HUNTING AND CONSERVATION OF FOREST PIGEONS IN SÃO TOMÉ (WEST AFRICA)

TESE APRESENTADA PARA OBTENÇÃO DO GRAU DE DOUTOR EM BIOLOGIA

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Lisboa

2015

"The greatest enterprise of the mind has always been and always will be the attempted linkage of the sciences and humanities. The ongoing fragmentation of knowledge and resulting chaos in philosophy are not reflections of the real world but artifacts of scholarship."

E.O. Wilson

(Consilience – The Unity of Knowledge)

RESUMO

Na ilha de São Tomé, são caçadas como recurso alimentar e/ou económico quatro espécies endémicas de pombos frugívoros. Nesta tese pretendi recolher e analisar as informações de base necessárias para a gestão dos pombos, que tenham em consideração a sua importância como recurso mas também o seu valor global de conservação. Para tal, recorri a uma combinação de métodos de amostragem de carácter biológico e social. Os resultados mostram que a caça de pombos é realizada para fins comerciais por um grupo restrito e especializado de caçadores, mas também amplamente praticada de forma oportunista pela generalidade dos caçadores e habitantes rurais. A pressão de caça sobre as duas espécies menos abundantes reflecte se nos seus padrões de distribuição e abundância e a sua extracção é provavelmente insustentável. No caso da espécie mais visada pela caça, a exploração é potencialmente sustentável, mas mais estudos são essenciais para a definição de medidas de gestão da espécie. Apenas uma das espécies não é caçada comercialmente e a sua exploração é sustentável. A conservação dos pombos a longo prazo requer a aplicação de medidas específicas; incluindo restrições legais à caça e venda, alternativas económicas à caça de aves e estratégias de educação/sensibilização dos consumidores.

SUMMARY

On the island of São Tomé, four endemic species of fruit pigeons are hunted as food and/or as an economic resource. This thesis intended to collect and analyze the baseline data required for the management of pigeons, which take into account their importance as a resource but also their overall conservation value. For this, I used a combination of biological and social sampling methods. The results show that harvest of endemic pigeons is performed predominantly for commercial purposes by a small and specialized group of hunters, but is also widely practiced opportunistically by most hunters and rural inhabitants. The hunting pressure on the two least abundant species already determines their patterns of distribution and abundance, and their extraction is probably unsustainable. Harvesting of the most hunted species is potentially sustainable, but more research is essential to the definition of measures to manage the species. Only one species is not commercially hunted and exploitation for subsistence is sustainable. The conservation of the species on the long term requires the development of specific measures; it is essential to promote legal restrictions on hunting and trading, to search for economic alternatives for bird hunting and define strategies of education / awareness of consumers.

ACKNOWLEDGMENTS

None of this would be possible without my PhD grant and the I&D project "Endemic pigeons of São Tomé: developing science-based conservation and sustainable use of African pigeons", both of them funded by the Portuguese Foundation for Science and Technology, from the Ministry of Science and Technology. I also thank to the Rufford Foundation by a Rufford Small Grant awarded to help with field work.

I have been very lucky to count on lot of a people, who either helped me throughout this odyssey or contributed hugely to it, and who I extend my sincere thanks. First of all, my supervisors: Prof. John E. Fa, the responsible for the my "turning" into the tropics in the first place, and in particular for São Tomé; Prof. Jorge Palmeirim, who has been supporting me all the way through the times in Africa, and whose patience and motivation have been invaluable; Prof. Francisco Rego, and his valuable inputs during the endless paper writings.

In São Tomé, I had wonderful support and connections. I would like to express my appreciation to Engª Arlindo Carvalho, Dr. Vitor Bonfim and Engº Salvador Sousa Pontes, who have helped with all the logistics about being resident and researching in a southern country, and have always been available to discuss potential inputs of the research. Technical and field support was ensured by the Associação Monte Pico, thanks to Luis Mário Almeida for all the cooperation from the beginning, and a very special thanks to the field assistants: Nity, Gabriel, Nelson and all that helped in many different ways. I've learned so much! You rock. Also thanks to Ricardo Lima and Bastien Lolumb, as well as the "Pigeons' project" team, for shared work and companionship.

The time spent in São Tomé was mostly amazing, and I owe a big thanks to the people who had shared any part of it. This includes the magic 7 months living in the mountains with two small children; a special thanks to all the Nova Moca community for making us feel so welcome and treating us as part of the village. I don't have enough space to name everybody, but there is a space inside fulfilled by all of them.

For the unconditional support and endless favours during all this time, an enormous appreciation to my family, particularly to my mother Rita and all the (enourmous) effort made for me to put this through. To Simão, for the patience and the big heart. But also to Zé, Celso, grandparents, extended family, my friends and everybody that encouraged and helped along the way, even that just by being there. A special thanks to Fátima for the support and encouragement this last months, the trigger to the "grand finale".

Finally, this thesis is dedicated to my boys, Malik e Said, who have growned with this project and with whom I have happily shared living and learning in São Tomé.

TABLE OF CONTENTS

Chapter 5

Chapter 6

LIST OF FIGURES

LIST OF TABLES

LIST OF CHAPTER APPENDICES

Chapter 1

INTRODUCTION

1.1. Hunting and Conservation in tropical forests: "The bushmeat crisis"

The world's tropical forests are among the most species-rich ecosystems on the planet, harbouring unique biota and containing more than fifty per cent of all species of plants and animals on just six per cent of the planet surface area (Poore and Sayer 1991, Cordeiro et al. 2007, Wilkie et al. 2011). Recognizably important by their rich and unique biodiversity, many areas of tropical forest have been mapped for conservation priority as "hotspots", featuring incomparable concentration of endemic species but also experiencing exceptional loss of habitat (Mittermeier et al. 1998, Myers et al. 2000)

Habitat destruction and degradation is still regarded as the major threat to tropical biodiversity (WCMC 1992, Reynolds et al. 2001; Mittermeier et al. 2003), but over the recent decades it has become clear that over harvesting of wild animals in tropical forests is an additional and severe threat (Redford 1992, Fa et al. 2002, Mittermeier et al. 2003, Peres 2009, Wilkie et al. 2011). Forest biodiversity is one of the vital components that sustain human life in parts of the tropics, where wild species are harvested for subsistence, medicine, cultural and traditional purposes, as well as for generating income (Poore and Sayer 1991, Milner-Gulland et al. 2003, de Merode et al. 2003). But as human population grows such harvest has intensified and became unsustainable in vast regions. In addition, infrastructural improvements are enabling hunters and gatherers to forge ever deeper into previously untouched territory in search of preferred prey, so the amount of forest untouched by man is decreasing rapidly and with it populations of particularly vulnerable species (Auzel and Wilkie 2000, Walsh 2003, Wilkie et al. 2000).

Hunting for wild meat is a world-wide phenomenon, occurring throughout the tropical forest areas of Africa, Asia and Latin America. Inter-continental variations can be explained partly in terms of the productivity of the forest ecosystems (Fa and Peres 2001), but other factors, such as the access to fish and other sources of protein, are determinant on the use of wild meat (Fa and Peres 2001, Brown 2003, Brashares et al. 2004). Much of recent research attention has focused on west and central Africa, where the levels of offtake are highest (Bakarr et al. 2001, Fa and Peres 2001, Barnes 2002, Bowen-Jones et al. 2002, Brown 2003). Nevertheless, high levels of dependence on wild meat are also found among the indigenous populations in the Amazon (Peres 2000,

Peres et al. 2006, Ohl-Schacherer et al. 2007), and several locations in Asia (e.g. Bennett and Rao 2002, Rao et al. 2011).

The very term 'bushmeat' is an African term that includes all wildlife species used for food (Bennett et al. 2007). The current harvest in Central Africa alone is estimated between 1 to 5 million tonnes of bushmeat in each year (Fa et al. 2002, Wilkie & Carpenter 1999). Overharvesting is highly costly to both wild populations, that face depletion or even extinction, and for the human livelihoods that depend directly or indirectly on wild resources for food safety - there is a notable overlap between countries of extraordinary biodiversity and those with poor and hungry people (Mainka 2002). The dual threats posed by wildlife extinctions and the livelihoods of the poorest people on Earth warrant the harvest of wild meat in the tropics a global conservation and development concern, designated as the "bushmeat crisis" (Bennett et al. 2007).

With a population growth considerably higher than the global average and increasing pressures on the environment, conservation in these biodiversity rich tropical countries is often not seen as a priority (Mainka 2002, Nasi et al. 2008). It is then crucial to understand when and where the wild meat trade is primarily a livelihoods issue, a biodiversity conservation crisis, or both, as no two regions experience quite the same problems (Bennet 2007, Milner Gulland and Rowcliffe 2007). Each situation has to be individually addressed so that long term, integrated efforts to supply alternative sources of protein and income, provide a way out of this crisis. Measures need to be defined to curtail the commercial trade in wildlife, secure wildlife populations in protected areas and/or educate hunters and buyers or through strong regulations (Robinson and Bennett 2002).

In this introduction I refer to the multitude of factors behind wild meat exploitation and the need to address each of them to understand the implications of harvesting and consuming wildlife. I further summarize the ecology of the pigeons and doves and the threats posed by harvesting of this group worldwide. Finally, I present the study area, the island of São Tomé, in São Tomé and Príncipe, contextualizing the aims and structure of this study.

1.1.1. Drivers of bushmeat harvesting and consumption

Wildlife harvesting is conducted primarily for food or income, and usually a combination of both (Bowen Jones et al. 2003, Nasi et al. 2008): it may be viewed as a continuum from subsistence-based rural consumption to mix subsistence-commercial hunting to hunting for commercial urban markets to the extreme case of hunting for the international trade in bushmeat (Brashares et al. 2011). There is copious evidence that wild meat is an important component of the dietary intake of many people (e.g., Ojasti 1996, Ntiamoa-Baidu 1997, Caspary 1999a and 1999b, Hofmann et al. 1999, Barnett 2000, Bennett and Robinson 2000, Caspary et al. 2001). In addition, the commercial value of wild meat is globally increasing and constitutes the basis of a substantial business in several countries, contributing for local, regional and international economies (Nasi et al. 2008, Parry 2009, Wilkie et al. 2011).

If there was no demand for bushmeat, then there would be no incentive for people to hunt wildlife to sell (Bowen-Jones et al. 2002). Demand can be crudely divided into two groups: consumers that prefer wild to domestic meat and consumers that have no (viable) alternative. The latter usually inhabit remote rural areas, and tend to be less selective (Ntiamoa-Baidu 1997). Harvest of wild species is often promoted by the improvement of roads and other accesses to the forest, often associated to the development of resource-extraction industries, such as logging or mining (Wilkie et al. 2000,Nasi et al. 2008). Another important factor contributing to uncontrolled exploitation of wild fauna is weak governance (Bowen-Jones et al. 2002). The legal framework to manage hunting is typically weak or non-existant in most tropical countries and this is usually a consequence of enforcement agencies lacking resources, trained personnel, or a supportive political environment. On the other hand, local communities who live close to the resource do not have access to legal authority or know-how to manage wildlife extraction sustainably (Bowen-Jones et al. 2002).

Bushmeat hunting is influenced and ultimately controlled by a multitude of biological, sociological and economic factors. Copious research has studied certain aspects of these complex interactions, but just a few studies address the different components subjacent to the issue. This is due to constraints posed by the difficulties of combining different expertise's' into research, and because of the time requirements and high cost of such multidisciplinary research.

1.1.2. Subsistence consumption of wild meats

As referred above wild meat provides a major source of protein for tropical forest people around the world. It provides a direct source of animal protein and a safety net in times of particular hardship (Ntimoa Baidu 1997), so local communities should benefit from the improved management of this source of income and nutrition. Throughout the humid tropics, however, human populations are growing and the area of forest is shrinking, thus threatening both wild species and food security of the rural poor.

The levels of consumption of wild meat vary considerably across the tropics. In Latin America, some indigenous groups account for 59.6g of protein consumed per person per day from wild meat, well above the minimum protein levels required for healthy subsistence (Townsend 2000). In the Congo Basin hunting has been estimated to contribute between 30 and 80% of the protein intake for forest-dwelling people (Koppert et al. 1996, cited in Wilkie 2001). In the Malaysian state of Sarawak, 67% of the meals of Kelabits contain wild meat, which is their main source of protein (Bennett et al. 2000). In contrast to urban areas where wild meat may be a luxury food, in rural areas with poor access to markets it is usually the cheapest - sometimes the only - type of animal protein available (e.g. Starkey 2004).

The relation between wild meat consumption and poverty remains unclear, and recent studies had put forward two somewhat contrasting hypotheses to explain broad patterns of wildlife consumption in the developing world (Robinson and Bennett 2000, Milner-Guland et al. 2003, Brashares et al. 2004): 1) Wild meats are inferior goods, providing a cheap and accessible source of food and income during times of economic or other hardship (e.g. lean season) to the poorest members of society (de Merode et al. 2003) and consumption declines with the growth of household wealth; and 2) Wild meats are normal goods, and demand increases as household wealth grows (Brashares et al. 2004, Wilkie et al. 2005, Schenk et al. 2006, Fa et al. 2009, Godoy et al. 2010). However, evidence suggests that use of bushmeat varies widely within (Bennett 2002) and amongst (de Merode et al. 2003) communities and across seasons (de Merode et al. 2003, Dei 1989); the dichotomy presented in the two hypotheses above may oversimplify what are likely to be complex and highly variable relationships among economics, geography, politics, and culture (Brashares et al. 2011). In particular, wealth is related with many other variables that influence hunting and bushmeat consumption

patterns. The extent to which people depend on bushmeat or could cope if the resource was removed is then not completely understood (DfID 2002, Brashares et al. 2011), and its variability impedes the development of management guidelines with general applicability.

1.1.3. Hunters' motivations and behaviour

Hunters are a critical entry point for any initiative of management and conservation of exploited fauna. It is hunters who are the direct link with wildlife that is killed for bushmeat, hence determining the choice and quantity of species harvested (Bowen-Jones et al. 2002). This is a heterogeneous group, constituted either by locals or migrants that may be hunting for home consumption or the occasional sale, or be professionals for whom the sale of bushmeat is the household's major source of income. A primarily subsistence hunter may sell any surplus and thus supplement his income (Wilkie et al. 1992). But the high demand for bushmeat from non-hunting households has resulted in an increasing number of professional or commercial hunters (Fa 2000).

If no alternative livelihoods are available, then even a low hunting effort may be profitable. Taking into account the fact that most hunters are also farmers, wild meat harvesting potentially provides an important supplement to households' diet and/or rural incomes in this group. Studies undertaken in low-income countries of central Africa, such as the Central African Republic (Noss 1998) and Cameroon (Gally and Jeanmart 1996), have found that hunters can earn up to 3.5 times more than the official minimum wage, and in Ghana they would earn the equivalent to a graduate entry on the Wildlife Service (Ntiamoa-Baidu 1997). A great proportion of the studies on the incentives for hunting have found that much of the harvest is sold, even in low income rural households (e.g. Kumpel et al. 2010, Maria Vega et al. 2013).

There are few barriers to start hunting as the investment costs are relatively low. But hunters' profiles are also determined by their access and choice of hunting gear. Rural poor subsistence hunters rarely can afford fire guns, and mostly use traps and snares. Commercial hunters make a higher investment, but the selling of busmeat usually covers and surpasses investment costs, allowing the use of fire weapons and improved technology. Besides, whereas some hunters supply their own snares and traps, many receive credit, guns and ammunition from individuals that end up having more

control over hunting than the hunters themselves (Bowen-Jones et al. 2002). The viability of different management and conservation programmes will then depend not only on the understanding of the incentives for hunting, but also of their prey choices, technology used and of their will to change livelihood activity (Bowen-Jones 2002, Kumpel 2006, Kumpel et al. 2010).

1.1.4. Biological impacts

Most tropical forests are low-productivity habitats, greatly increasing the likelihood that even relatively low levels of hunting will be unsustainable for many species. From an estimated 178 species currently hunted and used as wild meat in Central Africa, the survival of over half may be compromised by harvesting (Abernethy et al. 2013). Village subsistence hunting typically comprises smaller species, including ungulate and rodent species, often caught with traps or snares. Commercial hunting on the other hand, facilitated by a progressively easier access to guns, ammunitions and technologies as cell phones, extends to larger and rarer species, commonly sold in urban markets (Wilkie et al. 2011). Studies in Cameroon have shown that most large mammal species, including elephant, buffalo, bushbuck, chimpanzee, leopard, and lion, have become locally extinct within the past 50 years due to hunting (Maisels et al. 2001). Of 57 mammal, bird, and reptile species hunted throughout the Congo Basin, 60% are harvested unsustainably (Fa et al. 2002). Also in Asia at least one large mammal species has been lost due to hunting, and pangolin populations are being depleted throughout their natural range (IUCN 2014).

The situation is even more critical in many islands, where species, often endemic, have limited geographic distributions and the remaining areas of native forest are often too small to hold populations that can sustain harvesting. Many avian extinctions in oceanic islands were associated with overhunting after Human colonization (Duncan et al. 2002, Blackburn et al. 2004), and although some island species have been able to cope with some degree of extraction, Human population growth and increasing pressure make overhunting an actual threat. Fruit bats are extensively hunted, probably unsustainably, in several islands of Africa and the Pacific (Brooke and Tschapka 2002, Mickleburgh et al. 2002). In Bioko Island, Equatorial Guinea, primate populations were reduced by 90% in some areas and to local extinction

in others (Fa et al. 2000). In the island of Madagascar, one of the most important African biodiversity hotspots, there is anecdotal evidence that several endangered species may be threatened by overhunting (Jenkins et al. 2011).

With the increase of commercial hunting, "boom and bust" patterns often occur: when remote forests become connected to markets hunting rates initially increase, then rapidly decline as wildlife populations are depleted. But following depletion, consumers seek supplies from other species or other areas, causing ever expanding depletion zones (Wilkie et al. 2011). The process of defaunation by hunting in tropical forests has been recognized as causing the "empty forest syndrome" (Redford 1992). Since this seminal paper was published 22 years ago, this "syndrome" become a reality throughout much of Asia (Corlett 2007) and Africa (Fa and Peres 2001, Fa and Brown 2009) and is spreading rapidly to more sparsely settled tropical forest regions (Wilkie et al. 2011).

The implications of this defaunation for ecosystem functioning are still not fully understood, although many studies show that tropical forests depleted of large vertebrates experience reduced seed dispersal, altered patterns of tree recruitment, shifts in the relative abundances of species (Terborgh et al. 2001, Fa and Brown 2009) and various types of functional compensation (Effiom et al. 2013). Overhunting of wildlife is highly associated with loss of ecological integrity and significant, deleterious trophic cascades in tropical forests and other ecosystems (Terborgh et al. 2010, Abernethy et al. 2013). Current hunting practices in Central Africa are already modifying rainforest ecosystem function, and in synergy with changes in climate and land use may become increasingly influential in the future.

1.1.5. Sustainability of extraction

Sustainability was first defined in 1980, in the World Conservation Strategy, as the use of a natural resource that does not exceed its production (Robinson and Bennett 2000). Similar to fisheries and forests, wildlife can be viewed as a renewable resource whose regenerative capacity allows some level of harvest, while sustaining stock populations at ecologically viable levels (Weinbaum 2013). The unsustainable harvest of wildlife is a major threat to global biodiversity and to the millions of people who depend on wildlife for food and income (Weinbaum et al. 2013). Thus, the conservation challenge resulting from wild meat hunting is not to stop exploitation outright but to

prevent overhunting from depleting forests of their wildlife and species diversity, ultimately costing local people their food supply and potential revenues (Levi et al. 2011).

For hunting to be sustainable, it must be so both ecologically and socially sustainable. The harvest rate (driven by the demands of consumers and controlled by taboos, rules, regulations, enforcement and incentives) must not exceed production (mostly determined by the number of animals and their reproductive rates) (Bennett and Robinson 2000). Though conceptually sound, the definition of sustainability is incredibly hard to operationalize.

Measuring sustainability of wild life harvesting has been a major challenge for conservation in the last decades, and a considerable number of studies used an array of sustainability indicators to monitor conditions and trends of harvested wildlife species (e.g. Fa et al. 1995, Fitzgibbon et al. 1995, Muchaal and Ngandjui 1999, Noss 1998, Robinson and Bennett 2000b). Most commonly used sustainability indicators were demographic models of population growth, the Robinson and Redford model, population trends through time, harvest-based indicators, and comparisons of demographic parameters between sites (Weinbaum et al. 2013). Nevertheless, all indicators have shown limitations associated with effort required for data collection, scale of coverage, timeliness, accuracy and precision: In addition, some of the commonly used indicators have a weaker theoretical support and produce information whose reliability can be questioned (Weinbaum et al. 2013). Despite all the uncertainties, the use of the simplified indices developed so far is useful as a first indication of possible unsustainability, alerting managers to the need for further monitoring and evaluation of the harvest (Milner-Gulland and Akçakaya 2001).

1.1.6. Research needs and conservation action

To preserve the extraordinary biodiversity and maintain both the value of global goods and the range of ecosystem services currently provided by Central African rainforests, immediate management of hunting and conservation practices must be addressed (Bennett et al. 2007, Abernethy et al. 2013). Each hunting system has to be assessed individually and all the above factors - social, economic, cultural, biological and physical – need to be taken into account, so that managers and policy-makers can

formulate appropriate action to ensure sustainability of hunting. Research provides a valuable basis to the cross sectorial links needed to promote a sustainable use of wild meats, whereas local governance, development, public health, and private sectors should be engaged to play their roles and ensure that their actions complement direct conservation interventions (Bennett et al. 2007).

There is clearly the need to understand, in each individual situation (1) why do people hunt bushmeat, (2) who consumes bushmeat and why, (3) what are the effects of hunting in wildlife, and (4) given an understanding of these causes of bushmeat hunting, and the effects on wildlife, determine if the system sustainable. Only with such assessments, we can try to suggest options for intervention and incentives that can ensure the sustainable use of wild species, to be promoted by local and international bodies and institutions.

1.2. Pigeons and doves - the Columbidae

The Columbiformes (pigeons, doves, dodos and solitaires), with 316 living and recently extinct species (Gibbs et al. 2001), is the 4th largest bird order after Psittaciformes, Apodiformes and Passeriformes. Pigeons and doves are common names for the birds from the family Columbidae, which are used somewhat interchangeably and do not correspond to distinct monophyletic groups (Baptista et al. 1997). This is a successful group, widely distributed across all continents except for the poles, which in terms of body form have remained somewhat generalized, but have undergone a considerable adaptive evolution enabling species to survive in a wide range of conditions (Murton 1965, Gibbs et al. 2001).

1.2.1. Ecology and distribution

Pigeons are either granivorous or frugivorous, although some species feed occasionally on leaves, flowers, buds, arthropods, worms, and small snails. Typically strong flyers, they may undertake local or long distance movements in search of food and breeding grounds (Baptista et al. 1997, Gibbs et al. 2001). This behaviour has probably contributed to the dispersal of many species to numerous small islands where they have often evolved to endemic forms. Their wide distribution and evolutionary

success is possibly related to their breeding biology; they make a weak investment in nest building, but concentrate the breeding effort in a small clutch and rapid growth of their young (Gibbs et al. 2001). Pigeons are unique among birds in that they feed their young with a nutritious substance designed as "crop milk" produced by both parents (Mirarchi and Scanlon 1982, Baptista et al. 1997, Gibbs et al. 2001).

