*Panthera leo*	25
Llama	*Lama glama*	3
Marsh mongoose	*Atilax paludinosus*	3
Mountain zebra	*Equus zebra*	113
Northern night monkey	*Aotus trivirgatus*	1
Nyala	*Tragelaphus angasii*	102
Patas monkey	*Erythrocebus patas*	1
Plains zebra	*Equus quagga*	1245
Porcupine	*Hystrix africaeaustralis*	20
Pygmy marmoset	*Cebuella pygmaea*	9
Raccoon	*Procyon lotor*	4
Red hartebeest	*Alcephalus buselaphus*	1040
Red lechwe	*Kobus leche*	45
Red-handed tamarin monkey	*Saguinus midas*	9
Ringtailed lemur	*Lemur catta*	3
Rock hyrax	*Procavia capensis*	3
Sable antelope	*Hippotragus niger niger*	10
Small grey mongoose	*Galerella pulverulenta*	3
Small spotted genet	*Genetta genetta*	1
South african hedgehog	*Atelerix frontalis*	1
Springbok	*Antidorcas marsupialis*	11597
Steenbok	*Raphicerus campestris*	72
Straw colored fruit bat	*Eidolon helvum*	1
Striped polecat	*Ictonyx striatus*	2
Striped weasel	*Poecilogale albinucha*	1
Sugar glider	*Petaurus breviceps*	2
Suni	*Neotragus moschatus*	5
Suricate	*Suricata suricatta*	11
Vervet monkey	*Chlorocebus aethiops*	35
Waterbuck	*Kobus ellipsiprymnus*	86
Weeper capuchin	*Cebus olivaceus*	4
White-lipped tamarin	*Saguinus labiatus*	2
Wild dog	*Lycaon pictus*	3
Reptilia		
African helmeted turtle	*Pelomedusa subrufa*	20
African rock python	*Python sebae*	84
Aldabra giant tortoise	*Geochelone gigantea*	3
Amazon tree boa	*Corallus hortulanus*	5
American alligator	*Alligator mississippiensis*	2
Amethystine python	*Morelia amethistina*	3

Anchieta's cobra	*Naja anchietae*	1
Angulate tortoise	*Chersina angulata*	1503
Arizona kingsnake	*Lampropeltis pyromelana*	8
Armadillo girdled lizard	*Cordylus cataphractus*	3
Aurora house snake	*Lamprophis aurora*	92
Baird's rat snake	*Elaphe bairdi*	11
Ball python	*Python regius*	714
Bearded dragon	*Pogona vitticeps*	3
Beauty rat snake	*Elaphe taenuira*	306
Beetz's tiger snake	*Telescopus beetzii*	7
Berg adder	*Bitis atropos*	26
Bibron's thick-toed gecko	*Pachydactylus bibronii*	124
Black & white cobra	*Naja siamensis*	3
Black mamba	*Dendroaspis polylepis*	33
Black-headed dwarf chameleon	*Bradypodion melanocephalum*	1
Black-necked spitting cobra	*Naja nigricollis*	14
Blood python	*Python curtus*	52
Blue-tongue skink	*Tiliqua nigrolutea*	20
Boa constrictor	*Boa constrictor*	1360
Boomslang	*Dispholidus typus typus*	63
Brown house snake	*Lamprophis fuliginosus*	1169
Bush viper	*Atheris squamigera*	6
Caiman crocodile	*Caiman crocodylus*	1
Cape cobra	*Naja nivea*	180
Cape dwarf chameleon	*Bradypodion pumilum*	3
Cape skink	*Mabuya capensis*	1
Carpet chameleon	*Furcifer lateralis*	6
Carpet python	*Morelia spilota*	243
Centralian python	*Morelia bredli*	14
Children python	*Antaresia childreni*	8
Chinese cobra	*Naja atra*	11
Common brown water snake	*Lycodonomorphus rufulus*	5
Common cantil	*Agkistrodon bilineatus*	2
Common egg-eater	*Dasypeltis scabra*	242
Common kingsnake	*Lampropeltis getula*	1064
Common padloper	*Homopus areolatus*	87
Common slug eater	*Duberria lutrix*	3
Copperhead	*Agkistrodon contortrix*	93
Coral snake	*Aspidelaps lubricus*	39
Corn snake	*Elaphe guttata guttata*	4341
Cottonmouth	*Agkistrodon piscivorus*	52
Crested gecko	*Rhacodactylus ciliatus*	145
Cuban boa	*Epicrates angulifer*	7
Cunningham's skink	*Egernia cunninghami*	9
Dumeril boa	*Acrantophis dumerilii*	16
Dwarf python	*Python anchietae*	2
East african egg eater	*Dasypeltis medici medici*	1
Eastern blue-tongued skink	*Tiliqua scincoides*	5
Eastern rat snake	*Pantherophis obsoletus*	446
Eastern rattlesnake	*Crotalus adamanteus*	1
Egyptian cobra	*Naja haje*	20
Emerald tree boa	*Corallus caninus*	5
European pond terrapin	*Emys orbicularis*	1