Tropical forests harbour the highest pigeons' diversity, where they may be arboreal or partially or totally terrestrial, particularly in the absence of large predators. Most tropical species are frugivorous and have an important role as seed dispersers, being ecologically responsible for the maintenance of tropical forest diversity (Stiles 1985, Corlett 1998, McConkey et al. 2004), and in some cases the only vector by which seeds of certain tree species are dispersed (Meehan et al. 2005).

Many of the extant pigeons' species have a restricted geographic range; Stattersfield et al. (1998) identified 138 species of pigeons and doves amongst the 2623 bird species with a restricted range (species having a breeding range of 50.000 Km^2 or less). From these, a total of 120 species (86 % of the total) live on islands (not considering Australia). There are more restricted range species in the pigeon' family than in any other (Walker 2007).

1.2.2. Conservation and threats

Pigeons and doves, although widely distributed and often abundant, are also one of the bird families that are most prone to all the three main conservation threats: human persecution, introduced predators and habitat loss (Owens and Bennett 2000, Walker 2007). The family contains a significantly greater proportion of threatened species than expected by chance and, overall, nearly one third of extant columbids face some degree of extinction threat (Bennett and Owens 1997, Walker 2007). Most of the threatened species of pigeons are forest dependant in the tropical or subtropical range, with small geographic ranges and endemism significantly associated with extinction risk (Hughes 2004, Walker 2007, Birdlife International 2014a).

In earlier times, the Mauritius, Réunion and Rodrigues islands each harboured a large, flightless species of solitaire, including the well-known Dodo, which had pigeon affinities and are now extinct (Quammen 1996). In the last 160 years, 6 island pigeons

have become extinct in the wild, and many more have become relict in one or two restricted places (Oliveira 2003). Steadman (1997) suggests that all the extinct Polynesian pigeons have in common the fact that they were forest birds and that their extinction was related to anthropogenic factors - loss and degradation of habitats, hunting, and introduced competitors and predators. This applies to most, if not all, pigeons that have become extinct worldwide (e.g. Stattersfield et. al. 1998, Walker 2007).

Pigeons and doves are a relatively poorly studied group of birds, and just a few species have been the subject of autecological research and successful conservation action (Clout et al. 1991, Mander et al. 1998, Oliveira 2003, Walker 2007). As an example, captive breeding programmes have successfully brought two island species of pigeon back from the edge of extinction, the pink pigeon (*Columba mayeri*) and Socorro dove (*Zenaida greysoni*) (Butchart et al. 2006), but their future remains dependent of long lasting management measures to stop or reverse habitat destruction and predation from alien species (Jones and Merton 2012). In the Island of Madeira, the laurel pigeons' population recovered to safe numbers following a ban on hunting and full protection of its core habitat, the Laurel forest (Oliveira et al. 1999). But the species is still "conservation dependent", as illegal shooting, poisoning and particularly egg predation by rats still threatens the viability of a restricted range population.

In New Zealand there is considerable interest and effort to conserve the country's only native species of pigeon, the Near Threatened New Zealand pigeon, which has suffered rapid declines in recent years (Mander et al. 1998). Fully protected by law since 1921, New Zealand pigeons were previously hunted by Maori and European settlers alike, but also targeted by stoat predation and winter/spring starvation (Clout et al. 1991). The development and implementation of a nationally coordinated monitoring programme became a necessary first step in the development of a conservation strategy of the species.

Conservation projects are needed to highlight the plight of the species and secure their long-term future. The many threatened pigeon and dove species in the tropics should be targeted by timely awareness and conservation commitments to stop active threats and allow for the populations to recover and maintain their ecological roles in the preservation of native forests.

1.3. São Tomé – a small island with an unique biodiversity

São Tomé is the largest of the two oceanic islands that constitute the Democratic Republic of São Tomé and Príncipe (Fig. 1.1.), located in the Gulf of Guinea, West Africa. São Tomé and Príncipe have a total area of 1001 km^2, each of the islands with 857 km^2 and 142km^2, respectively. About 95% of the 187000 inhabitants of the country live in São Tomé. Both islands are internationally recognized as biodiversity hotspots, because of their high degrees of endemism in virtually all taxonomic groups, including birds.

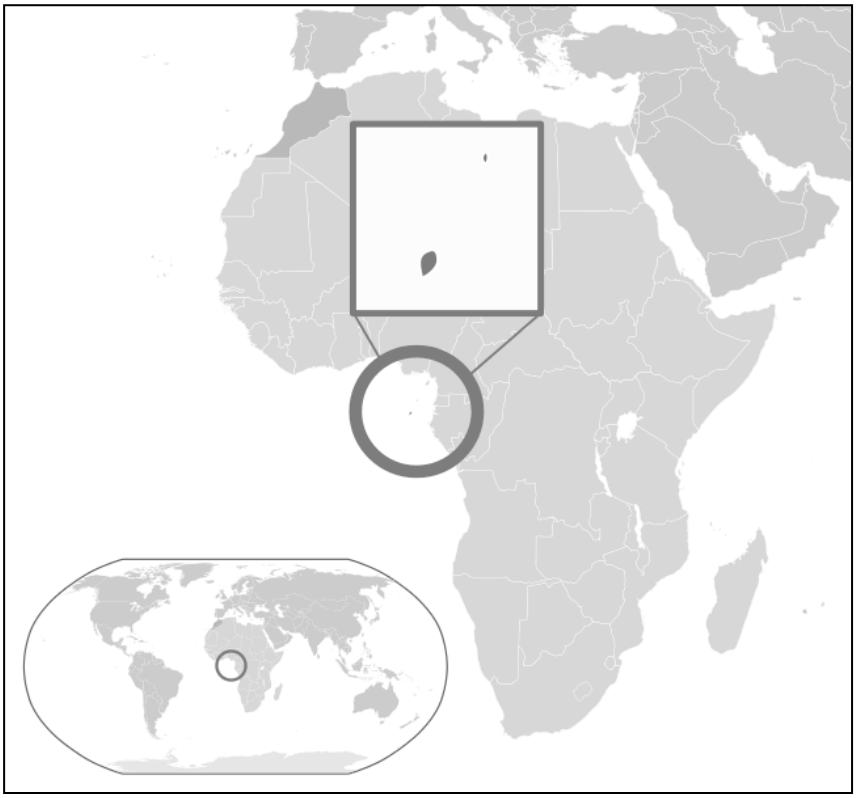

Figure 1.1 – World map indicating to the location of the Democratic Republic of São Tomé and Príncipe.

1.3.1. Geomorphology and climate

The Gulf of Guinea islands form a spectacular centre of endemism until recently forgotten by most biologists. It comprises three oceanic islands (Príncipe, São Tomé,

and Annobón), one land bridge island (Bioko) and one ecological island (Mt Cameroon), all part of the Cameroon line of volcanoes. São Tomé and Príncipe, unlike Bioko, were never connected to the African continent (Juste and Fa 1994). São Tomé (00°25'N–00°01'S, 06°28'E–06°45 E) is about 225 km distant from the west coast of Africa (Gabon), and right above the equator line.

São Tomé Island is extremely mountainous, with at least ten peaks of over 1000m in the west-central and southern sections and numerous rivers (none navigable). In the north it rises along a sharp ridge to 2024m at the Pico de São Tomé, its highest peak. The island's mountains intercepts the prevailing moist southwesterly winds throughout the year, so that rainfall in their southwestern parts probably exceeds 7000 mm annually (Birdlife International 2014b, Jones and Tye 2006). The northern area of the island is in the rain-shadow of the mountains and thus receives much less rainfall (600 mm per year in the extreme North, Jones and Tye 2006). The climate is equatorial, warm and humid, with one main dry season from June to September, more marked in the north and east of the island. A short dry season extends from December to February, but it may be unnoticeable in some areas or years. Annual average temperatures range between 22°C and 33°C in coastal areas, but considerably diminish with altitude (Birdlife International 2014b).

1.3.2. Forests and land use

São Tomé and Príncipe were discovered by Portuguese navigators in late 1470 and early 1471. Presumably uninhabited before discovery, it is probable that both islands were originally almost entirely covered with rainforest (Eyzaguirre 1986, Jones and Tye 2006). Exell (1944), recognized three main rainforest types in São Tomé: lowland forest from sea-level to 800 m, montane forest from 800 m to 1,400 m, and mist-forest from 1,400 m to the summit, the Pico de São Tomé (2,024 m). At the time of colonization there were also some small areas of mangrove and possibly some dry forest (Jones and Tye 2006),

After human arrival, São Tomé, together with Príncipe and other Atlantic Islands, were gradually subjected to the process of introduction and cultivation of several plant species (Carvalho et al. 2004). The most important crops were sugar cane, coffee, cocoa, banana and corn, and the plantation of subsistence and commercial crops

required the clearing of large areas of forest. Most of the lowland and part of montane forests were cleared in the northern and eastern areas of the island, and have virtually disappeared in its primary form (Carvalho et al. 2004). By the mid-19th century, as much as 70% of the island was cultivated under a system of large farms called 'roças', in which cocoa and coffee crops were grown under shade trees, mostly introduced *Erythrina* sp (Peet and Atkinson 1994, Birdlife International 2014b, Jones and Tye 2006). In the southern and central areas of the island, typically wetter and less accessible, the colonization was less intensive. This allowed the preservation of apparently intact areas, especially on the steep central slopes (mostly montane and mist forest), and along the south-west coast, where the last patches of lowland forest survived (Jones and Tye 2006).

As a result of a crash in cocoa prices and also because of the instability that followed the country's independence in 1975, the less productive or more remote plantations were abandoned, which enabled forest regeneration, mainly at mid-altitudes on the central and south-western mountains (Peet and Atkinson 1994, Jones and Tye 2006). Nowadays, the well-preserved old-growth forest block is buffered by this secondary forest, which is, in turn, predominantly surrounded by active shade plantations (Jones et al. 1991, Diniz et al. 2002). Scattered around these, there are areas dominated by various non-forested land uses (de Lima et al. 2012) (Fig.1.2).

Recent studies on the avian assemblages and land-use change in the island of São Tomé by de Lima et al. (2012, 2013) highlight the value of the human modified secondary and shade forests for endemic birds, but also alert against land-use intensification resulting in loss of canopy cover or reductions in the proportion of forested land uses. However, forested land uses cover almost 90% of the island, with primary forest, secondary forest and shade plantation covering similar proportions (data from Forest inventories conducted in 1989 and 1999, in Salgueiro 2001). However, decreases of primary forest and shade plantation and increases of secondary forest and non-forested land uses were registered between the 1989 and 1999 inventories (BDPA 1985, Salgueiro and Carvalho 2001).

Present land use patterns and ongoing development initiatives suggest that the major habitat modification likely to occur in São Tomé and Príncipe in the near future will be a loss of secondary forests. This is the result of reclaiming abandoned plantations, either to rehabilitate the cocoa industry, or to promote timber and fuelwood

production (Interforest 1990). Agricultural development and modern management of productive crops, which do not require shade trees, involve dramatic changes in land-use patterns that will undoubtedly have deleterious consequences for forest habitats and biodiversity (Salgueiro 2001, Jones and Tye 2006, de Lima et al. 2012).

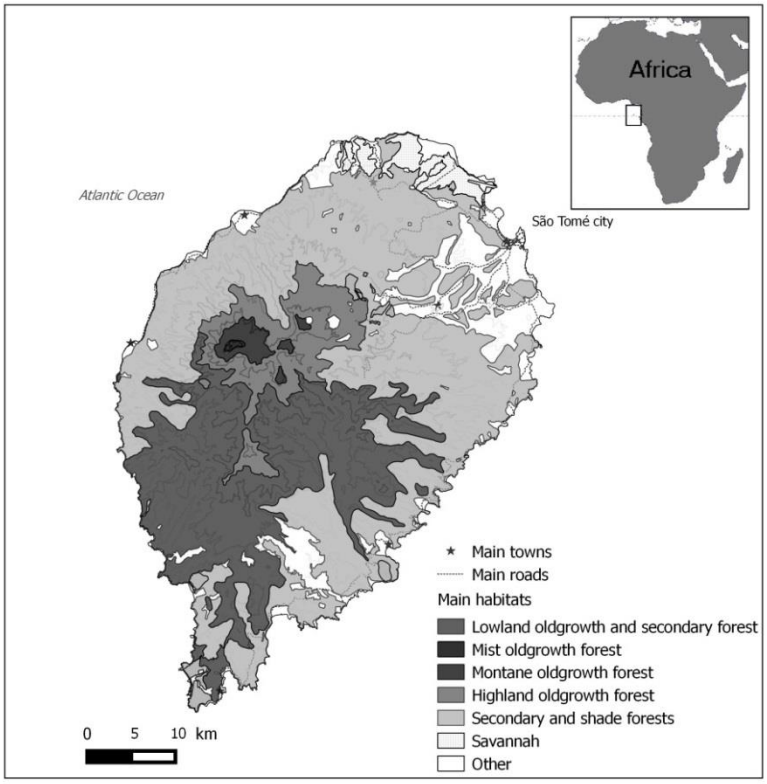

Figure 1.2 - Map of São Tomé Island with distribution of main forested habitats

1.3.3. Biodiversity: endemic, native and introduced species

The biodiversity of São Tomé e Príncipe is among the most important in tropical Africa (Collar and Stuart 1988). The islands are very species-rich, especially if their relatively small size is considered (Stattersfield et al. 1998). São Tomé and Príncipe are oceanic islands and were never linked to the mainland. All the native species got there by air (in the case of birds, bats and plants brought by them or by the wind), floating as seeds or in vegetation rafts or trees originating from large rivers such as the Niger and Congo (Measey et al. 2007). This isolation limited the number of species able to reach the islands but allowed them to evolve in environments that differ from the mainland

(Leventis and Olmos 2009). After 1471, numerous species of flora and fauna were brought-in by humans.

A total of 685 plant species have been recorded from São Tomé, of which 100 (15%) are endemic. Some groups are especially diverse, such as orchids, with 135 species (Vaz and Oliveira 2007). The native land vertebrates include nine bats (four endemic species and one subspecies), one endemic shrew, 14 reptiles (four endemic) and five endemic amphibians (Jones and Tye 2006, Measey et al. 2007, Rainho et al. 2010). Endemism is high among land snails, with about 60 endemic species in São Tomé, Príncipe and Annobon, including one endemic family and six endemic genera (Gascoigne 1994). Among the butterflies, São Tomé has 64 endemic species and Príncipe 45, 28 of which are shared between them (Pyrcz 1992).

The degree of endemism of the avifauna is particularly notable (Collar and Stuart 1988, Buchanan et al. 2011): of 45 resident terrestrial species, 17 are single-island endemics, three are endemic to the Gulf of Guinea oceanic islands (Annobon, São Tomé and Príncipe) and eight are widespread species represented on the island by an endemic subspecies (Melo 2007, de Lima et al. 2012). The forests of south-west São Tomé have been ranked second in importance in a list of 75 key forests for threatened birds in Africa (Collar and Stuart 1988), which highlights their conservation value.

São Tomé Island holds six species of pigeons and doves: the laughing dove *Streptopelia senegalensis*, which was introduced and is restricted to the vicinities of houses and plantations, the domestic pigeon *Columba livia*, which is not known to have any feral populations in the island, and four native forest pigeons, which are the focus of this work (Jones and Tye 2006). The bronze-naped pigeon *Columba malherbii* is endemic to the Gulf of Guinea, occurring also on the islands of Príncipe and Annobón, while the remaining species are single island endemics: the São Tomé green pigeon *Treron sanctithomae*, the São Tomé lemon dove *Columba simplex* and the maroon pigeon *Columba thomensis*. Two of these forest pigeon species are globally threatened, the green pigeon is vulnerable and the maroon pigeons is endangered (IUCN 2014). The bronze-naped pigeon is considered nearly threatened. The São Tomé lemon dove is not recognized by IUCN as a separate species, and is instead listed as a population of the least concern lemon dove *Columba larvata*. However, recent molecular work supports the recognition of the São Tomé lemon dove as a distinct species (Pereira 2013), as previously suggested by several authors (Baptista et al. 1997). All except the lemon

dove are extensively hunted (Atkinson et al. 1991, Jones and Tye 2006, Dallimer et al. 2009). Although they are all considered forest species, they have distinct habitat preferences and vary in their sensitivity to human disturbance (Atkinson et al. 1991, Dallimer et al. 2009, de Lima et al. 2012).

All large mammals were accidentally or deliberately introduced after the arrival of Man in 1471. Along with classic introductions of dogs, cats, rats, mice and domestic livestock, São Tomé now harbours populations of the mona monkey (*Cercopithecus mona*), African civet (*Civettictis civetta*), European weasel (*Mustela nivalis*) and feral pigs (*Sus domesticus*). The deadly black cobra (*Naja melanoleuca*) (WCMC 1992, Dutton 1994), and the West African giant snail (*Archachatina marginata*) were also introduced in the island, the latter less than 50 years ago (Albuquerque and Cesarini 2008).

1.3.4. Human population and development

The Democratic Republic of São Tomé and Príncipe is Africa's smallest economy and one of the poorest countries in the world. Approximately 34.5 percent of its population of ca. 187,000 (INESTP 2012) is poor and 10.4 percent live in extreme poverty (Alkire et al. 2011). Nearly two-thirds of the population lives in rural areas, but a growing proportion is concentrated in and around the capital São Tomé and adjacent districts, while only about 7,000 people are permanent residents of Príncipe (Klueh et al. 2007).

Social indicators are weak and improving slowly (IDA 2005). Poverty reduction is a major challenge, and access to basic social services such as health, education, water and sanitation, is not guaranteed to a large portion of the population. The weakened social structure is exacerbating regional disparities, with a negative impact on rural areas and vulnerable groups, especially woman (UNDP 2006).

After a prolonged period of economic mismanagement since independence, a series of economic reforms were implemented starting in 1996 (IDA 2005). Major changes in socioeconomic conditions made in subsequent years have had a great impact on the way of life and standard of living of the vast majority of the population in rural areas: a large percentage of families moved from a situation of almost total dependence

of third parties (employers or state) to a situation of dependence or of themselves, as they were given land but do not receive any wages or services (IDA 2005). Recent measures have been put in place to improve economic growth and diversify the economy, especially through banking and fiscal reform and an effort to develop new trade promotion channels (UNDP 2006, Klueh et al. 2007).

São Tomé and Príncipe's economic and social indicators are negatively affected by some of the basic challenges that afflict many small island states, which include: remoteness and insularity, susceptibility to natural disasters, weak institutional capacity, a narrow resource base, vulnerability to exogenous shocks, limited access to capital, and entrenched poverty (IDA 2005, UNDP 2006, Klueh et al. 2007).

1.3.5. Main threats to biodiversity

During the XIXth century, the Gulf of Guinea islands were studied by naturalists who underlined their biological value (e.g. F. Newton, J.V. Bocage and A. Moller; Gascoigne 1993). But after independence and as a result of political disruptions, they have remained isolated and the increasing economic pressures promoted unrestrained natural resource exploitation (Juste and Fa 1994). Only recently the islands received again attention from the outside, exposing the inevitable problems for sustainable development posed by poor and expanding human populations confined to small, geographically isolated oceanic islands and limited resources (Jones and Tye 2006).

Despite a considerable forest regrowth since the abandonment of several plantations at the time of independence, habitat modification is still considered the single most important threat affecting the islands biodiversity (Atkinson et al. 1991, Jones and Tye 2006). Changing socio economic settings indicate that land use change is likely to be increasing towards more intensive uses, with a population boom already showing a measurable impact over forestry resources (Salgueiro and Carvalho 2007, de Lima 2012). Agricultural development, with the consequent improvement of transport infrastructure and increased market opportunities for agricultural produce, are progressively threatening the areas surrounding the Ôbo National Park (Dallimer et al. 2009).

Many taxa are also potentially threatened by unrestrained hunting (Atkinson et al. 1991, Dutton 1994, Dallimer et al. 2009). More intensive land uses tend to be more visited by people, and therefore, direct top down anthropogenic activities such as hunting are also expected to increase. Although most of hunting activity is focused on introduced mammals, larger birds are commonly targeted by a wide group of harvesters (Jones and Tye 2006, Olmos and Turshak 2007, Dallimer 2009). Bird hunting often does not require specific weapons (slingshots are commonly used), and the tameness of endemic species, such as the maroon pigeon *Columba thomensis*, makes them particularly vulnerable (Peet and Atkinson 1994, Jones and Tye 2006).

Introduced species are likewise a potential threat to endemic and native biodiversity on the island. Human-introduced animals such as rats, mice, cats and dogs have caused the extinction of many endemic species on oceanic islands (Duncan et al. 2002, Steadman 2006). In São Tomé, introductions of animal species also include medium sized mammals, reptiles or land snails. Given the originally depauperate theriofauna of São Tomé it is likely that the introduced species have overall negative impacts on the native fauna and flora (Dutton 1994, Gascoigne 1994, Jones and Tye 2006). Nevertheless, it is difficult to estimate their impact; little is known about their ecology in São Tomé, each species has a different distribution along the land-use types and no land-use type is free of these species (de Lima et al. 2012).

1.3.6. Conservation initiatives

The global importance of the Gulf of Guinea islands for the conservation of biodiversity was recognized by Collar and Stuart (1988), who ranked the rainforests of São Tomé and Príncipe second out of 75 African forests in their importance as bird habitats, based on the numbers of their endemic species and their level of vulnerability. BirdLife International now includes Príncipe, São Tomé and Annobón among more than 200 Endemic Bird Areas (EBAs) worldwide (Bibby et al. 1992, Stattersfield et al. 1998) and all three islands are included among the Important Bird Areas (IBAs) of Africa (Fishpool and Evans 2001). It is also now well established that the Gulf of Guinea islands are of global importance for their levels of endemism in other taxa as well (Jones 1994).

In São Tomé and Príncipe, the development and definition of protected areas and most of environmental laws was largely supported by the European Programme ECOFAC, acting in the islands between 1995 and 2010. General enforcement is however low, with competent institutions often lacking technical capability and resources to effectively enforce existing legislation. Hunting laws and regulations are in discussion since 1995, but are still to be promulgated. The proposed document is probably too complex to effectively implement. All the critically endangered or endangered species and seabirds are proposed to be protected from hunting, but there is still no clear definition on how enforcement will be done.

1.4. Thesis contextualization

Island ecosystems are particularly relevant for biodiversity conservation. They hold a disproportionately high number of unique (endemic) terrestrial species that are simultaneously prone to extinction driven by land-use change, human prosecution, and impact of alien species (Owens and Bennett 2000, Kier et al. 2009, Maas et al. 2009, Waltert et al. 2011). Their well-defined boundaries and simplified ecosystems mean that islands can also provide a good experimental setup to understand biological processes.

The islands of São Tomé and Príncipe are no exception. Although the ecology of the islands is still not well known (Leventis and Olmos 2009), the relative accessibility to scientific research combined with a small area makes them outstanding natural laboratories. Their high conservation value within a continuum of habitat degradation at the fringe of development and a high population growth, provide a challenging research setting.

Concern over the conservation of the endemic pigeon species of São Tomé increased with the awareness of a growing hunting pressure throughout the years (Peet and Atkinson 1994, Jones and Tye 2006, Dallimer et al. 2009). Other pigeons in oceanic islands have suffered measurable impacts due to overexploitation (Duncan et al. 2002, Steadman 2007, Walker 2007), but no studies were ever conducted in Africa. In the São Tomean context, a small and isolated island with an expanding and generally poor human population, pigeon hunting may seriously compromise the species' survival. On the other hand, the apparently preferred harvesting of introduced animals in São Tomé

may serve the dual purposes of food security and conservation of native species. This study was developed as the first to characterize and analyse wild meat harvesting and consumption in an African oceanic island, with its particularities, and specifically analyse its impact and sustainability on the endemic pigeons' species.

1.4.1. Thesis structure and aims

This thesis' main objective is to collect and analyse the information required to manage the endemic pigeons of São Tomé, ensuring their long term use as a resource but also their conservation as species of global importance. The small range and size of the pigeon populations of São Tomé together with the harvesting pressure they face, makes them both species of high conservation concern and very good models for the development and testing of sustainability indices, a topic at the forefront of ecological and conservation research.

The four principal chapters (2 through to 5) of the thesis are written in the form of scientific papers. Two of these chapters have already been accepted for publication (Chapters 2, 3, Carvalho et al. 2014, Carvalho et al. in press). Chapter 2 examines the effects of potential hunting impact on endemic pigeons. The patterns of distribution of the four pigeons' species and their relation with potential hunting impact and other influencing variables are assessed. Chapter 3 presents an investigation of the motivations and socio economic profiles behind hunters' choices and behaviour. This chapter aims to assess why São Tomean hunters harvest bushmeat, and what are the socio economic factors behind their prey choices of native/endemic or introduced fauna. Chapter 4 aims to quantify the contribution of wild meats, and of endemic pigeons, for the diets of the rural people of São Tomé. It also assesses the determinants of consumption of different meat types, and analyses the potential for intervention for conservation of endemic species. Chapter 5 aims to assess the sustainability of extraction of all the four native species. Finally, Chapter 6, based on the review of the previous chapters, analyses the key outcomes and limitations of this study and identifies further research lines. It recognizes the relevance of this case study as a potential model for similar research in oceanic islands and/or with range restricted bird species. It then suggests options for intervention and incentives that can ensure the sustainable use of

wild species and especially endemic pigeons, to be promoted by local and international agencies.

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Chapter 2

FACTORS INFLUENCING THE DISTRIBUTION AND ABUNDANCE OF ENDEMIC PIGEONS IN SÃO TOMÉ ISLAND (GULF OF GUINEA)

Published as: CARVALHO, M., FA, J.E., REGO, F.C., DE LIMA, R., SANTOS, G. AND J.M. PALMEIRIM (in press). Factors influencing the distribution and abundance of endemic pigeons in São Tomé Island (Gulf of Guinea). *Bird Conservation International.*

2.1. Summary

Understanding factors that determine habitat use and abundance of exploited species is essential to develop effective conservation strategies. We studied the 4 forest pigeons in São Tomé Island to assess the species' distribution and abundance patterns. We determined ecological factors likely to be associated with each species' use of habitats and numbers, as well as the influence of hunting pressure. A total of 35 km of line transects were surveyed in the rainy season and at the start of the dry season. Pigeons differed in their use of habitats; there were also strong seasonality effects. The most abundant species was the lemon dove, the only non-hunted species. The São Tomé green pigeon and maroon pigeon were less abundant with more restricted ranges. Both species were strongly associated with old-growth forests. In contrast, the bronze-naped pigeon was relatively abundant and widespread; this species favours human-altered habitats such as shade forests and non-forested areas. Fruit availability measured within the different habitats was linked with the distribution and abundance of the three hunted species. Potential human predation pressure on all species was determined from hunting signs found along the surveyed transects. There was a significant negative correlation between the abundance of two of the hunted species and hunting pressure. Our results indicate the importance of adequately protecting old-growth and secondary forests as core habitats for the survival of viable populations of all pigeon species in the island. However, control of hunting is also crucial.

2.2. Introduction

Pigeons and doves (Columbidae) are amongst the most successful and widespread bird families. They have colonised most of the world's oceanic islands, reaching eastern Polynesia and the Chatham Islands in the Pacific, Mauritius, the Seychelles and Réunion in the Indian Ocean, and the Azores in the Atlantic Ocean (Batista et al.. 1997, Gibbs et al. 2001, Walker 2007a). They are also highly vulnerable to extinction from hunting, introduced predators and habitat loss (Owens and Bennett 2000). Hence, nearly one third of the extant Columbidae now face some risk of extinction. Most threatened pigeons and doves are found in tropical and subtropical regions, are forest dependent, and a large number inhabit islands (Walker 2007a).

The island of São Tomé, in the Gulf of Guinea, West Africa, is an important centre of bird diversity and endemism, and is inhabited by four pigeon species (Christy 1991, Stattersfield et al. 1998). Three of the four São Tomé pigeons are single island endemics (maroon pigeon Columba thomensis, São Tomé green pigeon Treron sanctithomae and the lemon dove Columba simplex). Another Gulf of Guinea species, the bronze-naped pigeon Columba malherbii, is also found on the islands of Príncipe and Annobon.

All São Tomé pigeons, except the lemon dove, are extensively hunted (Atkinson et al. 1991, Jones and Tye 2006, Dallimer et al. 2009, Carvalho et al. 2014). Three species are globally threatened, according to the IUCN Red List (IUCN 2013); the maroon pigeon is Endangered, the São Tomé green pigeon Vulnerable, and the bronze-naped pigeon Near Threatened. There is sufficient evidence available to show that populations of these birds have declined since the start of the 19th century (Bannerman 1931, Snow 1950, Peet and Atkinson 1994, Jones and Tye 2006, Olmos and Turshak 2007).

The pigeons are found within the island's forested habitats (Atkinson et al. 1991, Dallimer et al. 2009, de Lima et al. 2012). The maroon pigeon is associated with old-growth and older secondary forests, its main population restricted to an area of around 320km^2 of mid- to high-altitude old-growth forest (Peet and Atkinson 1994, Jones and Tye 2006). The São Tomé green pigeon is also common in old-growth and secondary forest, but similarly inhabits forest-edge habitats, shaded coffee and cocoa plantations (Jones and Tye 2006, Atkinson et al. 1991). It feeds high in the canopy that includes Ficus and Musanga fruits (Atkinson et al. 1991, Jones and Tye 2006). Bronze-naped pigeons are found in forests and forest scrub within the island's northern savannah habitats. It forages in groups both on the ground and high up in trees (Atkinson et al. 1991, Jones and Tye 2006). Lemon doves are described as common to abundant, found singly or in pairs, wherever there is dense cover on and near ground in old-growth forest, secondary, and shade plantations of coffee and cocoa, from sea-level to high elevations (Christy and Clarke 1998, Jones and Tye 2006).

In this paper, we present the first analyses of the abundance and distribution of all forest pigeons in São Tomé. We analyse: (a) the influence of environmental parameters on the distribution of pigeons; (b) whether fruiting patterns of trees affect

their distribution; (c) the phenology of distribution patterns; and (d) whether hunting pressure influences abundance.

2.2. Methods

2.2.1. Study area

São Tomé (857 km^2) is the larger of the two oceanic islands that constitute the República Democrática de São Tomé and Príncipe (Fig. 2.1). The island, located within the tropical belt, is about 250km from the African coast. Annual rainfall ranges from less than 1,000 mm in the northeast to more than 6,000 mm in the southwest, and is globally marked by two main seasons: the rainy season between September and May and the dry season (or Gravana) between June and August (Jones and Tye 2006). Mean annual temperatures vary between a minimum of 18° to 21°C to a maximum of 30° to 33°C, with little seasonal variation and high humidity all year (Carvalho et al. 2004). The island is characterised by a rough relief, with numerous and steep mountains and a maximum altitude of 2,024m at the Pico de São Tomé.

With no human presence before the Portuguese arrived in 1470, the original vegetation on the island comprised tropical lowland and montane forests on the wetter side of the island, and mossy forest at highest altitudes (Jones and Tye 2006). Native forest is distributed along a gradient from lower to higher altitudes (Fig. 2.1) with smaller trees (dbh< 2m) predominating at the highest altitudes. A drier forest type, present in the NE of the island, includes many deciduous trees, and is subject to frequent fires (Leventis and Olmos 2009). This area has been extensively cleared for farmland and estates and much of it has been turned into an anthropogenic savannah.

Although some forest areas have been heavily modified in the past for planting cocoa and coffee, there has been significant regeneration to secondary forest since the time of independence (1975) (Oliveira 2002, Carvalho et al. 2004). One third of the island, comprising areas of remaining lowland and mountain forests, was declared a protected area (Parque Natural do Obô) though there is little or no enforcement (Albuquerque and Cesarini 2009). Hunting legislation is in course since 1995, but still to be promulgated.

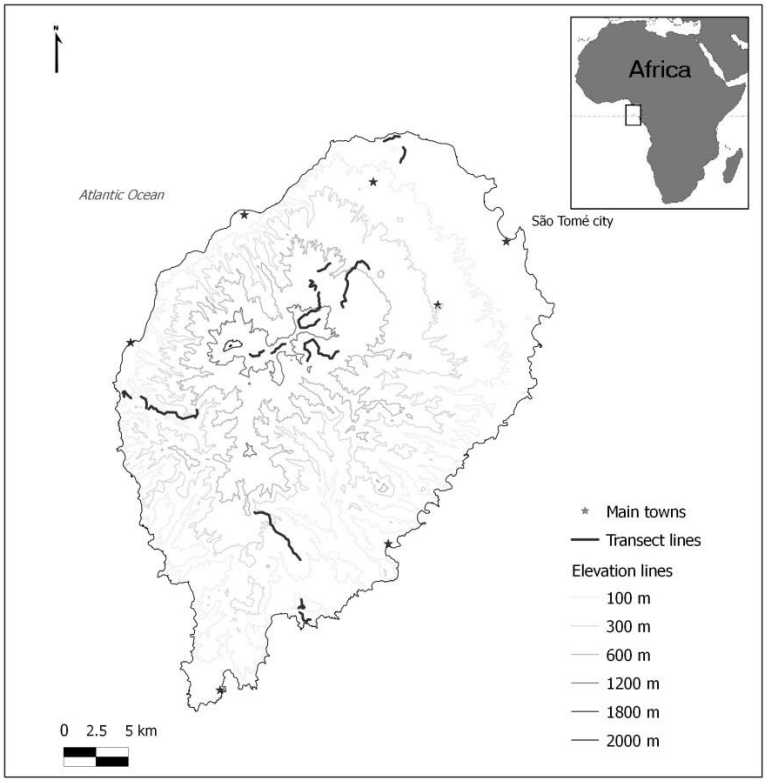

Figure 2.1 - Map of São Tomé showing locations of the sampled transects. Elevation is shown as contour lines.

The human population of the island is estimated at around 187,000 people (approx. 212 inhab./km^2, INESTP 2012); growth rate is 2.0% (CIA 2012). About 60% of the inhabitants of the island live in the capital and adjacent districts. Poverty levels are high with 34.5% of the population affected (Alkire et al. 2011). Infrastructure is generally poor.

2.2.2. Sampled habitats

We sampled pigeon populations within four broad habitat types, ranging from least disturbed formations (old-growth forest), through secondary forest to shade plantations and non-forested habitats (INTERFOREST AB 1990, Salgueiro and Carvalho 2001). Old-growth forests are areas of natural vegetation, often remaining in inaccessible parts of the island, which may contain some introduced and human-favoured species (e.g. *Bambusa vulgaris*, *Musanga cecropioides*, *Persea americana*,

Chinchona sp.). Secondary forests, derived from the cutting of old-growth forests, contain a large proportion of introduced species, but no cultivated plant species (Carvalho et al. 2004). In contrast, shade plantation forests are characterized by the presence of coffee or cocoa, and a variable canopy cover of native and introduced species. Non-forested areas included in the sampling are mainly savannahs but also include palm stands and open fields in forests' outskirts.

2.2.3. Bird surveys

We surveyed pigeons along 15 linear transects (total 35 km) in selected habitats (Fig. 2.1). Due to the difficult terrain, most transects followed existing trails. We walked 5 main (5-km long) transects; the maximum distance that could be sampled in one day in rough terrain without compromising census quality (Bibby et al. 2000). We also selected 10 shorter (1-km long) transects to increase sampling effort in habitats that were poorly represented within the main transects. All 15 transects were divided into 100-m sectors, within which we recorded habitat type (old-growth, secondary, shade or non-forested), altitude (measured with a GPS), and trail typology (forest trail, well marked footpath, old dirt road). In addition, the vegetation in each sector was characterized within two (10m x 10m) quadrats on either side of the initial point of each sector. In each quadrat we counted the number of trees (small: 30cm dbh - 2m, and large: >2m dbh), estimated canopy height and cover, as well as grass and shrub cover (Bibby et al. 2000, Buckland et al. 2008). All estimates were conducted by M.C. With the support of local assistants, tree species with fruits consumed by our study species, were counted along a 20m wide band along each transect. Fruiting status of all counted trees was documented from presence and ripeness of fruits present.

Bird censuses were undertaken by two trained observers (G.S. and Aristides Santana) during early mornings (between 5h and 11h). Transects were walked at a slow pace (1km/hour) and repeated twice, in January and June 2010 (rainy and dry season, respectively). Pigeons seen or heard were recorded, except for individuals observed flying over the transects.

2.2.4. Human presence and hunting pressure

To analyse the effect of anthropogenic factors on pigeons, an index of potential hunting pressure within each 500m transect sector was calculated as the average of site accessibility, human population, and signs of hunting activity. Site accessibility was estimated as the mean distance from the sector to the nearest road according to three distance classes (1: >5 km, 2: 2.5 - 5 km, 3: <2.5 km) and another parameter representing access type (1: lightly marked forest trail, 2: well-trodden path, 3: old road). The human population within a 5-km radius was obtained from the 2001 and 2012 population censuses (INESTP, 2012) and expressed as 1: <350 persons, 2: 351-700 persons), and 3: >700 persons. Signs of hunting activity (hunters, cartridges, piles of feathers, traps, and temporary hunting camps) were recorded during habitat surveys and bird counts. We recorded 1 (up to one sign) to 3 (more than 3 signs).

2.2.5. Fruit availability index

To analyse the effect of fruit availability on pigeon distribution and abundance patterns, we derived a seasonal fruit availability index for the 3 canopy-living species - São Tomé green pigeon, bronze-naped pigeon and maroon pigeon. The index was not applicable to the lemon dove as this species usually feeds on the ground and its diet is poorly known.

First, we identified 10 fruit bearing tree species as important in the diets of the 3 canopy-living pigeons (Table 2.1), from observations in the field, suggestions from local informants, and available bibliography (Christy and Clarke 1998, Jones and Tye 2006). We then assessed the seasonal fruiting pattern of for each tree species. In the transect areas, we selected 10 individuals of each tree species to follow. Each individual was visited twice in each season (January-February, June-July), and its fructification status classified in three levels: 0 - no fruits, 1 – few fruits and/or raw, 2 – many fruits and ripe. We derived a seasonal fructification index for each tree species (rainy season/dry season) by averaging the values obtained for the 10 followed individuals.

We then calculated a fruit availability index in each sampling sector for each bird species, per season, To achieve this, we multiplied the number of trees of each identified species in each sampling sector and by the estimated seasonal index of

fruiting for that sector in each season. For each of the pigeon's species and respective diets we estimated the fruit availability index by summing the values obtained for the four main species of trees of diet (Table 2.1) in every single sector.

T**able 2.1** - Fruiting trees identified as relevant food sources to use in fruit availability indexes built for the three species of pigeons: São Tomé green pigeon, bronze-naped pigeon and maroon pigeon. The observed fruiting refers to average number of fruits and its ripeness recorded in all identified trees located at sampled transects, and varies between 0 (no fruits or raw) and 2 (many ripe fruits).

Tree Species	São Tomé green pigeon fruit index	Bronze-naped Pigeon fruit index	Maroon Pigeon fruit index	Observed fruiting rainy season (Jan.)	Observed fruiting dry season (Jun.)
Ficus chlamydocarpa	+	-	+	1	2
Ficus exasperata	+	-	-	1	2
Ficus kameroonensis	+	+	-	2	1
Cecropia peltata	+	-	-	1.5	1.5
Cestrum laevigatum	-	+	-	0.5	2
Tetrochidium didymostemon	-	+	-	2	1
Maesa lanceolata	-	+	-	2	0.5
Schefflera mannii	-	-	+	1	2
Margaritaria discoidea	-	-	+	1.5	0.5
Morinda lucida	-	-	+	1.5	0.5

2.2.6. Analysis

We used ordination techniques to develop an effective visual summary of site-specific changes in forest type structure, including all samples in the same ordination space (Borcard et al. 2011). We employed non-metric multidimensional scaling (NMDS) ordination based on Euclidean dissimilarities of standardized environmental variables. This procedure is considered robust for site-data analyses and is able to recover compositional dimensions associated with the underlying environmental gradients (Minchin 1987). To test the null hypothesis that habitat structure was similar in different forest types, a nonparametric analysis of similarity (ANOSIM) was conducted on the raw environmental data (Borcard et al. 2011). Envfit function was performed to test for the significance of sampled variables and its relation with the axes of the ordinations (Borcard et al. 2011). These analyses were also used to select significant variables for the subsequent application of the statistical models.

An initial exploratory analysis was performed using the bird count data to determine if there were differences in abundance between habitats and seasons, for each species. General Linear Regression Models (GLM) were subsequently used to examine how canopy cover, number of large trees, habitat (old-growth, secondary, shade or non-forested), season (rainy or dry), indexes of potential hunting pressure and fruit availability (for São Tomé green pigeon, bronze-naped pigeon and maroon pigeon) affected presence and abundance of each of the study species (Bolker et al. 2009, Zuur 2009). To identify which variables best explained the abundance of each pigeon species, we used model selection based on Akaike's information criterion corrected for small samples sizes (AICc – Burnham and Anderson 2002, Barlow et al. 2010). We used the 'dredge' function from the 'MuMIn' package to test models defined by all possible variable combinations and rank them by their AICc-based model weight (Burnham and Anderson 2002).

All statistical procedures were carried out in R v. 2.10.0 (R Development Core Team 2009).

2.3. Results

2.3.1. Habitat structure

Variation in environmental variables among the sampled sectors was summarised using a non-metric multidimensional scaling ordination (NMDS). This graphic summary (Fig. 2.2) shows that the greatest environmental contrasts in the study area are the different forest types, which to a great extent reflect the degree of habitat disturbance by humans. In fact, the first ordination axis (Stress = 0.18, ANOSIM statistics R = 0.54, P = 0.001) represented a transition in habitat structure and disturbance levels, from native forest (on the left of the plot, with dense canopy cover) to increasingly open woodland types (Fig. 2.2.). The second axis indicated a gradient from forest with large trees and high canopies (at the top of the plot, usually shade forest, often abandoned) to a lower forest type with denser undergrowth (usually younger and regenerating secondary forest).

The two variables which explained most of the variance along the two axes were canopy cover (NMDS1) and canopy height (NMDS2). The ANOSIM analysis of similarities indicated that the habitat types have statistically distinct environmental characteristics (R = 0.54, P = 0.001)..

2.3.2. Species abundance and habitat use

The most common pigeon species counted in all transects was the lemon dove; a total of 759 birds observed (389 in the rainy season, 370 in the dry season) in 44.4% of the 350 sampling units. The species was widespread in all forested habitats (from old-growth to shade forests) a considerable lower presence in non-forested sampled sectors (Fig. 2.3). São Tomé green pigeons were recorded in fewer sectors (17.3%) and were found at lower numbers than the lemon dove (394 individuals, 144 in the rainy season and 250 in the dry season). Green pigeons were observed mainly in mature forested habitats (old-growth and older secondary), and non-forested areas were not important for this species (Fig. 2.3). In contrast, the bronze-naped pigeon was abundant in human-altered habitats, including shade forests and non-forested areas (such as savannah). This species was observed in 37.8% of sectors; 830 individuals (643 in the rainy season, 187 in the dry season). The species was observed significantly less during

the dry season (Mann-Whitney U-test, V= 17570, p<0.001) (Fig. 2.3). The maroon pigeon was the rarest species, being observed mainly in old-growth forests and some isolated individuals in secondary growth and non-forested areas. This species was observed in just 0.5 % of sectors, totalling 37 individuals (Fig 2.3). The abundance of all the pigeons' species significantly varied among the four sampled habitat types (Kruskall Wallis test, p<0.05).

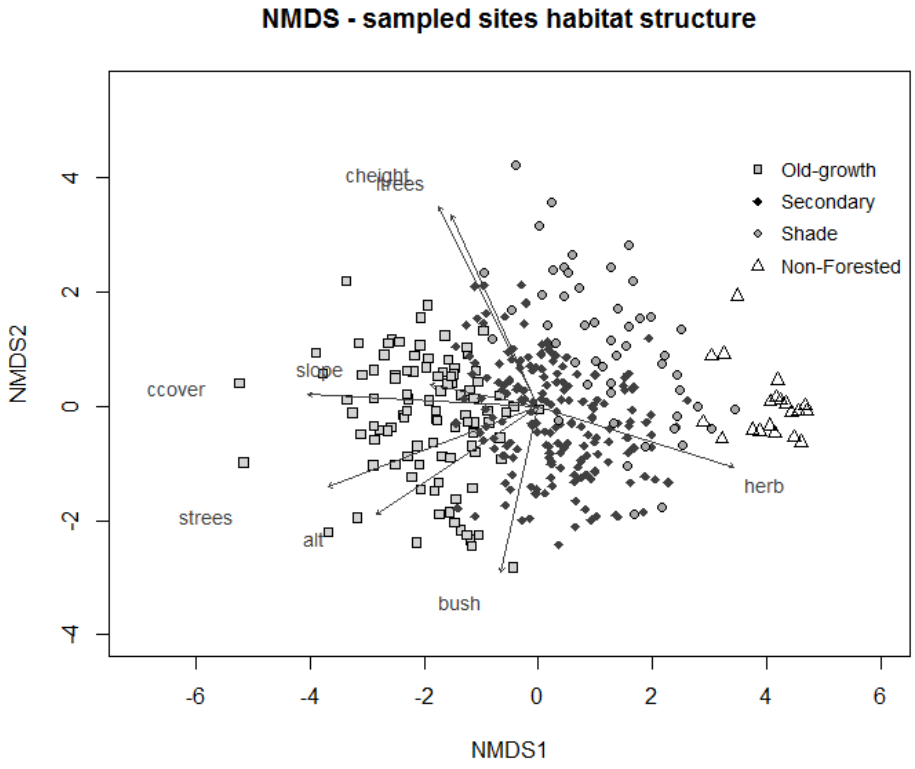

Figure 2.2 - Two dimensional non-metric multidimensional-scaling ordination of transect sectors (as points, N=347) based on nine environmental variables (habitat type, altitude (alt), % canopy cover (ccover), canopy height (cheight), slope (slope), number of large tr trees (ltrees), number of small trees (strees), % shrub cover (bush), % grass cover (herb)) (Stress = 0.18). The diagram symbolizes the sectors' compositional dimensions associated with assessed environmental gradients and general habitat typology. Each habitat type is represented by a distinct symbol. Fitted environmental variables are represented as arrows, and correspond to their input for the ordination axes, both in direction and length of the arrow.