False water cobra	*Hydrodynastes gigas*	26
Flat nose tree viper	*Trimeresurus puniceus*	1
Forest cobra	*Naja melanoleuca*	30
Frilled lizard	*Chlamydosaurus kingii*	11
Gaboon viper	*Bitis gabonica*	46
Gargoyle gecko	*Rhacodactylus auriculatus*	13
Giant ground gecko	*Chondrodactylus angulifer*	301
Girdled lizzard	*Cordylus warreni*	4
Gold dust day gecko	*Phelsuma laticauda laticauda*	1
Gopher snake	*Pituophis catenifer*	105
Great lakes bush viper	*Atheris nitschei*	3
Green anaconda	*Eunectes murinus*	1
Green iguana lizard	*Iguana iguana*	19
Green mamba	*Dendroaspis angusticeps*	64
Green tree python	*Morelia viridis*	20
Grey-banded king snake	*Lampropeltis alterna*	62
Herald snake	*Crotaphopeltis hotamboeia*	8
Hermans tortoise	*Testuda hermanii*	4
Horned adder	*Bitis caudalis*	31
Indian python	*Python molurus*	572
Indian spectacled cobra	*Naja naja*	4
Kalahari tent tortoise	*Psammobates oculiferus*	1
Karoo tent tortoise	*Psammobates tentorius*	13
Kenyan sand boa	*Gongylophis colubrinus*	47
Knysna dwarf chameleon	*Bradypodion damaranum*	7
Leaf tailed gecko	*Uroplatus phantasticus*	1
Leopard gecko lizard	*Eublepharis macularius*	10
Leopard tortoise	*Geochelone pardalis*	1435
Lowland swamp viper	*Proatheris superciliaris*	6
Macklots python	*Liasis mackloti*	6
Madagascan ground boa	*Acrantophis madagascariensis*	9
Madagascan tree boa	*Sanzinia madagascariensis*	1
Madagascar day gecko	*Phelsuma madagascariensis*	18
Many-horned adder	*Bitis cornuta*	4
Massasauga	*Sistrurus catenatus*	4
Mellers chameleon	*Chamaeleo melleri*	4
Mexican kingsnake	*Lampropeltis mexicana*	67
Milk snake	*Lampropeltis triangulum*	514
Mole snake	*Pseudaspis cana*	187
Monocled cobra	*Naja kaouthia*	17
Mozambique spitting cobra	*Naja mosambica*	33
Natal green snake	*Philothamnus natalensis*	13
Natal midlands dwarf chameleon	*Bradypodion thamnobates*	3
New guinea blue skink	*Tiliqua gigas*	2
New guinea red-bellied turtle	*Emydura subglobosa*	1
Nile crocodile	*Crocodylus niloticus*	3367
Nile monitor	*Varanus niloticus*	2
Nubian cobra	*Naja nubiae*	4
Olive grass snake	*Psammophis mossambicus*	3
Olive house snake	*Lamprophis inornatus*	67
Oriental rat snake	*Ptyas mucosus*	5
Ottoman viper	*Montivipera xanthina*	2
Panther chameleon	*Furcifer pardalis*	31

Papuan taipan	*Oxyuranus scutellatus canni*	2
Parsons chameleon	*Chamaeleo parsonii*	3
Pine snake	*Pituophis melanoleucus*	75
Popes tree viper	*Trimeresurus popeiorum*	19
Prairie king snake	*Lampropeltis calligaster*	6
Puff adder	*Bitis arietans arietans*	195
Purple mangrove viper	*Trimeresurus purpureomaculatus*	10
Radiated rat snake	*Elaphe radiata*	10
Rainbow boa	*Epicrates cenchria*	333
Red spitting cobra	*Naja pallida*	11
Red-eared terrapin	*Chrysemys scripta elegans*	7
Reticulated python	*Python reticulatus*	66
Rhinoceros viper	*Bitis nasicornis*	15
Rinkhals	*Hemachatus haemachatus*	58
Rock monitor	*Varanus albigularis*	123
Russian amur rat snake	*Elaphe schrencki*	2
Ruthvens kingsnake	*Lampropeltis ruthveni*	10
Sahara horned viper	*Cerastes cerastes*	23
Savannah monitor	*Varanus exanthematicus*	10
Sharp nosed pit viper	*Deinagkistrodon acutus*	2
Shield nose snake	*Aspidelaps scutatus*	1
Side-winding adder	*Bitis peringueyi*	3
Snouted cobra	*Naja annulifera*	23
South american rattlesnake	*Crotalus durissus*	42
Southern brown egg eater	*Dasypeltis inornata*	28
Speckled padloper	*Homopus signatus*	1
Spotted bush snake	*Philothamnus semivariegatus*	5
Spotted harlequin snake	*Homoroselaps lacteus*	4
Spotted house snake	*Lamprophis guttatus*	3
Spotted python	*Antaresia maculosa*	133
Spotted skaapsteker	*Psammophylax rhombeatus*	36
Spur thigh tortoise	*Testudo graeca*	1
Sri lankan green pit viper	*Trimeresurus trigonocephalus*	2
Striped skaapsteker	*Psammophylax tritaeneatus*	5
Sungazer	*Cordylus giganteus*	16
Taiwan beauty snake	*Orthriophis taeniurus friesi*	12
Tentacled water snake	*Erpeton tentaculatum*	1
Veiled chameleon	*Chamaeleo calyptratus*	227
Velvet gecko	*Homopholis mulleri*	2
Vine snake	*Thelotornis capensis*	7
Water monitor	*Varanus salvator*	8
Western diamond back rattlesnake	*Crotalus atrox*	173
Western hog nosed snake	*Heterodon nasicus*	1
White-lipped tree viper	*Trimeresurus albolabris*	80
Yellow anaconda	*Eunectus notaeus*	251