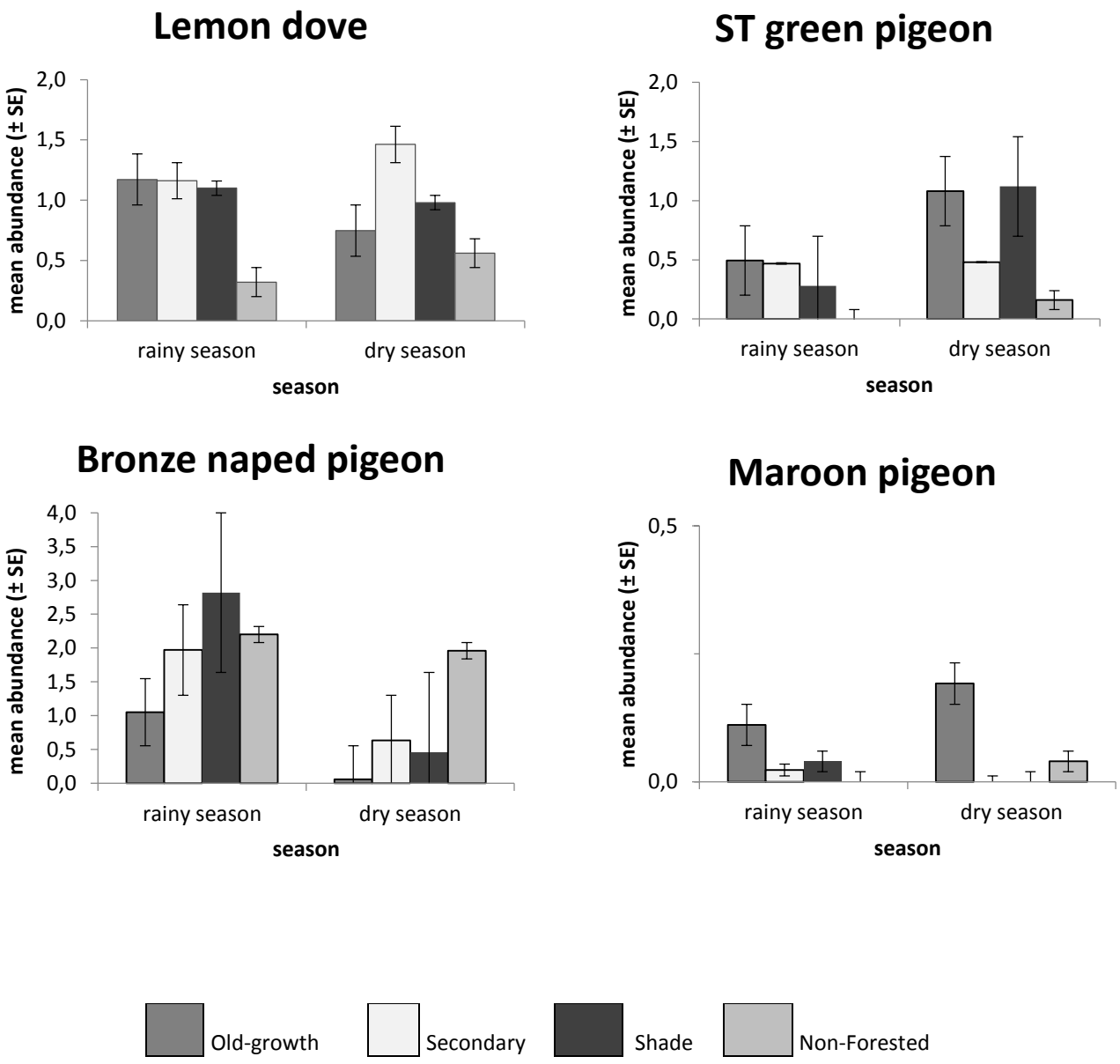

Figure 2.3 – Mean abundance per sector of all four pigeon species in sampled habitats (old-growth (N= 99), secondary (N=171) and shade (N=56) forests, and non-forested areas (N=24)), per sampling season.

Habitat use during the wet and dry seasons for each pigeon species is shown in separate ordination diagrams in Figure 2.4.

Lemon dove numbers were similar during both seasons, but frequencies per habitat varied during the dry season, lemon doves tended to concentrate in old-growth, shade and particularly in young or regenerating secondary forests (characterized by a lower tree canopy and denser undergrowth and shrub cover).

São Tomé green pigeons underutilised degraded habitats and young or regenerating forests, and were more common overall in more mature forests with higher canopies and greater canopy cover, during both seasons. They were seasonally present in shade forests, concentrating at this habitat during early dry season.

The bronze-naped pigeon was more abundant in lower altitude forests with denser shrub cover than in forest with high trees. It was not present in high-altitude forests. During the rainy season it was more common in lower old-growth forests. Its distribution on shade forests is seasonal, as it uses this habitat type more extensively during the rainy season. It was observed in non-forested habitats in both seasons, but more in the rainy season.

The maroon pigeon data suggest a greater concentration in highland forests during the early dry season, with groups of up to 10 individuals being noted during this period. However, the species was also observed in low altitude old-growth forest, secondary forest and in a non-forested sector, mostly during the wet season, in pairs or as isolated individuals.

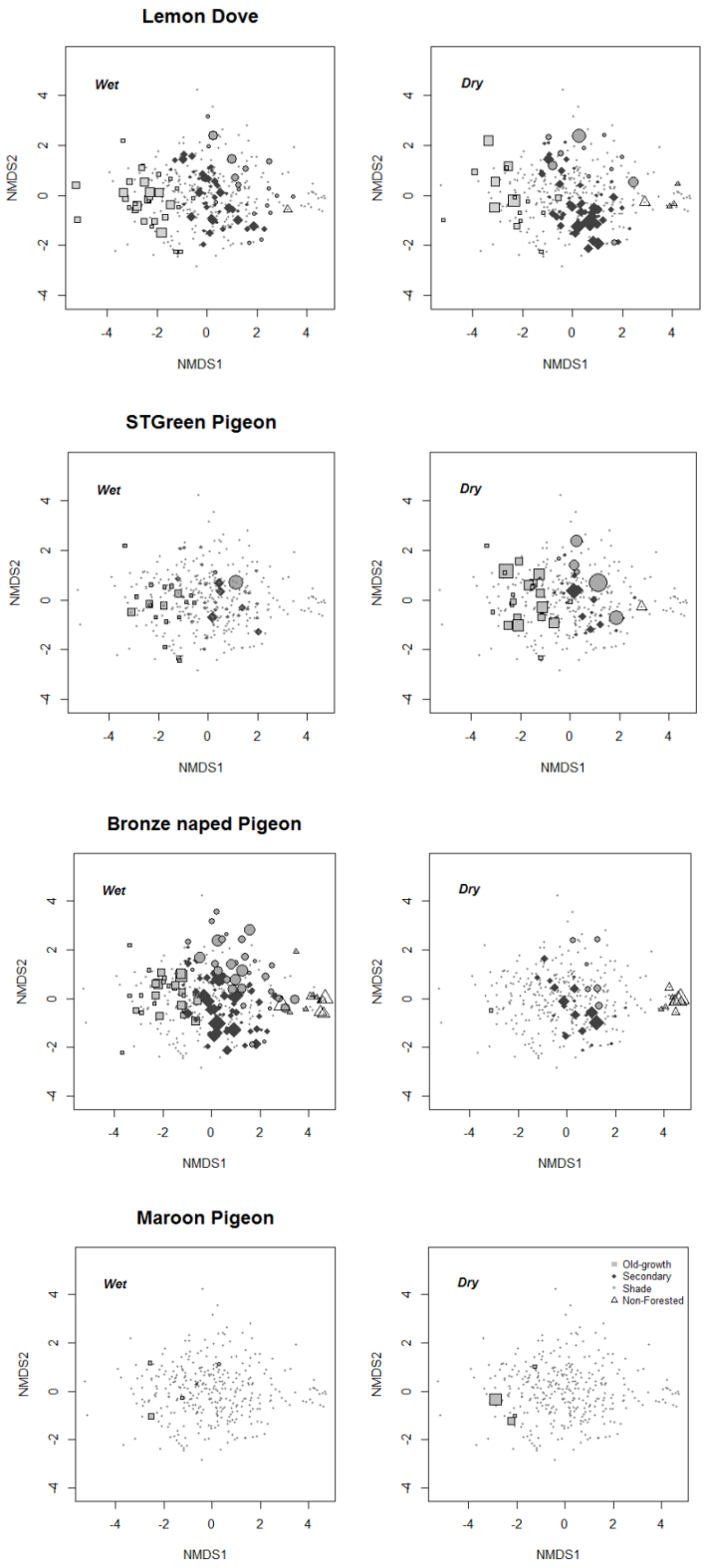

Figure 2.4 - Use of ecological space by the four species of pigeons in rainy and dry seasons, using as a reference the transect sectors' ordination, as in Fig. 2.2. Small dots are sampled sectors and symbols indicate the sectors where each pigeon species was observed. The size of the symbols reflects the pigeon abundance, and its shape and colour the different habitats (as in Fig. 2.2).

2.3.3. Factors associated with species abundance and distribution

Results of associations between environmental variables and pigeon abundance and distribution for the four São Tomé pigeon species are given in Table 2.2. Presence and abundance of the lemon dove were associated with habitat, especially secondary forest during the dry season (coef = 0.69, P = 0.03). Potential hunting pressure was also negatively correlated with the species' presence and abundance, significant during the rainy season (coef = -2.06, P = 0.05). Presence and abundance of the São Tomé green pigeon was significantly correlated with hunting pressure during both seasons (coef = -0.72, P<0.001). Fruit availability was positively related with abundance of this species (coef = 0.05, P = 0.02). For the bronze-naped pigeon, season was linked to the distribution and abundance of the species (coef = -1.33, P<0.001). There was a negative relation with altitude (coef = -0.001, P<0.001) and canopy cover (coef = -0.01, P =0.04), but a positive regression with canopy height (coef = 0.02, P = 0.05), associated with its seasonal use of shade forests. Species abundance was positively correlated with secondary forest (coef = 0.54, P = 0.02); this effect was stronger during the dry season (coef = 2.54, P<0.001). Bronze-naped pigeon abundance was not correlated with fruit availability although close to significance (coef = 0.028, P = 0.06), as this species tends to congregate in the available fruiting trees in closed forests. This effect is significant for the rainy season (coef=0.040, P=0.013).

The number of large trees (coef = 1.03, P<0.001), and fruit availability, particularly during the dry season (coef = 0.33, P<0.001), were positively correlated with distribution and abundance of the maroon pigeon, while with human pressure the correlation is negative (coef = -2.92, P = 0.017).

Potential hunting pressure is negatively correlated with the abundance of three of the four species of pigeons (Fig. 2.5). The abundance of the lemon dove, São Tomé green pigeon and the maroon pigeon declined with increasing potential hunting pressure. This effect was not observed for the bronze-naped pigeon.

Table 2.2 - Results of the GLM models with significant variables selected by the best model and model averaging of top performing models (using dredge, delta<2; RI – relative importance of the variable for best regression models). Significant values are in bold.

Species	variables	GLM- full model		Model averaging		GLM - rainy season		Model averaging		GLM - dry season		Model averaging	
		Coef	P	*P*	RI	coef	p	P	RI	coef	p	P	RI
Lemon dove													
	Habitat - Secondary	**0.437**	***0.03***	***0.04***	1	0.174	*0.490*	*0.73*	0.61	**0.685**	***0.03***	***0.02***	1
	Human pressure	-0.16	*0.1105*	***0.08***	0.79	-0.206	*0.114*	***0.05***	0.83	-0.09	*0.54*	*0.45*	0.17
São Tomé green pigeon	Fruit availability	**0.052**	***0.02***	**0.01**	1	**0.056**	***0.089***	***0.07***	0.72	**0.058**	***0.05***	**0.04**	0.83
	Human pressure	**-0.72**	***<0.001***	***<0.001***	1	**-0.481**	***0.087***	***0.01***	1	**-1.003**	***0.001***	***<0.001***	1
Bronze-naped pigeon	***Intercept***	**1.947**	***<0.001***	***<0.001***		**1.244**	***0.004***					***<0.001***	
	Habitat - Secondary	**0.537**	***0.02***	***0.01***	1	-0.130	*0.582*	*0.58*	0.4	2.540	***<0.001***	***<0.001***	1
	Altitude	**-0.001**	***<0.001***	***<0.001***	1	**-0.001**	***<0.001***	***<0.001***	1	-1.9E-04	*0.72*	*0.51*	0.15
	ıopy cover	**-0.007**	***0.04***	***0.04***	0.85	**-0.01**	***0.007***	***0.04***	0.85	5.2E-05	*0.99*	*0.73*	0.12
	Canopy height	**0.023**	***0.06***	***0.04***	1	**0.024**	***0.052***	***0.03***	1	-2.3E-03	*0.93*	*na*	na
	Fruit availability	**0.028**	***0.06***	*0.75*	0.84	**0.040**	***0.013***	***0.01***	1	3.7E-03	*0.91*	*na*	na
	Season	**-1.331**	***<0.001***	***<0.001***	1								
Maroon pigeon	Large trees	**1.026**	***<0.001***	***0.002***	1	**1.089**	***0.008***	***0.03***	1	**0.008**	***0.04***	***0.06***	0.76
	Fruit availability	**0.206**	***<0.001***	***0.01***	1	0.092	*0.493*	*0.56*	0.17	**0.33**	***<0.001***	***<0.001***	1
	Human pressure	**-0.292**	***0.02***	***0.02***	1	**-2.843**	***0.045***	***0.07***	1	na	*na*	***<0.001***	1
	Season	**-1.258**	***0.09***	*0.10*	0.56								

2.4. Discussion

2.4.1. Distribution and abundance

The observed patterns of distribution and abundance of the 4 species of pigeons on São Tomé reflect habitat structure, food availability and hunting pressure, with a marked seasonal effect in most cases. Secondary forests were significantly associated with the distribution of, at least, three of the studied pigeon species. This was important for the lemon dove and bronze-naped pigeon, but we also found a significant association for the São Tomé green pigeon. Secondary forest is presently the most abundant forest type in São Tomé, but also the one most threatened by deforestation (selectively or intensively) and land-use intensification.

Old-growth forests found at higher altitudes seem to support a higher abundance of the maroon pigeon and the São Tomé green pigeon. However, these species association with these habitats may be the result of loss of populations of these species from lowland forests. In fact, both species were once noted as common and widespread, even within the coastal areas and Rolas Islet (Jones and Tye 2006). Remote old-growth forests now probably constitute the core habitat for these pigeons because of their inaccessibility to bird hunters.

At lower altitudes, shade forests with high canopies as well as non-forested open habitats (mainly savannah) are linked to relatively large populations of the bronze-naped pigeons. However, its commonness in these human-altered areas makes the species more susceptible to hunting, making the regulation of this activity vitally important.

2.4.2. Importance of fruit availability

Fruit availability in sampling sectors was identified as a significant correlate of the distribution and abundance of the maroon pigeon, São Tomé green pigeon and bronze-naped pigeon. As in other studies, forest pigeons were observed to respond to spatial differences in fruit abundance within fragments and habitats (Lambert 1988, Levey 1989, Strong and Johnson 2001, Oliveira et al. 2006). Although fruit availability was shown to affect bird distribution and abundance patterns, relating seasonal bird movements and fruit availability will require more research to clarify

this point. Our study may have been limited by the fact that we did not monitor all species of fruiting tree species, but the four species recorded in our study represented significant food items for pigeons. This is so because São Tomé pigeons, like other frugivorous Columbidae, are opportunistic feeders that consume a large variety of fruits when available (e.g. Bancroft et al. 2000, Oliveira et al. 2006, Walker 2007b).

As in previous studies, the highest tree fruit diversity and abundance was typical of secondary and shade forests (e.g. Levey 1988, Dewalt et al. 2003, Hart et al. 2013). In these habitats, a number of pioneer and transitional forest trees such as Musanga cecropioides and several Ficus species, as well as the introduced South American Cecropia peltata, are found. Fruits from all these tree species are important for canopy-living pigeons (Levey 1988; Carvalho 2004). Figs, even though low in lipids and proteins, are very abundant seasonally and represent a large part of the diets of many tropical pigeons, up to 50% for Treron species in continental Africa (Lambert 1989, Walker 2007b, Devi and Sikia 2012).

Old-growth forests generally have a lower fruit availability than secondary forests, though it may be relatively constant throughout the year (Levey 1988). Asynchronous fruiting patterns of the various tree species found in the different habitats ensure year-round food resources for the pigeons. Although we are certain that the São Tomé pigeons forage in a variety of habitats information on this is limited. Further research is required to clarify these birds' dietary patterns and their role as dispersers. Moreover, detailed studies of fruiting tree phenology and distribution will assist conservation managers on the island to ensure the long-term survival of its forests and biodiversity.

2.4.3. Impact of hunting

We show that hunting pressure is negatively correlated with the distribution and abundance of three pigeon species; lemon dove, maroon pigeon and São Tomé green pigeon. Although the lemon dove is not considered a game species on the island, we found that its presence and abundance was negatively correlated with potential hunting pressure. Children and rural inhabitants opportunistically take the species and even this infrequent human pressure may explain the correlation, although this needs further study. In contrast, there is evidence to support that hunting of the bronze-naped

pigeon, São Tomé green pigeon and the maroon pigeon is heavy (and may be increasing) given the considerable commercial value these species have in bars and restaurants in the main cities (Carvalho et al. 2014). The relatively low abundance and restricted range of the maroon pigeon and the São Tomé green pigeon may be a function of hunting intensity, since both species have been intensively hunted for decades or even centuries (e.g. Bannerman 1931, Snow 1950, Jones and Tye 2006). However, differences in each species' reproductive rate and niche width may also explain the disparities observed in their ecological densities on the island. The bronze-naped pigeon, for example, despite heavy hunting pressure is more abundant presumably because it has adapted to utilising human-altered habitats and a wider range of resources than the other pigeon species. In general, commercial hunting is a real threat for pigeons and other bird species on the island; they are relatively tame and easy to shoot at close range, which has enabled hunters to take large numbers of individuals in a short space of time (Carvalho et al. 2014).

2.4.5. Conservation measures

Previous studies in São Tomé have highlighted that human-modified habitats such as secondary forests and shade plantations, are important as reservoirs for a significant numbers of the island's endemics (e.g. de Lima et al. 2012, Rocha 2008). In our study we also confirm this to be the case for most of the island's endemic pigeons, at least seasonally. Although there is still much forest left on São Tomé, the fast growing human population and consequent urbanization may change this; plans for infrastructure development and an intensifying agricultural pressure are ongoing (Dallimer et al. 2011, Klueh et al. 2007, UNDP 2006). Combined with factors such as invasive species associated with human settlement, as well as increased illegal logging and exploitation of other natural resources, most endemic birds and particularly hunted pigeons are likely to be at increasing risk of extinction.

In our study we confirm that habitats and hunting pressure explain pigeon abundance must be used to drive conservation actions for these species. The São Tomé green pigeon and the maroon pigeon are likely to be less threatened because of their association with the more inaccessible old-growth forests, though improved roads and continuous opening of agricultural fields are of major concern. Most of pigeon hunting

is conducted by commercial urban hunters coming from main towns to forest fringes' (Carvalho et al. 2014), and an increase of accessibility of well-preserved forests will surely intensify hunting pressure over both pigeons. For these species, adequate habitat protection and the strong application of hunting restrictions within the national park are necessary, since the main habitats for these species are here.

The protection of the bronze-naped pigeon may be more problematic given that it is most often found in human-altered habitats, particularly in the dry season. This pigeon is known to use agricultural land where it feeds on the abundant fruits of the shrub Cestrum laevigatum along hedgerows. More research is needed on the drivers of seasonal movements of this species and its use of native and altered habitats.

All three exploited species are known to have declined in numbers during the last decades and the main reason seems to be excessive hunting (Carvalho et al. 2014). Thus, enforcement of strong hunting regulations perhaps through the definition of restricted areas and periods for hunting, specific quotas for the more abundant species and the total ban of species such as the maroon pigeon would alleviate the current situation. A combination of hunting control and habitat preservation has resulted in the recovery of other forest pigeon species (e.g. Pierce et al. 1993, Oliveira 2006).

Supporting the conservation authorities on the island to implement the existing hunting legislation and enforce protection should also be accompanied by more targeted environmental education and raising awareness amongst all islanders. São Tomé hunters and game consumers are not aware of the difference between endemic, native or exotic species, or the conservation problems resulting from overhunting. A main element of this strategy must be to reduce demand by consumers in town and city restaurants. Hunters, and particularly bird hunters, should also be involved in conservation efforts, both by capturing their knowledge on the species and as a critical point for the definition of livelihood alternatives which can ensure pigeons' conservation.

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Appendix 2.I - Coordinates for the start of each transects' main habitat sections, and the corresponding numbers of birds recorded in each seasonal replicate.

Transect line	**Habitat**	**Lenght (km)**	**Coordinates initial point**		**Lemon dove**		**São Tomé green pigeon**		**Bronze naped pigeon**		**Maroon pigeon**	
			x	*y*	*N (wet)*	*N (dry)*	*N (wet)*	*N (dry)*	*N (wet)*	*N (dry)*	*N (wet)*	*N (dry)*
Transect 1	Old-growth	4.6	N0 17.173	E6 36.040	22	57	58	37	28	2	10	0
	Secondary	0.3	N0 18.046	E6 36.010	3	0	0	0	2	0	1	0
	Shade	0.1	N0 18.274	E6 36.033	0	0	0	0	0	0	0	0
Transect 2	Shade	1.0	N0 13.497	E6 29.062	17	24	12	52	71	3	1	0
	Secondary	0.6	N0 13.434	E6 29.459	3	2	4	2	0	0	0	0
	Non-Forested	0.4	N0 13.378	E6 29.787	0	2	0	2	3	1	0	1
	Secondary	2.2	N0 13.389	E6 30.035	17	16	13	6	58	1	0	0
	Old-growth	0.8	N0 13.254	E6 30.942	19	2	0	0	0	0	0	0
Transect 3	Secondary	5.0	N0 15.847	E6 36.785	26	42	11	2	21	11	0	0
Transect 4	Secondary	0.3	N0 17.680	E6 36.974	8	17	0	0	8	4	0	0
	Shade	1.0	N0 17.868	E6 36.932	12	4	4	18	12	3	0	0
	Secondary	0.7	N0 18.088	E6 37.026	14	12	0	2	28	5	0	0

	Shade	3.0	N0 18.611	E6 37.227	36	21	0	0	66	17	0	0
Transect 5	Non-Forested	0.1	N0 07.398	E6 35.207	0	3	0	4	4	0	0	0
	Secondary	2.4	N0 07.445	E6 35.174	44	54	0	16	14	8	0	0
	Old-growth	2.5	N0 08.460	E6 34.312	24	9	4	48	0	2	0	2
Transect 6	Non-Forested	1.0	N0 24.186	E6 39.473	8	2	0	0	52	34	0	0
Transect 7	Non-Forested	1.0	N0 24.644	E6 39.309	0	7	0	0	35	14	0	0
Transect 8	Secondary	1.0	N0 18.439	E6 35.890	11	22	9	4	24	28	0	0
Transect 9	Secondary	1.0	N0 19.136	E6 35.989	13	3	0	14	69	1	0	0
Transect 10	Secondary	1.0	N0 13.953	E6 28.360	22	8	6	5	71	6	0	0
Transect 11	Shade	0.2	N0 14.018	E6 28.751	6	3	0	0	14	4	0	0
	Secondary	0.8	N0 13.966	E6 28.861	9	11	5	2	26	4	0	0
Transect 12	Old-growth	1.0	N0 16.185	E6 34.589	7	8	6	3	2	0	2	0
Transect 13	Old-growth	1.0	N0 15.849	E6 33.730	18	0	1	17	1	1	3	17
Transect 14	Secondary	1.0	N0 05.708	E6 35.310	24	28	7	16	21	38	0	0
Transect 15	Secondary	1.0	N0 05.183	E6 35.241	26	13	4	0	13	0	0	0
Total		*35.0*			*389*	*370*	*144*	*250*	*643*	*187*	*16*	*21*

Chapter 3

HUNTER MOTIVATIONS FOR TARGETING EXOTIC OR ENDEMIC SPECIES ON THE ISLAND OF SÃO TOMÉ, GULF OF GUINEA

Published as: CARVALHO, M., PALMEIRIM, J.M., REGO, F.C., SOLE, N., SANTANA, A. AND J.E. FA (2014). Hunters' profiles and motivations to hunt exotic versus endemic species in the Island of São Tomé, Gulf of Guinea. *Oryx.*

3.1. Summary

Hunting and invasive species are amongst the main causes of biodiversity declines and documented species extinctions on oceanic islands. On the island of São Tomé, however, hunting of introduced mammals (monkeys, civets and pigs) or endemic bird species has contrasting conservation impacts. Introduced mammal hunting may benefit native fauna and flora, but pressure on endemic birds poses a real threat to some species. We conducted semi-structured interviews with 119 hunters to assess the relative importance of native and introduced prey species. We obtained information on hunter profile, preference, and practice, as well as their perception of prey population trends. A total of 11 species were hunted. Among these the most commonly hunted were five invasive mammals and five endemic birds. All five birds are of high conservation importance. We employed cluster analyses to distinguish the main hunter groups, based on hunted species, techniques used and final destination of the quarry. Three clear groups emerged: a smaller bird hunter group and two larger groups (Mona monkey or feral pig hunters). Bird hunters were all from urban areas, but most pig hunters were rural residents. Monkey hunters were mostly rural workers though a smaller proportion were from urban settings. Bird and monkey hunters were primarily motivated by commercial gains though hunting for enjoyment and food were also important reasons. In general, mammal hunting is an opportunistic activity that if regulated can be sustainable, and contribute to lowering the impact of invasives on local fauna as well contribute to local livelihoods. Given the economic drivers involved in bird hunting, intervention to reduce or even eliminate this form of hunting will require enforcement of legislation and raising awareness of the issues involved.

3.2. Introduction

Humans have impacted island ecosystems through habitat modification, hunting and the introduction of domesticated and feral animal species (Kirch 1982; Didham et al. 2005a, 2005b). Rabbits, goats, pigs and cattle are common island introductions, but in some cases wild mammals have also been deliberately released (e.g. monkeys, Glen and Cords 2002). Commensals such as rats, mice, cats and dogs

have caused the extinction of many oceanic island endemics following human arrival (Steadman 2006, Duncan et al. 2002).

Oceanic islands in the Gulf of Guinea, off the west coast of Africa, have been subject to centuries of habitat alteration and impacts from introduced species (Hodges and Newitt 1988). The larger of these islands, São Tomé, has been classified as critically important due to the numbers of restricted range bird species occurring together (Bibby et al. 1992, Stattersfield et al. 1998, Buchanan et al. 2011). The island has 17 endemic birds, including two endemic genera as well as endemic subspecies; most are forest dwellers (Birdlife 2012).

Habitat modification is still considered the single most important threat affecting the island's endemic birds, but most taxa are also potentially threatened by non-native mammal species and by uncontrolled hunting. Bird hunting is mentioned in the literature since the first naturalistic expeditions and throughout (e.g. Snow 1950, de Naurois 1983, Jones and Tye 1988, Peet and Atkinson 1994), but its impact still little understood (de Lima et al. 2012). Species most at risk from any increase in hunting pressure are the endemic pigeons such as the maroon pigeon (*Columba thomensis*), which is particularly susceptible due to its relatively large body size associated with a tame behaviour, the São Tomé bronze-naped pigeon (*Columba malherbii*) and the São Tomé green pigeon (*Treron sanctithomae*). Any hunting of the dwarf olive ibis (*Bostrvchia bocagei*) can also have serious negative consequences as the species has a very small population and is considered Critically Endangered (IUCN 2011).

Mammals such as the African civet (*Civettictis civetta*), the Mona monkey (*Cercopithecus mona*), and feral pigs (*Sus scrofa*) were introduced to the island of São Tomé in the 17th century, and are common throughout the island's forested habitats (Dutton 1994, Glenn and Bensen 1996, Oliveira 2002). Feral pigs are known to modify habitats by reducing native plant species abundance, increasing the establishment of invasive non-indigenous plants, and even indirectly negatively impacting native forest bird species (Nogueira-Filho et al. 2009). Pig foraging and travelling patterns will also cause watershed degradation by increasing soil erosion. On the other hand, monkeys introduced to islands may not impact habitats directly, but can become significant predators of endemic birds, particularly of their nests (Nowak 1991, Furuichi 2006), as well as compete with frugivorous birds for food resources

(Walker 2007). Pigs and monkeys are recognised worldwide as highly destructive invasives (Gurevitch 2004, Cruz et al. 2005, Nogueira et al. 2007), and are also known to potentially impact endemic birds in São Tomé (Dutton 1994).

Introduced mammals are among the most hunted quarry on São Tomé. Hunting of these exotic species can, under particular circumstances, deflect attention from native species (Desbiez et al. 2012). But, the hunting of endemic birds, either opportunistically or for commercial purposes, can severely impact the survival of most of these taxa. This is so because tropical island forest birds generally have reduced fecundity, longer developmental periods and increased investments in young than mainland counterparts (Covas 2012). Such reproductive traits are likely to render island birds more sensitive to increased adult mortality rate from hunting, as shown for Holocene bird extinctions in New Zealand (Duncan et al. 2002).

Hunting of wildlife either for cash or for food is often an essential activity that supports the livelihoods of the poor in many parts of the world (Bowen-Jones et al. 2003, Bennett et al. 2007). However, overexploitation of wild species is a main driver of defaunation of many tropical forest ecosystems. Thus, understanding what motivates people to hunt wild animals is a critical first step to identify causes of unsustainable practices, threats to and opportunities for conservation, and intervention options (Pailler et al. 2009). Here we investigate: 1) the relative importance of native and introduced prey species to hunters on the island, 2) hunters' motivation, preference and practice of hunters dedicated to endemic bird hunting and introduced mammal hunting and 3) analyze hunters' perceptions on populations trends of hunted prey and barriers to achieve sustainability. Finally, we use our results to recommend measures to encourage introduced mammal hunting and reduce focus on the endemic birds. The main interest of this study is that it juxtaposes two hunting systems which have contrasting impacts on native wildlife.

3.3. Study Area

São Tomé (857 km^2) is the larger of the two oceanic islands that constitute the Democratic Republic of São Tomé and Príncipe (Fig. 3.1). The island is located around 200km from the African coast. Annual rainfall ranges from less than 1,000 mm

in the northeast to more than 7,000 mm in the southwest. Mean annual temperatures vary between a minimum of 18° to 21°C to a maximum of 30° to 33°C, with little seasonal variation and high humidity all year (Carvalho et al. 2004). The island is characterized by a rough relief, with numerous steep mountains and a maximum altitude of 2,024m.

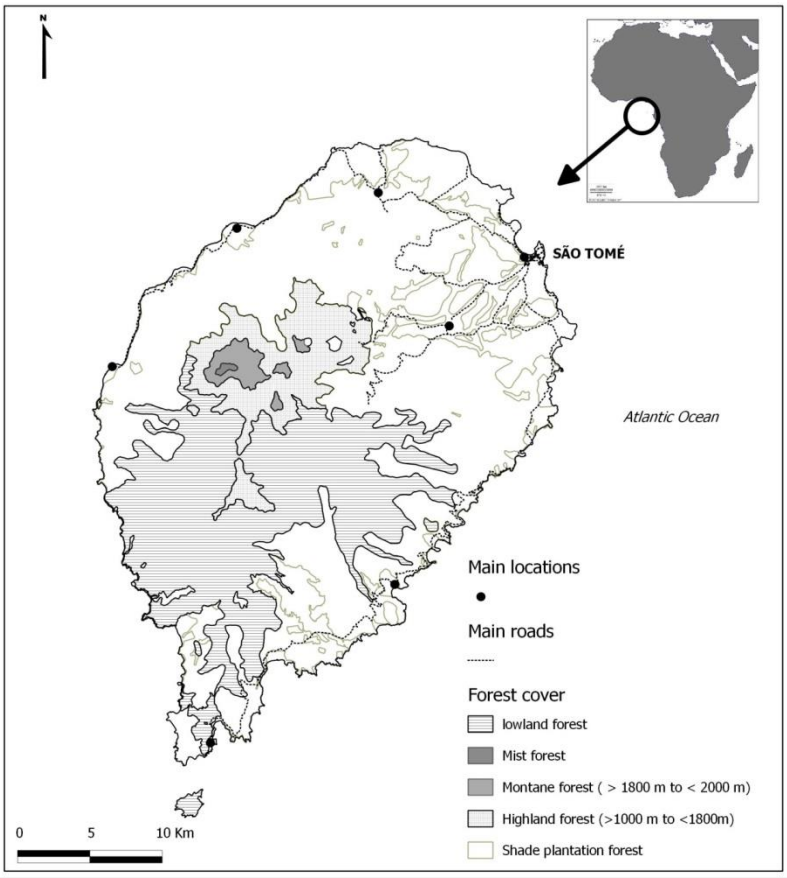

Figure 3.1 - Map of the island of São Tomé, showing main locations and main forest cover types.

With no permanent human settlement before the Portuguese arrived in 1470, the original vegetation on the island was comprised of old-growth forest in the lowland areas (below 800m) and montane and mist forests on the higher and wetter side of the island (Jones and Tye 2006). Mist forest is still found at highest altitudes, but presently only a few patches of old-growth forest remain in the steeper and inaccessible slopes. Although lowland forests have been heavily modified in the past

to plant cocoa and coffee, there has been significant regeneration of secondary forest due to the economic collapse of these crops (ongoing since 1930´s) (Oliveira 2002; Carvalho et al. 2004). A drier forest type results from a rain shadow effect on the north-eastern side of the island. This forest type has been extensively cleared for farmland and estates and is presently replaced by savannah and agroforestry (Carvalho et al. 2004).

Nearly one third of the country has been declared a protected area, the Parque Natural do Obô (Albuquerque and Cesarini 2009). The Park comprises most of the remaining old-growth and large areas of secondary forest, but there is little enforcement. Hunting legislation has been in preparation since 1995. It was reviewed in 2012, but still awaits promulgation. According to the new proposal, hunting of endemic bird species as in the case of São Tomé green pigeon and bronze-naped pigeon (totally restricted during known breeding periods) should be density regulated. It is forbidden to hunt threatened species, namely the maroon pigeon and the dwarf olive ibis.

The human population is estimated at around 187,000 people (approximately 212 inhabitants/km^2, INESTP 2012); growth rate is 2.0% (CIA 2012). About 60% of the inhabitants of the island live in the capital and adjacent districts (INESTP 2012). Poverty levels are high with 34.5% of the population affected (Alkire et al. 2011). Infrastructure is generally poor.

3.4. Methods

3.4.1. Hunter interviews

We used a total of 12 key informants (former or current hunters, restaurant owners or managers and people engaged in local civil associations), and a snowball approach to identify hunters operating on the island (Bernard 2006). The list was checked regularly with informants, generally during hunters' interviews, until no new names were mentioned. We identified 196 resident and active hunters on the island, of which we were able to interview a total of 119 (61%). The remaining hunters (n = 77) were taken out of the sample because of the difficulty to meet them, or their reluctance to be interviewed. Out of these, 20 were sport hunters; medium/high-

income earners, most São Tomean though seven were long-term resident expatriates. All sport hunters lived in the main city or surrounding areas, hunted occasionally, in groups, and for enjoyment.

All interviews were undertaken between June 2008 and December 2010 in the homes of the selected hunters. We applied a questionnaire of 17 questions; most were open-ended questions, so care was taken not to lead the process (see Appendix 1 in Supplementary Materials). Several questions were designed to triangulate information, and have confidence about the answers provided by respondents. Interviewee participation was always voluntary, all hunters agreed to be interviewed beforehand, and no incentives were offered. The length of the interview was such that sufficient time was available for interviewees to answer all questions asked without attention drop-off.

The applied questionnaire aimed to gauge their socio-economic situation and current livelihood activities as a means of determining whether wealth status affected hunting motivation. We first asked interviewees to tell us which wildlife group (mammal, birds or no preference) or species they preferred hunting. We questioned hunters about the methods they most commonly used (e.g. shotguns, airguns, spear, dogs, snares or traps) and their main reason for hunting. We asked hunters if the animals they hunted were for their own consumption, to sell, or both. If animals were sold, hunters were asked to whom they sold their quarry. Because we wanted to know if hunting was fulltime or subsidiary work, we enquired about each hunter's main professional activity. We also asked hunters the question, - why do you hunt? - to allow interviewees to express their own views. Finally, we asked hunters their opinions of general prey abundance trends during the last decade as well as those species they considered to be less abundant at present.

3.4.2.Data analyses

All statistical analyses were performed using SPSS (IBM 2011). To understand the relative significance of the different prey species to São Tomé hunters, we estimated a hunting importance value (*Hv*) for the species named (adapted from Fernandes-Ferreira 2012 and Phillips 1994). For the question - what animals do you hunt? - no minimum or maximum number of answers was defined, and this varied

between respondents from one to eight species (each species could only be mentioned once). The resulting value was based on the number of times a species was mentioned by the interviewees within the totality of citations.

$$Hv = \sum(\frac{Hsp}{n}) * N \qquad \text{eqn 1.}$$

where *Hsp* is number of times a species is mentioned as a targeted animal, *n* the total number of citations (n = 400), and *N* the number of interviewed hunters (n = 119).

We also estimated a Preference Value (*Pv*) based on species named by the interviewees as preferred to hunt (excluding zeros – no preference). Hunters' cited between one to three preferred species.

$$Pv = \sum(\frac{Psp}{n}) * N \qquad \text{eqn 2.}$$

where *Psp* is number of times each species is mentioned as a preferred species, *n* the total number of citations (n = 158), and *N* the number of interviewees (n =119).

Subsequently, 116 of the interviewed hunters (three cases were excluded due to missing data) were described using a set of numerical (age, literacy, number of years dedicated to hunting) as well as categorical variables (urban or rural origin, hunting as the main activity, other professional activities, methods and gear used to hunt, transport used, reasons for hunting). For a full description of each variable, see Appendix 2 in Supplementary Materials. Factors with the highest inertia were used to identify hunter groups using a cluster analysis (Punj and Stewart 1983; Ketchen and Shook 1996; Bernard 2006). As a first approach to the classification, the chosen categorical variables were recoded as dichotomous variables, assigning equal weights to all components. Then, we conducted a hierarchical cluster analysis using Ward's linkage method with Euclidean distances to identify relatedness among hunters (Ward 1963) from which we produced a dendrogram as our preliminary cluster solution.

Following Punj and Stewart's (1983) recommendation on a combined analysis, we used an iterative partitioning algorithm using the cluster centroids of the preliminary analysis as starting points. We employed a two-step cluster analysis with no cluster limits using Schwartz Bayesian criteria to assess the importance of each variable to explain the characteristics of hunter groups, as defined by the hierarchical cluster analysis (Ketchen and Shook 1996). Following this, the variance between the resulting groups was tested for significance using a one-way ANOVA for continuous variables and a Pearson chi-squared test for dichotomous variables.

3.5. Results

3.5.1. Prey species

Interviews lasted an average of 26 min. (range 18-39 min.). A total of six mammals and five bird species were specifically mentioned by the interviewed hunters (Table 3.1). Fruit bats were the only native mammals mentioned, whereas all bird species except the introduced helmeted guinea fowl (*Numida meleagris*) were endemic and threatened or near threatened according the IUCN Red List (Table 3.1). Reported hunting values and prey preference (as shown by preference values) were highest for Mona monkeys and feral pigs, and lowest for guinea fowl, feral cat, ibis and small passerine birds. Endemic pigeons had hunting and preference values similar to fruit bats and civets but lower than for pigs and monkeys.

3.5.2. Hunter groups

Three homogeneous groups, Group A (11.2% of all hunters) and Groups B and C (88.8% of all hunters), were identified through cluster analysis. Results of the two-step cluster analysis indicated significant differences in the characteristics of the three statistically defined hunter groups (Table 3.2). Data for all variables used to characterise each hunter group are also given in Table 3.2.

Table 3.1 - General characteristics of prey species cited by hunters in interviews. The species' status in São Tomé, derived hunting and preference values for each taxon, as well as their IUCN Red List threat status (IUCN 2011).

	Species	Endemic	Native	Introduced	*Hv*	*Pv*	IUCN threat status[1]
Mammals							
Feral pig	*Sus scrofa*	-	-	+	22.02	47.01	LC
Mona monkey	*Cercopithecus mona*	-	-	+	24.40	35.99	LC
Fruit bat	*Eidolum helvum*	-	+	-	15.17	7.35	LC
Civet	*Civettictis civetta*	-	-	+	14.88	8.82	LC
Feral cat	*Felix catus*	-	-	+	2.38	0	LC
Birds							
São Tomé green pigeon	*Treron sanctithomae*	+	-	-	13.09	8.82	Vu
Maroon pigeon	*Columba thomensis*	+	-	-	11.90	3.67	En
Bronze-naped pigeon	*Columba malherbii*	+	-	-	11.31	4.41	NT
Helmeted guinea fowl	*Numida meleagris*	-	-	+	2.68	0	LC
Dwarf ibis	*Bostrychia bocagei*	+	-	-	0.60	0	CR
Small passerine birds		+	+	+	0.60	0	

Footnote:

1: LC = Least Concern; NT = Near Threatened; Vu = Vulnerable; En = Endangered; CR = Critically Endangered.

Group A hunters were primarily bird hunters, mostly targeting pigeons (92.3%) though some also hunted fruit bats (53.8%) and Mona monkeys (30.8%). No feral pigs were hunted by this group. Hunter groups B and C, comprising 50% and 38.8% of all interviewed hunters respectively, were characterised by a clear preference for hunting mammals rather than birds. Most Group B hunters preferred to hunt monkeys (98.3%), while Group C hunters favoured hunting feral pigs (95.6%). A lower

proportion of Group B hunters (12.1%) had no prey preference, with 1.7% mentioning at least one bird species as the preferred prey.

All bird hunters used air guns, with 61.5% also operating shotguns. Pig hunters never used air guns but not all had shotguns (only 64.4%); a large proportion commonly hunted with spears (68.9%), dogs (84.4%) and/or snares (22.8%). Monkey hunters predominantly used shotguns (96.6%), although a lower proportion also employed air guns (20.7%) and/or dogs (25.0%).

Bird hunters were all residents of urban or peri-urban areas, around São Tomé capital and adjacent districts. Most (76.9%) hunted frequently (between 2 and 5 times a week), with 46.2% declaring hunting as their main professional activity. Monkey hunters lived in rural as well as urban settings practicing hunting as a secondary activity, between 1 and 4 times a month (48.3%), using public transport (37.6%) or rented motorbikes (12.2%) to get to an appropriate access point in the forest from which to continue on foot. Most pig hunters (86.7%) were farmers or palm wine producers (75%). This group hunted 2 - 5 times per week (62.2%) often during breaks from agricultural activities; most walked to the forest (97.8%).

Bird hunters had significantly higher literacy levels (53.8% had completed at least their 9th school grade) than the other two hunter groups. Average literacy of pig hunters was low, but higher amongst monkey hunters (most had completed their 7th grade). The latter also worked in other activities besides hunting (46.2% were employed in the service industry). Pig hunters were the youngest (average age, 29.5 years old) and monkey hunters the oldest (35.7 years old) amongst the three groups.

Table 3.2 - Group profiles of São Tomé hunters derived from cluster analysis.

Variables	Variable Importance in clustering	Hunter Groups A (birds) (*n* = 13)	B (monkey) (*n* = 58)	C (pig) (*n* = 45)	Between group variability (Pearson χ^2)	*P*
Personal characteristics						
Age	n/a	31.3	35.71	29.5	5.60**	0.005
Dependents	0.02	1.85	3.86	2.11	14.88**	0.001
Literacy level	0.221	8.5	7	4	21.73**	<0.001
Lives in rural setting	0.31	0	62.1	86.7	33.49	<0.001
Lives in urban setting	0.31	100	37.9	13.3	33.49	<0.001
Main professional activity						
Hunting	0.11	46.2	8.6	15.6	11.41	0.003
Primary sector – farming	0.24	0	67.2	75.6	25.61	<0.001
Secondary sector – industry	0.04	0	13.8	4.4	4.19	0.123
Tertiary sector – services	0.23	100	31.0	26.7	25.01	<0.001
Prey choice						
Prefer mammals	0.53	15.4	87.9	100	56.14	<0.001
Prefer birds	1.00	100	1.7	0	106.74	<0.001
No preference	0.07	0	12.1	0	7.45	0.24
Feral pigs	0.42	0	53.4	95.6	45.25	<0.001
Mona monkey	0.46	30.8	98.3	40	49.01	<0.001
Civet	0.04	30.8	39.7	57.8	4.67	0.97
Fruit bat	0.18	53.8	60.3	17.8	19.41	<0.001
Maroon pigeon	0.37	92.3	34.5	4.4	39.08	<0.001
São Tome green pigeon	0.29	92.3	43.1	11.1	31.18	<0.001
Bronze naped pigeon	0.34	92.3	39.7	6.7	36.09	<0.001
Guinea fowl	0.06	15.4	12.1	0	6.35	0.42

Other birds	0.03	7.7	1.7	0	3.52	0.172
Hunting methods						
Shotgun	0.18	61.5	98.6	64.4	19.63	<0.001
Air gun	0.56	100	20.7	0	59.71	<0.001
Spear	0.46	0	8.6	68.9	49.59	<0.001
Dogs	0.43	0	27.6	84.4	45.68	<0.001
Snares	0.07	0	6.9	22.2	7.62	0.022
Traps	0.13	0	6.9	31.1	14.02	0.001
Reasons for hunting						
Hunts for food	0.22	49.0	15.4	17.25	13.62	0.001
Hunts for sale	0.13	2.22	46.16	6.90	23.58	<0.001
Hunts for both	0.13	48.8	38.46	75.86	10.95	0.004
Sell local communities and neighbours	0.04	27.6	7.7	37.8	4.57	0.102
Sell restaurants and traders	0.25	60.3	76.9	15.6	26.65	<0.001
Effort						
Hunts intensively (2-5 times a week)	0.09	76.9	37.9	62.2	9.71	0.008
Hunts regularly (1-4 times a month)	0.07	7.7	48.3	37.8	7.42	0.025
Hunts occasionally	0.07	15.4	13.8	0	6.97	0.031
Go by foot	0.20	46.2	67.2	97.8	20.89	<0.001
Bus or public transport	0.16	38.5	37.6	4.4	16.57	<0.001
Motorbike - own	0.12	30.8	5.3	2.2	13.34	0.001
Motorbike - rented	0.05	7.7	12.1	0	5.76	0.56

3.5.3. Hunting drivers and motivations

Bird hunters predominantly hunted to sell their quarry (total 84.6%, 76.9% of which sold their game to restaurants or to traders), with less than a quarter of these hunters claiming to hunt exclusively for food (Table 3.2). Also, most monkey hunters hunted for commercial gain (82.8%) with 60.3% selling their quarry to restaurants or traders. On the other hand, pig hunters said they hunted primarily for food, either for their own consumption or to sell (48.9%) to neighbours or local residents (Table 3.2). A main reason given by a large proportion of hunters in the three groups was that they hunted because they enjoyed it (Fig. 3.2). Only amongst bird hunters was survival mentioned as a major reason for hunting, paired with enjoyment. Very few respondents answered that hunting was necessary to feed the family or to supplement their income. This suggests that the commercial demand for birds plays an important role in the household economy of bird hunters. Mammal hunting, either for food or commercial reasons, is largely motivated by enjoyment, suggesting a lesser dependency of mammal hunters on protein or income provided by the hunt.

3.5.4. Hunters' perceptions

Most interviewed hunters (81.5%) claimed that there were fewer animals nowadays than a decade before, with only1.7% suggesting there were more, and 16.8% did not know. The main reason given by 68.1% of interviewed hunters was the rise in hunter numbers, though a smaller proportion suggested habitat degradation (7.5%). Of the bird hunters, 42.8% mentioned that all prey species had declined, but in particular the maroon and green pigeons (Fig. 3.3). Around 30% of pig hunters stated that there had been a fall in numbers of feral pigs but also civets. A lower proportion of monkey hunters (15.5%) suggested that monkeys had declined. Monkey hunters (27.6%) also confirmed a drop in pig numbers.

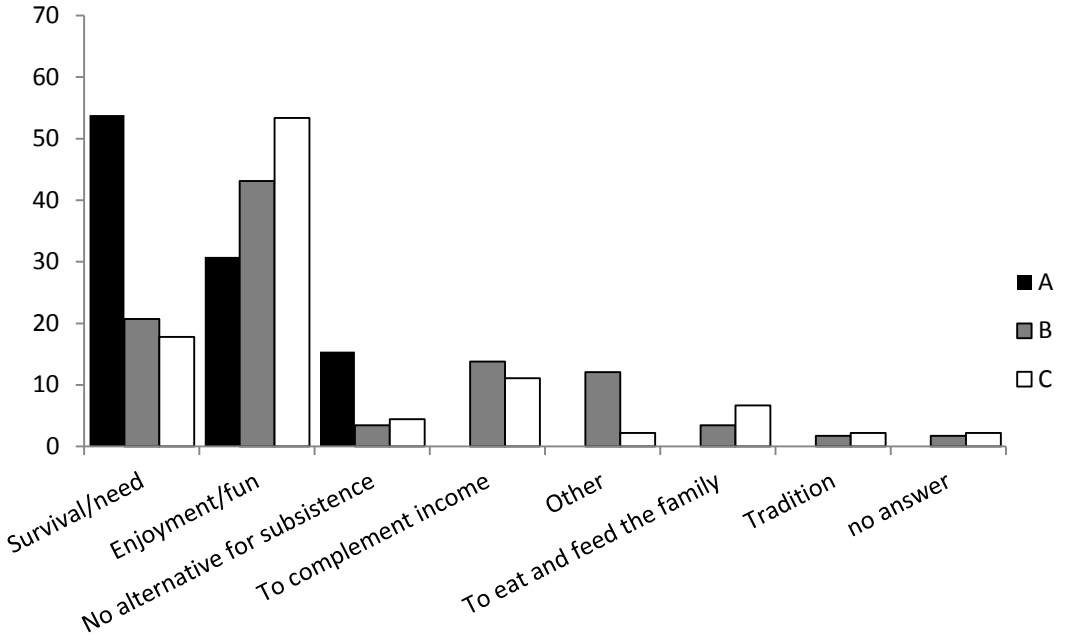

Figure 3.2 - Distribution of responses given by São Tomé Island hunters of their reasons for hunting. Hunter groups: A= bird hunters; B = monkey hunters; C = pig hunters.

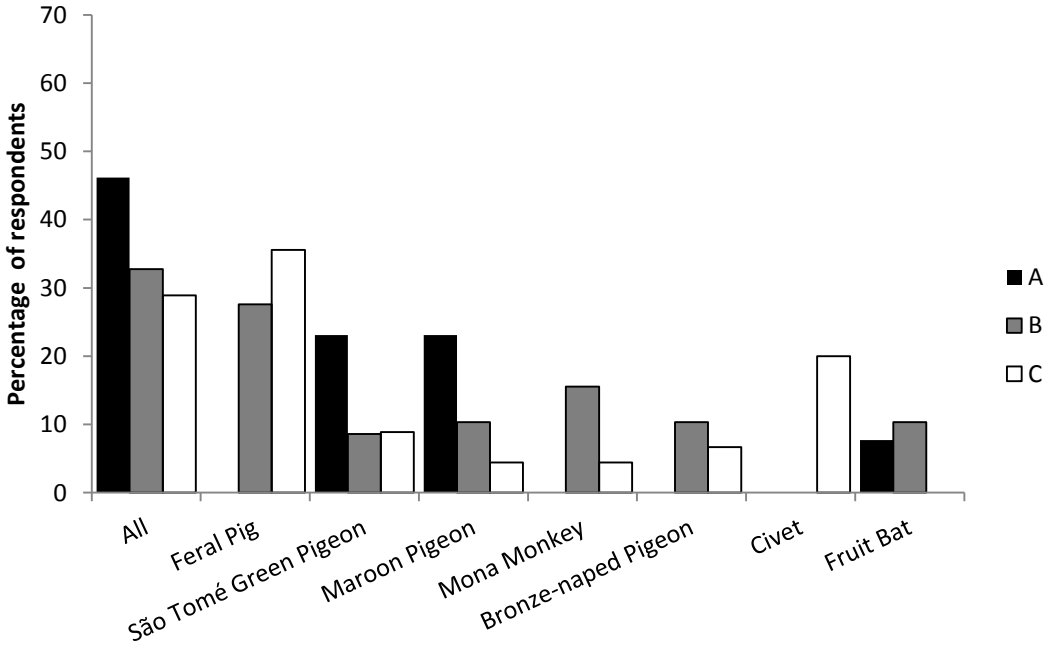

Figure 3.3 - Distribution of responses given by São Tomé Island hunters of perceived changes in prey species populations during the last decade. Hunter groups: A= bird hunters; B = monkey hunters; C = pig hunters.

3.6. Discussion

Bushmeat hunting of introduced species can have a positive outcome for wildlife conservation, as described for feral pigs in the Brazilian Pantanal (Desbiez et al. 2011). However, situations in which hunting of introduced biota as well as native wildlife co-occurs are little known. In this study, we presented information on the general characteristics of three hunter groups operating in the island. We showed that these hunter groups targeted a distinct assemblage of prey species, though some overlap existed. Each hunter group differed in their ages, educational background and socioeconomics. In particular, the average age of each hunter group reflected the physical requirements imposed by each hunting type. Because pig hunting demands more active pursuit of prey by the hunter, this is often carried out by younger men, and hence these hunters were the youngest. By contrast, monkey and bird hunting is less demanding as is reflected in the older average ages of these two hunter groups, in comparison to pig hunters.

Bird hunters in the island, who pursue endemic birds and namely pigeons, are likely to be of major concern for the conservation of the island's unique biodiversity. Despite a smaller number of men being involved in pig or monkey hunting, bird hunters are known to be very effective in taking large number of birds during a hunting session. This is because the island's birds are relatively tame and therefore easy to shoot at close range. Hunters are also able to predict where birds are likely to congregate (e.g. around fruiting trees), and hence take a high number of individuals in a short space of time. The amount of time spent hunting birds, often taking place within a single day, is much shorter compared to other wildlife hunting. Bird hunting is also more lucrative form of commercial hunting than targeting pigs or monkeys because the return on investment is higher. The cost of hunting gear, airguns and their ammunition (air gun pellets), is comparatively lower than shotguns and cartridges. Moreover, the price offered per bird is high on a weight basis.

Despite the numbers for domestic and local trade are difficult to assess, as most of the birds do not pass through markets, demand for birds for sale in city restaurants is likely to be high. According to our informants hunted birds are almost immediately bought from the hunters, and often are pre-ordered from hunters by restaurants and local traders/sellers. Although no direct evidence of the impact of

hunting on bird populations is yet available, hunters claim that a decade earlier they shot hundreds of birds, particularly pigeons, whereas only dozens are currently taken. Historical accounts also suggest that large numbers of pigeons were hunted in the 1950s and these species were widely distributed (e.g. Snow 1950; Amadon 1953; de Naurois 1983, 1988). Most hunters in our study acknowledged a negative trend in all exploited species, especially pigeons, which most linked to increased hunter numbers. Although declines in introduced mammals were reported, endemic pigeons are likely to be the most threatened by overhunting, as also suggested by a number of authors (Collar and Stuart 1988; Christy and Clarke 1998; Olmos and Turshak 2010; Dallimer et al. 2009; de Lima et al. 2012)

In contrast to bird hunting on the island, the hunting of pigs and monkeys not only reduce the impact of these introduced mammals on the native wildlife, it also provides a reliable, culturally acceptable, and free meat source and income for a substantial number of resident families. Our study is a first step towards understanding the strength and significance of hunting practices and their long-term effects on the biota and ecosystems in São Tomé. Elucidating the dynamics and long-term ecological effects generated by pigs and monkeys is a crucial step towards increasing our understanding of and more effectively managing biotic interactions in this island and thus preserve its valuable habitats and the many endemic species that they harbour. Although the current study is a useful step in characterising the hunters, their motivations and target species, data on the actual and potential impact of hunting on prey populations is essential. Information on numbers taken, age structure of individuals killed or potential impact on the populations of the quarry species were collected for this study and will be published elsewhere.

Exploitation of wildlife is unhindered throughout São Tomé since there are few legal or other types of restrictions. As in most other west-central African countries, hunting legislation on the island is poor, and there is limited capacity to enforce promulgated laws (Bowen Jones et al. 2002; Rowcliffe et al. 2004). Furthermore, São Tomé hunters and game consumers are not aware of the legislation and most do not know the difference between endemic, native or exotic species, or the conservation problems resulting from overhunting. Controlling bird hunting and regulating the trade to restaurants will require a combination of enforcement of legislation but also raising awareness amongst stakeholder groups (including

restaurants that sell birds). Hunting regulations for endemic birds must be evidence-based, and implemented. If hunting quotas for endemic pigeons and perhaps other species are to be implemented, knowledge of densities, association with the different habitat types and breeding seasonality is fundamental. Capturing hunters' knowledge and developing a common base from which to regulate better hunting, needs to be done urgently. Alternatively, farming of native species, such as the São Tomé harlequin quail (*Coturnix delegorguei histrionica*), which is already widely bred in aviaries, could be a substitute for the current demand for birds in restaurants, as well as create incentives for bird hunters to shift to mammal hunting.

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Appendix 3.I - Description of variables used in the analyses of hunter characterstics

Personal characteristics

Age * - in years

Descendants * - number of people financially dependent on the interviewee

Literacy * - last school grade completed

Lives in rural setting – location of residence in a rural area

Lives in urban setting – location of residence in urban or peri-urban areas (centre or suburbs of the main city in each district)

Main professional activity

Hunting – named as the main professional activity at the present time of the interview

Primary sector – main professional activity named makes direct use of natural resources and so economically included in primary sector

Secondary sector – main professional activity named related to production of manufactured and other processed goods and so economically included in secondary sector

Tertiary sector – main professional activity named related to the production of services and so economically included in tertiary sector

Prey choice

Prefer mammals – first preferred prey named was one of the listed mammal species

Prefer birds - first preferred prey named was one of the listed bird species

No preference – explicitly mentioned not to have a preference, or didn't mention any species

Feral pigs – feral pig was named as the preferred or one of the preferred prey species

Mona monkey - Mona monkey was named as the preferred or one of the preferred prey species

Civet - Civet was named as the preferred or one of the preferred prey species

Fruit bat - Fruit bat was named as the preferred or one of the preferred prey species

Maroon pigeon - Maroon pigeon was named as the preferred or one of the preferred prey species

São Tome green pigeon - São Tome green pigeon was named as the preferred or one of the preferred prey species

Bronze naped pigeon - Bronze naped pigeon was named as the preferred or one of the preferred prey species

Guinea fowl - Guinea fowl was named as the preferred or one of the preferred prey species

Other birds - Other birds were named as preferred prey species

Hunting methods

Shotgun – named as single method or one of the hunting methods used

Air gun - named as single method or one of the hunting methods used

Spear - named as single method or one of the hunting methods used

Dogs - named as single method or one of the hunting methods used

Snares - named as single method or one of the hunting methods used

Traps - named as single method or one of the hunting methods used

Reasons for hunting

Hunts for food – when "to eat" was the reason alleged to hunt

Hunts for sale – when "to sell" was the reason alleged to hunt

Hunts for both – when "both to eat and sell" was the reason alleged to hunt

Sell local communities and neighbours – When any of "to sell" or "both" were recorded in the previous question, and communities and neighbours were identified as final destiny of the hunt sold

Sell restaurants and traders – When any of "to sell" or "both" were recorded in the previous question, and restaurants or individual traders were identified as final destiny of the hunt sold

Effort

Hunts intensively (2-5 times a week) – frequency of hunting sessions named was between two and five times a week

Hunts regularly (1-4 times a month) - frequency of hunting sessions named was between one and four times a month

Hunts occasionally - frequency of hunting sessions named was "occasionally" or "once in a while"

Go by foot – Walking was named as the only or one of the habitual ways of transport to hunting areas

Bus or public transport – Bus, taxis or other public transports were named as the only or one of the habitual ways of transport to hunting areas

Motorbike – own – Owned motorbike was named as the only or one of the habitual ways of transport to hunting areas

Motorbike – rented – Rented motorbike was named as the only or one of the habitual ways of transport to hunting areas

Appendix 3.II – Semistructured interview applied to São Tomé's hunters

Hunter Interview

Code: ___ Location:_____

Interviewer(ers): Date: Time:

Name of hunter: Age and gender:

Place of birth: How long living in the community:

Household code (when applicable): Literacy (last school grade completed):

Marital status: Number of children:

1. How long do you live here?

   Why did you moved?

2. For how long do you hunt?

   Is hunting your main activity right now?

   What other professional activities do you have/had?

3. Which methods do you use to hunt?

   Which method you prefer?

   Why?

4. From the following list of subsistence activities, could you please enounce the frequency you spent with each one:

Everyday (or almost everyday)

Two to three times a week

Once a week

One or two times a month

Rarely

Never

Ocasionally

Activity	Frequency	Activity	Frequency
Fishing		Fire wood collection	
Hunting with fire weapon		Paid work	
Hunting using other methods		Sale of products	
Snail collection		Livestock maintenance	
Agriculture – own field		Construction works	
Agriculture – for others		Housework	
Wood cutting		Other	

5. What are the areas do you usually hunt?

   What are your preferred places?

   When do you usually move to new places and why?

6. How frequently do you go out hunting?

   What transport(s) do you use?

   How long lasts a hunting journey (number or hours or days)?

7. Do you generally hunt alone or with company?

   (*If accompanied*) Who? Does (s)he hunts?

8. What animals do you usually hunt?

   Do you hunt to eat or sell, normally?

   (If to sell) Who do you sell the animals to?

9. What animals you prefer to hunt?

   Why?

10. Why do you hunt?

11. Are there better periods to hunt, along the year?

    Which are the better seasons to hunt each animal?

12. Do you spend more time hunting nowadays or before?

    Why?

13. Do you think there are more, less, or the same number of animals in the bush these days? Why? Which animals do you think are less these days?

14. Do you have your own shotgun?

    (*yes*) a)When did you bought it? How much it cost? Where did you buy it?

    (*no*) b) Is it borrowed or rented? From whom?

    Are there other people that borrow it? You know how many?

    How much do you pay to rent it?

15. Do you have your own Airgun?

    When did you buy it? How much it cost? Where did you buy it?

16. Where do you get ammunition?

    How do you acquire it?

    How much does it cost?

17. Do you use helpers or carriers to bring the animals from the forest?

    How many?

    How much do you pay them?

18. Is there any place you found restrictions to hunt? Where? From whom?

19. Would you like your children to become hunters too? Why?

Chapter 4

WILD MEAT CONSUMPTION IN SÃO TOMÉ ISLAND, WEST AFRICA: IMPLICATIONS FOR CONSERVATION AND LOCAL LIVELIHOODS

Submitted to publication as: CARVALHO, M., REGO, F.C., PALMEIRIM, J.M. AND J.E. FA (in review). Wild meat consumption in São Tomé Island, West Africa: Implications for Conservation and local livelihoods. *Ecology and Society*.

4.1. Summary

The importance of wild meats for rural people is a well-documented situation in tropical forests worldwide. However, the case of oceanic islands remains relatively poorly studied. We aimed to characterize and quantify the contribution of wild meats to the rural diets of São Tomé Island, and the relative importance of native and introduced fauna. Consumption patterns of 716 household-weeks in ten communities located around the Obô Natural Park were assessed using semi structured interviews. The most important protein foods consumed are fish and the introduced West African giant snail. Wild terrestrial vertebrates are consumed by a small fraction of sampled households. Consumption of wild snails and wild mammals is associated with a combination of isolation and wealth. Poorer families depend on snails as inferior good and richer households consume either fruit bats or introduced mammals, possibly in the absence of alternative foods. Preferred foods are largely domestic, although not the most consumed and typically by wealthier households in more accessible communities. Birds are widely consumed, particularly in more populated households. Despite associated with small quantities per household, subsistence use of birds when extrapolated to the island's rural population may outcome in a very high harvest, particularly for the species of pigeons which are also hunted commercially. The observed situation suggests that native and endemic fauna do not constitute relevant protein sources for rural families. However, endemic birds and native fruit bats are harvested for household consumption and constitute a commonly used resource that need to be regulated.

4.2. Introduction

Wild meat (bushmeat) provides a major source of protein for tropical forest people around the world (Wilkie and Carpenter 1999, Milner-Gulland et al. 2002, Bennett et al. 2007). In the Congo Basin, hunting has been estimated to contribute between 30 to 80% of the protein intake for forest-dwelling people (Koppert et al. 1996), and in rural areas with poor access to markets, wild meat often constitute the cheapest or even the only type of animal protein available (eg. Starkey 2004). Harvesting is affecting a wide range of wild species and extensive research conducted

in the last decades evidences the extent and unsustainability of wild meat extraction in several Central African countries (eg. Bakarr et al. 2001, Fa et al. 2002).

Interest in hunting as an important threat in islands has lagged behind continental areas, but a growing number of reports on the continental islands of Bioko and Madagascar demonstrated wild meat consumption to affect endemic and particularly vulnerable species (Fa et al. 2000, Jenkins et al. 2011). Islands have long been recognized as being important for biodiversity conservation, often conciliating high endemism with heavy human pressure, and featuring predominantly in the priority areas with conservation needs (Handerson and Whittaker 1980, Myers et al. 2000, Fishpool and Evans 2001, Burgess et al. 2006). Oceanic islands, in particular, have been strongly affected by human intervention and the combination of habitat destruction or degradation, introduction of alien species and overharvesting of native fauna (Henderson and Whittaker 1980). But despite the impact of overharvesting native fauna to be relatively well documented for oceanic islands (eg. Duncan et al. 2002, Brooke and Tschapka 2002, Fitzpatrick and Keegan 2007), no previous studies were found to address the importance of wild species for human populations in these ecosystems. Understanding the patterns and the factors to influence consumption of wild species from local communities is an important first step for designing approaches to address any major threat to endemic biodiversity (Bowen-Jones et al. 2002).

São Tomé Island, the largest Oceanic Island in the Gulf of Guinea off the west coast of Africa, has been classified as critically important due to the numbers of restricted range bird species occurring together (Bibby et al. 1992, Stattersfield et al. 1998, Buchanan et al. 2011), and general high endemism levels in all taxonomic groups. Habitat modification is still considered the single most important threat affecting the island's endemics, but some taxa are also potentially threatened by uncontrolled hunting (Peet and Atkinson 1994, ENPAB 2004, Carvalho et al. 2014). Although commercial and subsistence hunting are mostly concentrated on introduced species (such as feral pigs, monkeys and civets), native fruit bats, endemic snails and birds, particularly Columbidae (pigeons and doves), are also commonly targeted for both sale and food (Dallimer and Melo 2010, Rainho et al. 2010, Carvalho et al. 2014). There are no studies targeting consumption of wild species neither in rural nor urban contexts, though wild species are documented to be part of rural livelihoods in

São Tomé and Príncipe and potentially impacted by exploitation (Atkinson et al. 1991, Dallimer et al. 2009, Dallimer and Melo 2010, Rainho et al. 2010, Carvalho et al. *in press*).

In order to contribute to the knowledge required to manage subsistence hunting in a sustainable manner in São Tomé, but also to understand the pressure that rural consumption has over endemic fauna, with this study we aimed: a) to quantify the contribution of wild meat for protein intake in rural communities of São Tomé; b) to evaluate the contribution of introduced versus native wild fauna; c) identify the factors that determine the patterns of bushmeat consumption. We discuss results in the scope of the particular case of São Tomé and relative values of introduced and endemic species. The analysis and understanding of this context is essential for the promotion of local policies and practices that sustain both their wildlife values and secure livelihoods, potentially as an example for other oceanic islands within the world.

4.3. Methods

4.3.1. Study site

São Tomé (857 km^2) is the larger of the two oceanic islands that constitute the Democratic Republic of São Tomé and Principe (Fig. 4.1). It is located just north of the equator, about 250 km west of mainland central Africa. The island is characterised by rugged terrain with numerous steep mountains, reaching up to 2,024m at the Pico de São Tomé. This strong relief creates a marked precipitation shadow effect, with average annual rainfall ranging from less than 600 mm in the northeast, to over 6000 mm in the southwest (Bredero et al. 1977). Altitude also creates a strong temperature gradient, with annual averages ranging from 25.5° C at sea level to less than 13.5° C above 1500m (Silva 1958). Humidity is high throughout the year in most of the island and there is little seasonal variation (Carvalho et al. 2004). However, two main seasons can be distinguished; the rainy season between September and May and the dry season (g*ravana*) between June and August. There is also a less demarcated dry period of a few weeks (*gravanito*), which normally takes place between December and March (Jones and Tye 2006).

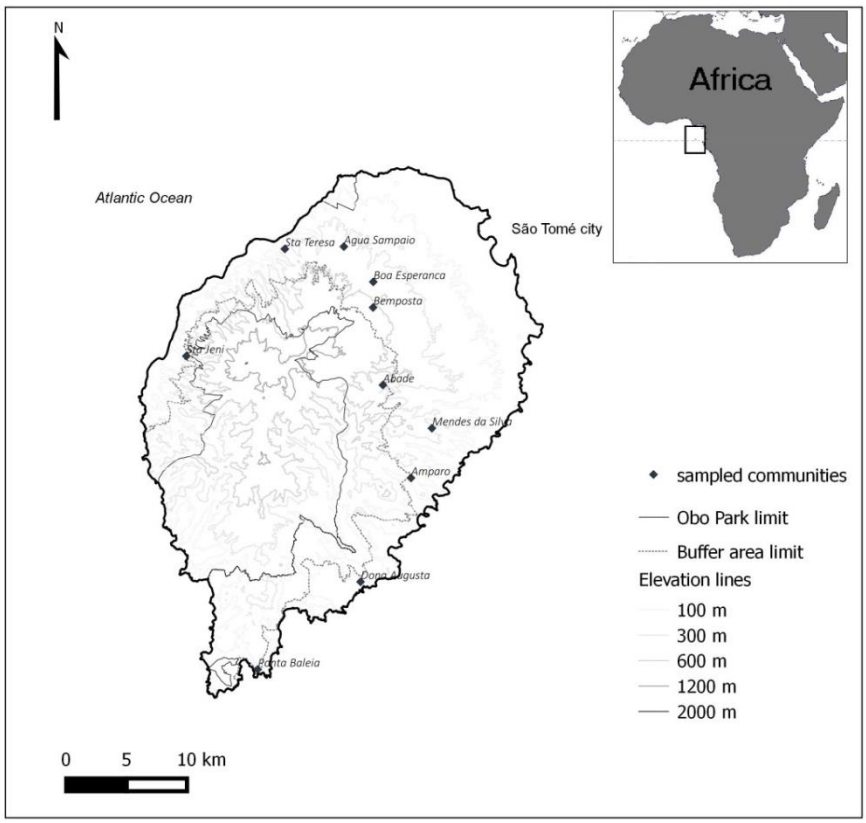

Figure 4.1 – Location of sampled communities in São Tomé Island. The rectangle on the inset shows the location of the island off the west coast of Africa.

With an inequality distributed population of about 180 000 people, an average density of 210 inhabitants per km^2, and an estimated growth rate of more than 2% per year, the preservation of wild species on the Island depends largely on the difficult terrain and its inaccessibility. About 34.5% of the population lives in multidimensional poverty (Alkire et al 2011), largely depending on natural resources as cannot afford imported goods. Almost one-third of the island's land area has been designated a protected area, the Parque Natural do Obô (Albuquerque and Cesarini 2009), which includes most of the remaining old-growth forest and large areas of secondary forest, but there is little enforcement. There are around 40 rural communities scattered in the forests outskirts, with variable access to roads, production and trade of food items, and particularly susceptible to poverty (FAO

2012). Legislation on hunting has been in preparation since 1995. It was reviewed in 2012 but has yet to be promulgated (Carvalho, *pers.obs*).

4.3.2. Data collection

Ten rural communities distributed by São Tomé Island's five districts comprising a rural area were selected (Fig.4.1), stratified by their location (two per district) and selected by approximate number of inhabitants and existence of previous contacts in the area. The country population census of 2001 (INESTP 2001) was used as a baseline for community selection. The number of people in communities varied from 100 to 200 inhabitants, between 30 and 50 households. An initial presentation of the project aims and collaborators were made publically at each community before the start of field work. All studied communities were characterized according to (i) their geographical location relative to Natural Park, ocean and capital city and accessibility from main roads, and (ii) general socio economics (energy, water, sewage, transports, number of hunters, farmers, palm wine collectors and chainsaw operators).

In each community, households were mapped, numbered and randomly selected for sampling, depending on their will to participate. If a household was not available or not willing to be interviewed, another number was selected. Information was collected through a semi structured interview with the household head or, when absent, with the person responsible for preparing food. In the first interview questions to characterize household structure and socio economic status were asked, including number of inhabitants, gender, age, occupation and literacy of head of family; household type, access to energy, water and sewage; ownership of agricultural fields and/or livestock and family production; total regular income for all family members; quantification of 14 family assets (*e.g.* cellphone, generator, motorbike, stove, tv, dvd, firegun, airgun). We also included questions on the three preferred foods of different protein sources (fish, eggs, different domestic meats and bushmeat species). Although this characterization was only made in the first interview in latter interviews we asked if there were any relevant changes.

To compare data among households and communities, occupancy of each household was converted into AMEs (Adult Male Equivalent: male person aged>10

years was 1 AME, females aged>20 years=0.72 AME, females 10–19 years=0.84 AME, and all children aged <9years=0.6 AME) (Albrechtsen et al, 2006).

The data on consumption was assessed four times in a yearly cycle between October 2011 and September 2012: during the main rainy season (October-November), short dry season (February-March); second rainy season (May) and end of main dry season (August-September). All animal food items (meat, fish, eggs) consumed during the week (seven days recall) before the interview were quantified (number of units and kgs), and its provenience and cost were identified. Other food types were not included. All animal products recorded were transformed in edible Kg/AME, to assess protein intake, as described in Annex4.1.

4.3.3. Household wealth group

For analysis of household relative wealth and based in previous experiences from pilot studies in rural communities in São Tomé, we combined a group of assessed wealth indicators to use as proxy for subsequent analysis. A Two-step cluster analysis of the interviewed households was performed based on the following indicators: household type and number of divisions, quantity of possessed assets (each asset as an independent variable), household access to energy and sewage and the household head literacy. The analysis separated two fairly distinct clusters: 65% of inquired were allocated to a less wealthy group and 35% to a wealthier one, with more possessions and higher living standards (most important featured variables: generator/tv/dvd ownership and quantity, energy supply, type of household and number of divisions). The cluster membership was assigned as a new categorical variable for the household socio economic characterization, designed as wealth group.

4.4.4. Site accessibility

An ordinal index was developed to analyze the relative consumption patterns of bushmeat, fish and domestic meat in relation to the accessibility from each community to populated areas and main roads. A categorical measure of the main access quality (from good to bad condition road, ranging from 1 to 4, respectively) was registered during communities' characterization. It was then multiplied by an

index of relative distance through that access to the closest densely populated center along the main road (used as a proxy for trading point of consumption goods). This distance was classified in 3 categories: less than 2.5 km; between 2.5 and 7 km and more than 7 km. An inaccessibility index for each community was then obtained, ranging from 1 to 12, from more accessible to increasingly inaccessible, respectively.

4.4.5. Data analysis

We used univariate tests to investigate correlations among consumption patterns and indicator variables of household wealth, social status and geographic location. Furthermore, ordination techniques were used to develop an effective visual summary of rural consumption patterns, including all interviewed households in the same ordination space (Borcard et al. 2011). We employed non-metric multidimensional scaling (NMDS) ordination based on Bray-Curtis dissimilarities, using the mean presence of different food types on the consumption replicates of sampled households. Envfit function was performed to test for the significance of sampled socio economic and geographic variables and its relation with the axes of the ordinations (Borcard et al. 2011). These analyses were also used to select significant variables for the subsequent application of the statistical models.

We then examined the relationships between patterns of consumption and households' socio-economic characteristics by fitting a series of statistical models to the data. To identify the best predictors of the consumption of different food types, we used a general linear model (GLM) for consumption data and a series of variables as predictors: Number of AME in the household; literacy of household head; household income per day; number of hunters in the community and distance to the Obo Natural Park. The categorical variables inaccessibility (from 1 to 12) and wealth group (1 – lower, 2 – higher), were also used. Models were applied to two different datasets: GLM with binomial family and logit link on presence of consumption of each food type per household and a normal GLM with log link function for the mean quantity consumed of each food type in sampled replicates (Crawley, 2007). Minimal adequate models were also selected in binomial and gaussian GLM from the maximal model with the "dredge" function (package MuMIn) (Barton 2012), which searches

all possible predictor combinations and selects models by comparing values of second-order Akaike's information criterion (AICc).

All statistical procedures were carried out in R v. 2.10.0 (R Development Core Team 2009).

4.4. Results

4.4.1. Protein consumption

We sampled a total of 195 households, corresponding to 819 people and between 16 and 21 households per community. We did not managed to assess every selected household in each of the four sampling events, so we obtained a sampling effort of 716 households-weeks (out of the 780 possible), corresponding to 3043 people-weeks. All sampled households have eaten some animal product during the recall week. Fish and West African snails (*Archachatina marginata*) are the most important components of the rural diets in São Tomé (Table 4.1). Fish was the most widely consumed food, present in 92% of the sampled households, but consisting only 22% of the total contribution for protein intake.

Wild meat consumption totalizes 53.6% of total protein consumption. Giant snails represented 45.7% of protein based diet of sampled households, introduced mammals constituted about 4%, fruit bats 3% and birds only 0.7%. Species consumed included the one introduced species of snail, West African snail (*Archachatina marginata*), one endemic species of snail, Obo snail (*Archachatina bicarinata*), three introduced mammals (Feral pig, *Sus domesticus*, Mona monkey, *Cercopithecus mona* and African civet, *Civettictis civetta*), native fruit bats (*Eidolum helvum*), eleven endemic and one native species of birds. Despite the great contribution represented by giant snails, its consumption was restricted to 62% of the households. From the wild vertebrates, fruit bats were the more widely consumed, registered in 9.6% of the sampled households.

Domestic meats have a relatively low contribution for rural diets. Chicken is the domestic animal with higher protein contribution (11%) and the most widely consumed (by 39% of the households). Domestic mammals (Pig, goat and sheep) constituted only 5.9% of total consumption in 2.5% of sampled households.

Nevertheless, the vast majority (72%) of preferred species named by respondents are domestic species (Fig. 4.2), corresponding 45% to domestic mammals (mainly pig), and 27% to domestic birds (mainly chicken). Wild species are preferred by only 13% of the sampled households, 8% with reference to introduced mammals, 3% fruit bats and 2% wild birds. Fish is mentioned as preferred by 12% of households and snails by 3%.

Table 4.1 – Characterization and relative consumption of animal food items in sampled households (N=195) at rural communities of São Tomé (corresponding to a sampling effort of 716 household weeks).

Food items	**Species (where applicable)**	**Introduced/ Native/ Endemic**	**Units**	**Total consumption (edible Kgs)**	**Mean consumption (edibkg/AME)**	**Assessed contribution for total protein intake (%)**	**Sampled households consuming this food type (%)**
Fish		NA	2987	454.6	0.26	22	92
Chicken		NA	277	233.8	0.12	11	39
Duck		NA	12	24.3	0.02	2	2
Pig		NA	3	91.1	0.06	5.3	0.9
Goat and Sheep		NA	1	9.5	0.01	0.4	1.6
Eggs		NA	1138	56.9	0.03	2.6	53
Giant snail	*Archachatina marginata*	*Int*	14581	819.1	0.54	45.7	62
Obo snail	*Archachatina bicarinata*	*End*	10	0.5	0.00	0	0.6
Feral pig	*Sus domesticus*	*Int*	1	49.5	0.02	1.6	0.16
Civet	*Civettictis civetta*	*Int*	4	33.5	0.02	1.5	0.6
Mona Monkey	*Cercopithecus mona*	*Int*	14	23.3	0.01	1	4
Fruit bat	*Eidolum helvum*	*Nat*	307	58.7	0.04	3.1	9.6
Maroon pigeon	*Columba thomensis*	*End*	8	1.6	0.00	0.1	0.6
Bronze naped Pigeon	*Columba malherbii*	*End*	25	2.2	0.00	0.1	2.2
Green pigeon	*Treron sanctithomae*	*End*	24	2.9	0.00	0.2	1.9
Other birds			45	3.8	0.00	0.3	2.5
	Ploceus grandis	*End*	11				
	Turdus olivaceofuscus	*End*	10				
	Columba simplex	*End*	9				
	Prinia molleri	*End*	6				
	Serinus ruffobruneus thomensis	*End*	3				
	Anabathmis newtonii	*End*	3				
	Ploceus sanctithomae	*End*	1				
	Zosterops lugubris	*End*	1				
	Phaeton lepturus	*Nat*	1				

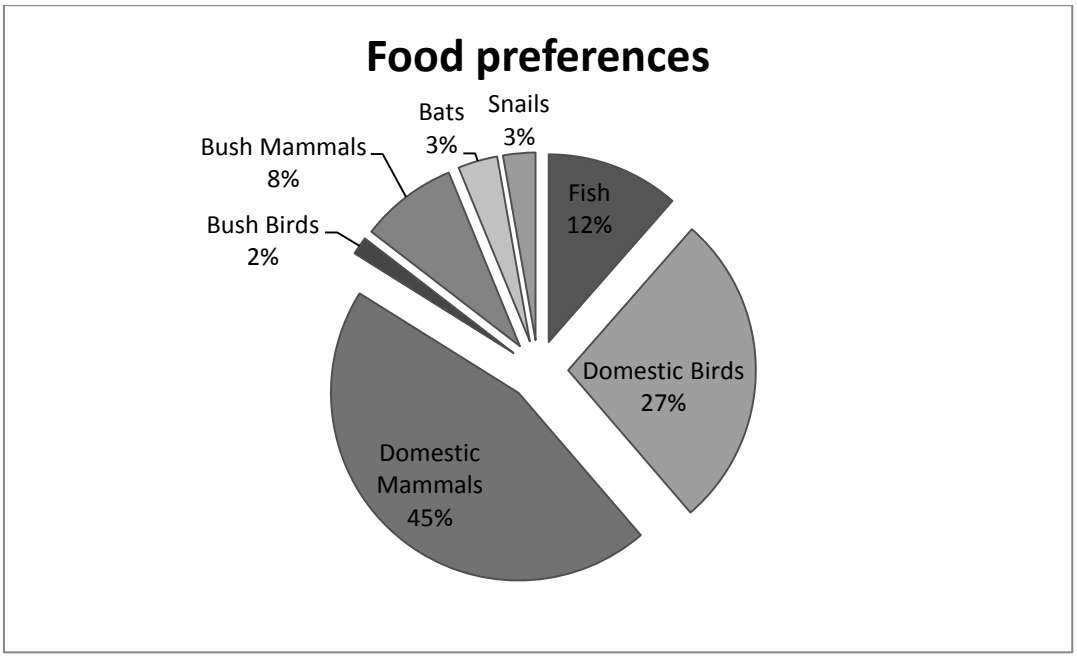

Figure 4.2 – Preferred type of food named by respondents during first interview.

4.4.2. Wealth and consumption of food types

The poorest families (wealth group=1) eat significantly more snails than wealthier households (wealth group=2), representing 54% and 30% respectively of the protein intake in the groups' diet (Mann Whitney U-test, $p<0.001$) (Figs. 4.3 and 4.4). Wealthier families eat significantly more protein other than snails (Mann Whitney U-test, $p=0.41$), mainly domestic animals and eggs (wealth group=2) (Mann Whitney U-test, $p=0.47$) (Figs. 4.3 and 4.4). For the other food types, including fish and wild vertebrates, no significant differences were shown amongst wealth groups (Figs. 4.3 and 4.4).

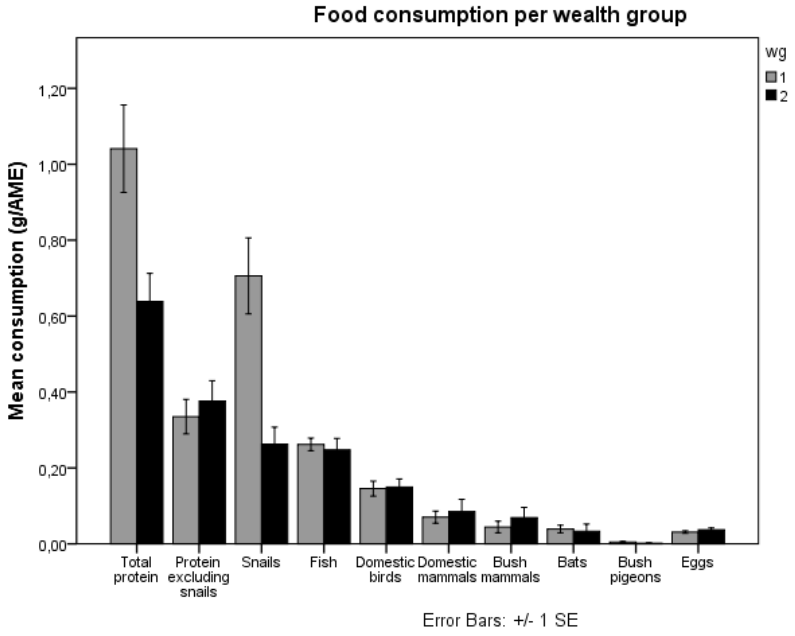

Figure 4.3 – Average protein intake of each food type per wealth group (1 – lower wealth indicators, 2 – higher wealth indicators).

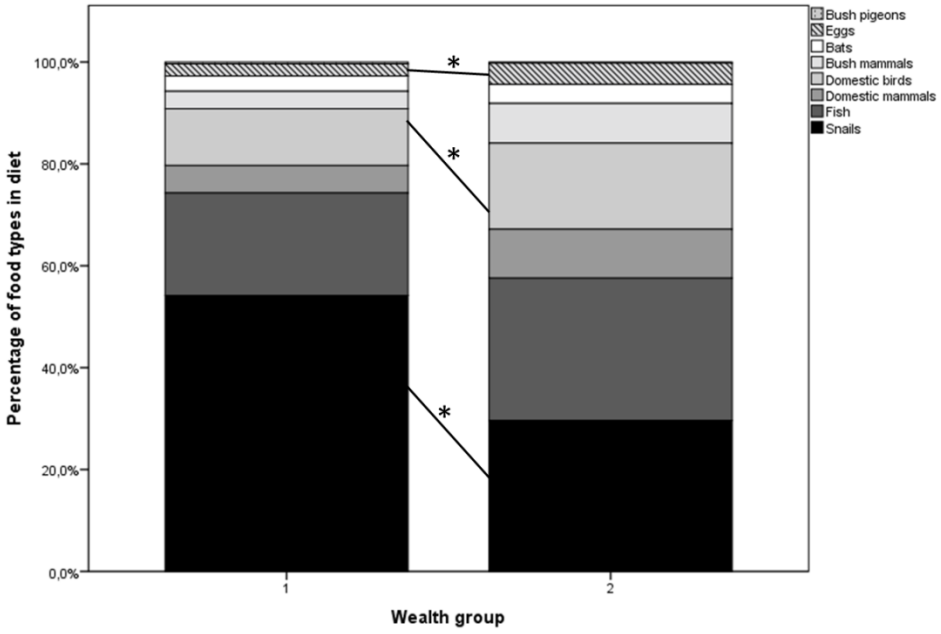

Figure 4.4 – Proportion in diet of each food type for considered wealth group (1 – lower wealth indicators, 2 – higher wealth indicators). Stars mark significant differences on proportion taken of specific food type.

4.4.4. Patterns of bushmeat consumption

The ordination of consumption patterns of sampled households allows a graphical representation of their relation with assessed variables and highlights the relevance of wealth and isolation of households in the consumption of different food types (Fig. 4.5). The first axis of the NMDS ordination of the households' consumption patterns (Stress = 0.18) reflects the increase of consumption of chicken and eggs. The second NMDS axis represents the gradient between a high consumption of giant snails and an increasing consumption of fish. Other domestic and bushmeat items are positively associated with first axis and negatively with second, and were mainly consumed by a specific group of households. Fitting the socio-economic and geographic variables into the ordinated consumption patterns, the variables which explained most of the variance along the two axes are the average quantity of assets and the households' wealth group (NMDS1) and the inaccessibility opposite to the number of adult male equivalents (AME) in the household (NMDS2).

´ Consumption of giant snails is clearly related to household inaccessibility, with higher consumptions also associated with poorer families. As for wild vertebrate animals, and particularly of fruit bats and introduced mammals, consumption is mostly associated with an increasing inaccessibility of the households, but also with relative wealth (Fig. 4.6). In the case of wild birds, the patterns are not so evident, and the consumption is more widely distributed throughout the sample: birds' consumption within less isolated and poorer households is also perceptible from ordination plots.

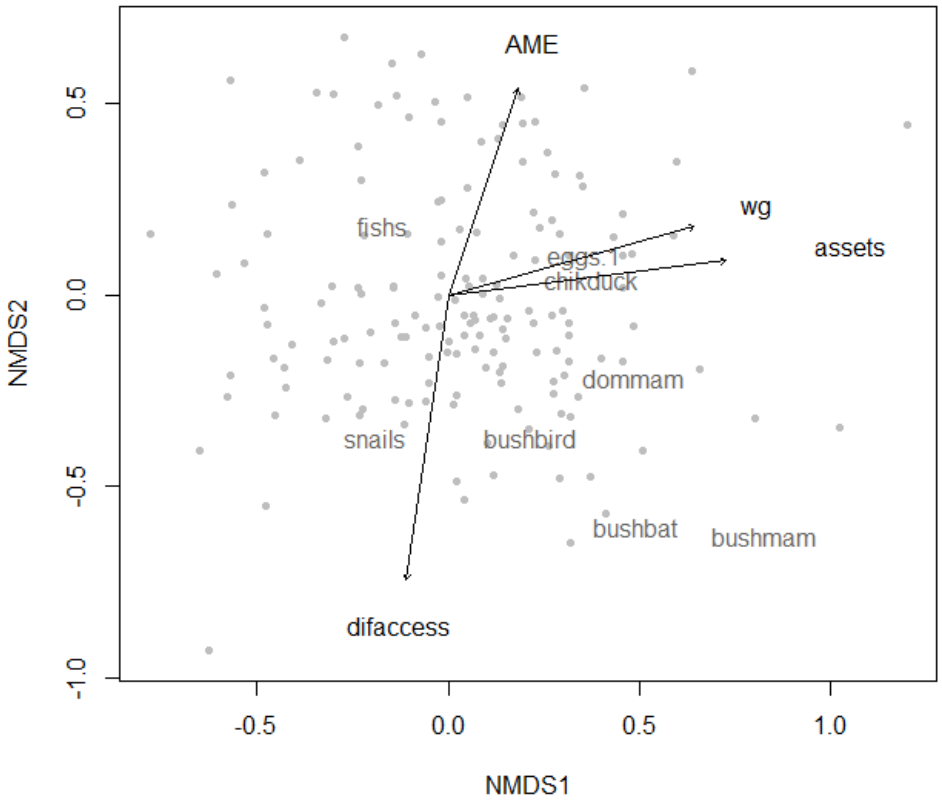

Figure 4.5 – NMDS ordination of average consumption frequencies of animal food items per household (Stress=0.18), with the scores of each species on ordination axes indicated by its position on the diagram. The grey dots on the back are the households, distributed in the diagram based on their average consumption of each food type. The arrows represent the fitted variables for household's socio economic characterization: AME (number of Adult Male Equivalents at the household), wg (Wealth Group), assets (average number of listed assets of the household) and difaccess (inaccessibility index). These were the significant variables (p max=0.05) identified from a larger introduced group.

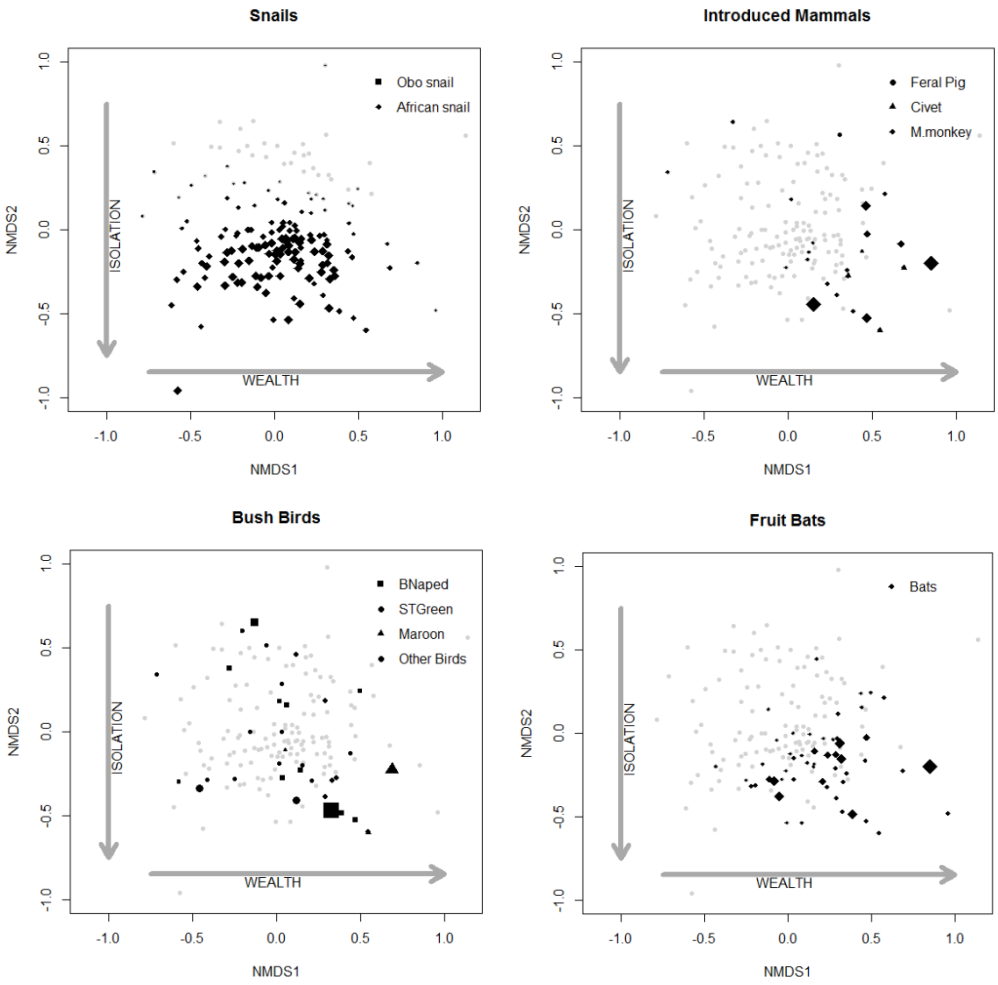

Figure 4.6 – NMDS ordination of average consumption frequencies (Stress=0.18). The grey dots on the back are the households, distributed in the diagram based on their average consumption of each food type (as Fig.4.5).The black dots are the households where each of the wild species was consumed (according to legend). The size of the dots is proportional to the mean times it was registered as consumed in the four samples. The data for pigeons and other birds was pooled in same diagram as well as the data for introduced mammals.

4.4.5. Determinants of wild meat consumption

Fish consumption is widespread by almost all the rural households and no variables related specifically to the presence of fish in diet, but the quantity taken is predicted by the number of AMEs in each household (Table 4.2). Giant snails' consumption, on the other hand, is determined by the household isolation from the main roads, and the amounts of snails taken related to a lower literacy of the household head.

Wild vertebrates' consumption is in some extent related to a measure of wealth. For introduced mammals' income per day is determinant of consumption together with a relative lower literacy of household head, and quantity predicted by higher wealth group. Fruit bats consumption is at first hand determined by the number of hunters in the community and a higher literacy of the household head, but the quantity consumed is also predicted by a the household higher wealth group. Variables identified as predicting the consumption of wild birds, namely endemic pigeons, were a larger household (more AMEs) and a higher declared income per day. No specific variables were selected for the quantity consumed, possibly because associate amounts are in general very low.

Table 4.2 – Results of the application of GLM to the consumption data of wild food types. Two datasets were used: one based on the presence/absence of consumption per household, and the second using the mean edible quantity (in Kgs) consumed per each household (average data from all replicates). The independent variables used in models were: number of AME in the household, income per day, wealth group and literacy of household head; inaccessibility, distance to Obo Park and number of hunters in the community.

Food type	**Predictor variables - consumption (binomial)**	**coef (p value)**	**Variables in all best models (AIC, delta<2)**	**Predictor variables – quantity (normal)**	**coef (p value)**	**Variables in all best models (AIC, delta<2)**
Fish	*Intercept*	5.56 (0.002)	*Intercept (+)*	AME	0.02 (0.007)	*AME (+)*
				Literacy h.head	$9.4*10^{-3}$ (0.08)	Wealth group (+)
Snails	Inaccessibility	0.42 (<0.001)	Inaccessibility (+)	*Intercept*	1.2 (<0.001)	*Intercept (-)*
				Literacy h.head	- 0.19 (0.007)	Literacy h.head (-)
Bush Birds	*Intercept*	- 2.23 (0.004)	*Intercept (-)*	*Intercept*	0.06 (0.02)	*Intercept (+)*
	AME	0.2 (0.08)	Income/day (+)			
			Literacy h.head (-)			
Bush Mammals	*Intercept*	- 4.12 (0.002)	*Intercept (-)*	Wealth group	0.39 (0.04)	*Intercept (-)*
	Income/day	$2.2*10^{-5}$ (0.09)	Literacy h.head (-)			Wealth group (+)
Fruit Bats	Number hunters	0.20 (0.05)	*Intercept (-)*	Wealth group	0.18 (0.04)	*Intercept (-)*
			Literacy h.head (+)	Number hunters	0.06 (0.003)	Number hunters (+)

4.5. Discussion

4.5.1. Wild meat consumption

We show that protein intake is typically sustained by fish and introduced West African snails. The importance of fish is well-known in Central African countries, where fish resources represent between 25% to 50% of the total food supply (Watson & Brashares 2004, Jenkins et al. 2011, Vega et al. 2013). In contrast, land snails are a well-documented wildlife protein source in Nigeria and some parts of Africa, but its actual importance as human food and in the livelihoods of local people is a point generally overlooked in most of the studies about bushmeat consumption (Osemeobo 1997, Nasi et al. 2008). As demonstrated in our results, in the rural areas of São Tomé land snails are particularly important for the more vulnerable people, namely the most isolated and poorer households. The snails are harvested by all social groups, including women and children (Carvalho, *com pess.*) so enhancing their relevance as a widely accessible natural resource (Hardouin 1995). Complementarily, as a recently introduced species with a rapid expansion and potential impact over native flora and fauna (Cowie et al. 2009), including the endemic Obo Snail (Gascoigne, 1994), the correct management of the West African snail must not only ensure food safety in rural areas but also its control as an invasive species. Adittionally, potential health problems caused by zoonotic transmission should be taken into account, a major concern as some land snails are known to be an intermediate host for several human pathogens (Hardouin 1995, Pokora 2000).

As snails, wild mammals are also typically consumed in more isolated communities but in this case wealth is an important predictor for its consumption as they have to be either hunted or bought from hunters. Households with similar wealth rank but situated in more accessible areas rather consume domestic meats, consistently referred as preferred foods. These results suggest that wild meats are eaten in consequence of availability of alternatives and not as a superior good (Brashares et al. 2011). The lack of preference for bushmeat was already described in the islands of Bioko (Equatorial Guinea), where urban consumers distinguish less between bushmeat and domestic meat than between fresh and frozen (East et al. 2005) or Madagascar (Jenkins et al. 2011), but also for the rural people in Gabon who

are highly price sensitive with respect to their choice of meat, with taste playing a smaller role (Wilkie et al. 2005).

Wild birds are also not preferred, but widely consumed. Opportunistically harvested without any costs, often with slingshots and traps, during daily routines of children and farmers (Carvalho, *com pess*.), we show that subsistence consumption of wild birds in rural communities' extent to several endemic species, with higher numbers associated with all four species of pigeon. Endemic pigeons represent a very small part of the rural diets but its consumption is suggestively influenced by the household size, as it may represent an additional contribution to family meals in a context where meat is relatively rare. Despite associated with small quantities per household, subsistence hunting of pigeons when extrapolated to the island's rural population may outcome in a very high harvest, particularly for the species of pigeons which are also hunted commercially (Carvalho et al. 2014, Carvalho et al. *in press*).

4.5.2. Conservation implications of consumption patterns

Wild meat subsistence consumption in São Tomé constitutes a rare situation in the documented African context. The island's high conservation value is related to relatively small bodied species, which typically have a lower value to local harvesters (Bennett and Robinson 2000). In contrast to the islands of Bioko and Madagascar, where subsistence harvest of endemic and native mammals represents an acknowledged threat to their conservation (Fa et al. 2000, Albrechtsen et al. 2006, Jenkins et al. 2011), in São Tomé most of wild species used for food were introduced and have a potential negative impact on native ecosystems (Dutton 1994, Jones and Tye 2006).

Nevertheless, endemic birds and native fruit bats are harvested for household consumption and constitute a commonly used resource that need to be regulated. Even occasional consumption of wild species by individual households can result in an important pressure on a species when human populations are high relative to area of natural habitat (Robinson and Bennett 2000), or where targeted species have demographic characteristics making them vulnerable (Peres 2000). There are signs that the exploitation of these species impacts their abundance and distribution throughout the island (Rainho et al. 2010, Carvalho et al. *in press*) and some of these

species are also intensively targeted by commercial hunting, worsening their status (Carvalho et al. 2014).

More research is needed to understand the dynamics of the wild species consumed and develop specific conservation and management guidelines. Still, this is the first study of this kind on an oceanic island, where we quantify the consumption of the introduced species to rural inhabitants and evidence that the correct management of wild animal resources may not only ensure a food safety net for rural people but also alleviate the pressure over native and endemic species. Promoting the replacement of native wildlife for hunting and consuming of introduced species, may ensure a constant, culturally acceptable, readily available and low cost source of meat (Desbiez et al. 2011). For that end, policies and development guidelines must be conducted with hunters and local populations, so that awareness for the global importance of endemic species to be raised and attention to be deviated towards introduced fauna.

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Appendix 4.I – Conversion table for food items' units

Values used for the conversion of unit animal foods to weight and edible weight consumed by interviewed households (expressed in kg). Average weight and edible quantity were estimated from references to the edible proportion of similar species or group of species, indicated in the last column.

Food items	***Species (where applicable)***	***Weigth per unit (Kg)***	***Edible weight (%)***	***Price per Unit (Euro)***	***Price per kg (Euro)***	***References (species body weight and edible proportion)***
Fish		*Variable*	0.55	Varies	2,45	Torry res.stat. (1989)[1], Holland et al. (1983)[2]
Chicken		1.300	0.65	3,5	2,65	Bender (1992)[3], Chan et al. (1996)[4]
Duck		3.00	0.60	12,5	4,08	Albreschtsen et al.(2006)[5]
Domestic pig		48.30	0.60	*Variable*	4,08	Bender(1992)[3], Chan et al. (1996)[4], Bonfim (2002)[6]
Goat		25.00	0.60	50	3,27	Bender(1992)[3], Chan et al. (1996)[4]
Sheep		20-30.00	0.60	60	4,08	Bender (1992)[3], Chan et al. (1996)[4]
Egg		0.050	1.00	0,24	4,90	Holland et al. (1989)[7]
West African giant snail	*Archachatina marginata*	0.116	0.38	0,016	0,14	Ajayi et al. (1978)[8]
Obo snail	*Archachatina bicarinata*	0.116	0.38	na	na	Ajayi et al. (1978)[8]
Feral pig	*Sus domesticus*	50.00	0.60	Na	4,08	Bonfim (2002)[6]
Mona monkey	*Cercopithecus mona*	2.733	0.60	5 to 15	2,55	Albreschtsen et al.(2006)[5]
African civet	*Civectis civetta*	12.335	0.60	25	2,03	Albreschtsen et al.(2006)[5]
Fruit bat	*Eidolum helvum*	0.300	0.60	0,8	2,4	Albreschtsen et al.(2006)[5]
São Tomé green pigeon	*Treron sanctithomae*	0.230	0.50	1,2	5,32	Omojola et al.(2012)[9]

Bronze naped pigeon	*Columba malherbii*	0.165	0.50	1	6,06	Omojola et al.(2012)[9]
Maroon pigeon	*Columba thomensis*	0.400	0.50	1,5	3,75	Omojola et al.(2012)[9]

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Chapter 5

ASSESSING SUSTAINABILITY OF WILDLIFE HARVESTING: COMMERCIAL AND SUBSISTENCE HUNTING OF SÃO TOMÉ ISLAND ENDEMIC PIGEONS

5.1. Summary

São Tomé´s endemic pigeons are a commonly used resource in the Island, exploited commercially by a small group of specialized hunters but also opportunistically by a wide number of harvesters. In this study, we estimate the population numbers for the four endemic species of pigeons, using census data from linear transects placed in the islands' main forested habitats. We also estimate total extraction of each species from the regular assessment of a hunters' sample offtake (N=29 hunters), and calculate subsistence consumption of wild pigeons in ten rural communities (N=195 households). We then apply several indicators to assess the sustainability of pigeon hunting under different scenarios. The species presently more at risk is the endangered Maroon pigeon, unsustainably harvested in practically all scenarios. Harvesting of the São Tomé green pigeon is also possibly unsustainable, and practical measures are needed to reduce or cease the extraction and effective protect both species under national regulation. Levels of extraction may be sustainable for the two most abundant species of pigeon, the lemon dove and the bronze naped pigeon, but for the bronze naped pigeon the impact may be underestimated. There is the need of specific hunting regulation based on further research on the birds' biology and habitat use. Controlling bird hunting and regulating the trade will require a combination of enforcement of legislation and raising awareness among all stakeholder groups.

5.2. Introduction

The harvest of wildlife for human consumption is known to constitute a major threat to biodiversity in the tropics (Robinson and Bennett 2000, Fa et at. 2002, Abernethy et al. 2013). Either for commercial or subsistence purposes, hunting of wild fauna is frequently not sustainable (Alvard et al. 1997, Robinson and Bennett 2000b, Fa et al. 2001), and compromises the survival of some of the world's rarest species. Generally, the preferred and most affected species are large bodied mammals with slow reproductive rates, which are continuously overharvest and tend to be progressively replaced in markets and diets by smaller species (Wilkie and Lee 2004, Fa et al. 2005, Albrechtsen et al. 2006). However, hunting affects a wide array of

species of several taxonomic groups and body sizes (Bennett and Robinson 2001), including endemic and endangered animals. Research conducted in the African islands of Bioko and Madagascar revealed an intense exploitation of unique primates, birds and reptiles (Albrechtsen et al. 2006, Jenkins et al. 2011)

The growing concern with the decline of wild harvested species and the need to define sustainable levels of extraction led in the last decades to the development of a large number of sustainability indicators (Robinson and Redford 1991, Bodmer 1994, Weimbaum et al. 2013). In theory, wildlife can be viewed as a sustainable renewable resource if the removal of individuals from populations does not exceed the net production of new individuals (Robinson and Bennett, 2000). But sustainability, although relevant for the definition of management and conservation strategies, has proven extremely difficult to operationalize (Weinbaum et al. 2013).

The impact of harvesting on a population depends largely on the magnitude of the extraction relative to the population size (Runge et al. 2006). Thus, an estimate of the size of harvested populations is necessary, as it is some measure of the harvest (Robinson and Redford 1994, Runge et al. 2006). The difficulties imposed by large distribution and catchment areas, and complex commodity chains involving several actors and hunting methods, makes sustainability assessments frequently restricted to arbitrarily defined areas and either commercial or subsistence hunting (Ling et al. 2006, Brashares et al. 2011). Although the sustainability of bushmeat hunting and consumption in the tropics have been the focus of a considerable number of studies in several continents (eg. Fa et al. 2002, Colishaw at al. 2005, Ohl-Schacherer et al. 2007), there is a gap of knowledge on the relative impact of subsistence-based rural consumption, mixed subsistence-commercial hunting and hunting for commercial urban markets within any country (Brashares et al. 2011).

São Tomé is an oceanic Island in the Gulf of Guinea. Although rather small (857 km^2), it has high conservation value due to the extraordinary concentration of endemic species, including many birds (Bibby et al. 1992, Stattersfield et al. 1998, Buchanan et al. 2011, Le Saout et al. 2013). Habitat modification is considered the single most important threat affecting the island's endemics, but uncontrolled hunting is a key threat to some birds (Peet and Atkinson 1994, ENPAB 2004, Carvalho et al. 2014, Carvalho et al. *in press*). Bird hunting is driven both by subsistence and commercial purposes (Carvalho et al. 2014). The analysis of hunters' profiles allowed

identifying a specialized group of hunters primarily dedicated to commercial pigeon hunting, highlighting the need to assess the sustainability of present rates of harvest of these species (Carvalho et al. 2014). Recent research on the pigeons' distribution in São Tomé also underpinned the need to understand the impact of hunting over the four endemic species, as hunting pressure may be already conditioning the birds' abundance and distribution patterns (Carvalho et al. in press).

Despite its global importance, São Tomé's forests receives little effective protection from hunting (Olmos and Turshak 2007, Dallimer et al. 2009). Nearly one quarter of the island is classified as São Tomé Obô Natural Park (Direcção Geral do Ambiente 2006), comprising various forested habitats, but enforcement is practically non-existent. Hunting legislation, which has been in preparation since 1995, is still to be promulgated, but is unlikely to be very effective, as resources to enforce environmental laws in São Tomé and Príncipe are highly insufficient (Albuquerque and Cesarini 2009).

The main goal of this work is to assess the sustainability of endemic pigeon harvesting in the island of São Tomé, taking into consideration the cumulative impact of commercial and subsistence hunting. To achieve this we will: 1) estimate population size of São Tomé's four endemic pigeon species; 2) quantify current levels of extraction by hunters and of consumption in rural communities; and 3) apply several indicators to assess the sustainability of pigeon hunting under different scenarios. Finally, we will provide suggestions to reduce the impact of hunting on São Tomé's endemic pigeons. This is an essential baseline for the support of conservation and management strategies of endemic pigeons of São Tomé as exploited species.

5.3. Methods

5.3.1. Study site

São Tomé is the larger of the two oceanic islands that constitute the Democratic Republic of São Tomé and Príncipe (Fig. 5.1). It is located just north of the equator, about 250 km west of the coast of central Africa. The island is characterised by rugged terrain with numerous steep mountains, reaching up to

2,024m at the Pico de São Tomé. Rainfall varies dramatically from over 6000 mm in the southwest to just 600 mm in the northeast, which is in the rain shadow of the mountains (Bredero et al. 1977). Altitude also creates a strong temperature gradient, with annual averages ranging from 25.5° C at sea level to less than 13.5° C above 1500m (Silva 1958). Humidity is high throughout the year in most of the island (Carvalho et al. 2004). Two main seasons can be distinguished; the rainy season between September and May and the dry season (g*ravana*) between June and August. There is also a less accentuated dry period lasting a few weeks (*gravanito*), which normally takes place between December and March (Jones and Tye 2006).

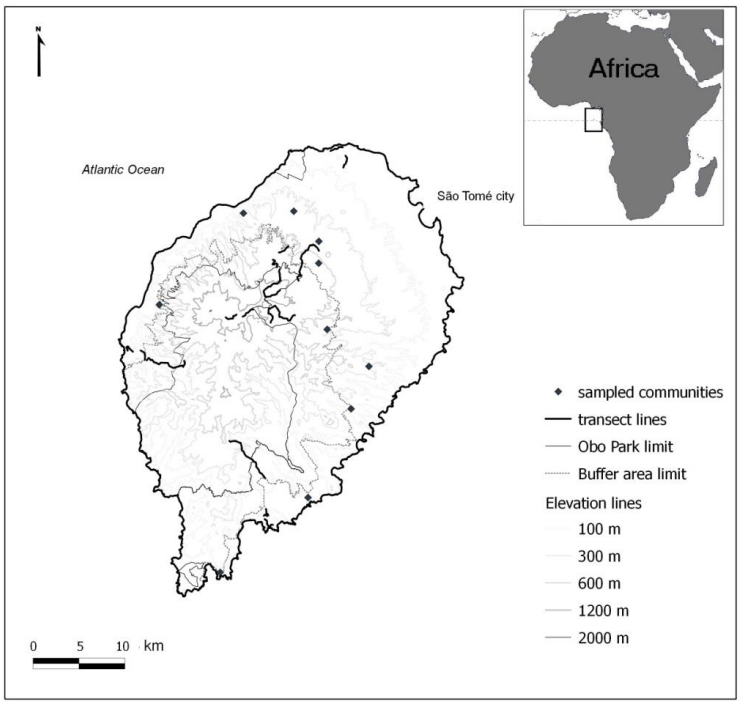

Figure 5.1 - Map of São Tomé Island, showing the location of sampled transects and rural communities.

The avifauna of São Tomé is particularly unique and includes 50 resident species, of which 20 are endemic and eight are represented by endemic subspecies (Christy 1991, Stattersfield et al. 1998, Melo 2007). It harbours four native forest pigeons, which are the focus of this work: São Tomé green pigeon *Treron*

sanctithomae, São Tomé lemon dove *Columba simplex* and maroon pigeon *Columba thomensis* are endemic to the island, while the bronze-naped pigeon *Columba malherbii* also occurs on the islands of Príncipe and Annobón. In addition, two exotic columbids area present: the laughing dove *Streptopelia senegalensis*, which is restricted to the vicinity of houses and plantations, and the domestic pigeon *Columba livia*, which is not known to have any feral populations in the island (Jones & Tye 2005).

Two of the forest pigeon species are globally threatened; the green pigeon is vulnerable and the maroon pigeon is endangered (IUCN 2014). The bronze-naped pigeon is nearly threatened, while the São Tomé lemon dove is not recognised by IUCN as a separate species, and is listed as a local population of the least concern lemon dove *Columba larvata*. Recent molecular work supports the recognition of the São Tomé lemon dove as a distinct species (Pereira 2013), as previously suggested by several authors (Baptista et al. 1997). With the exception of the lemon dove all native columbids are extensively hunted (Atkinson et al. 1991, Jones and Tye 2006, Dallimer et al. 2009, Carvalho et al. 2014). They are mostly forest species, but vary in habitat preferences and sensitivity to human disturbance (Atkinson et al. 1991, Dallimer et al. 2009, de Lima et al. 2012, Carvalho et al. *in press*).

5.3.2. Pigeon population estimates

We sampled pigeon populations along five 5 km transects and ten 1 km transects, scattered across the island to represent variability in altitude, rainfall, land-use types and human population density (Fig.5.1). Transects were divided into 100 m sectors, which were classified according to the habitat type (old-growth and secondary forests, shade plantation and non forested – Carvalho et al. *in press*) and altitude. Counts were performed by two trained observers, Gabriel dos Santos. and Aristídes Santana., between 5 and 11 a.m. walking at a slow pace (c. 1km/hour). All columbids observed or heard were recorded, but flying over birds were excluded. Each transect was sampled twice, once in January and once in June 2010, to represent the rainy and dry seasons, respectively. Supplementary transects were performed, in which the distance to each bird detected was measured using a Nikon professional range-finder. By estimating distances to birds detected independently, we guarantee

greater accuracy of distance measurement and a constant pace during transects to estimate abundance.

We used Distance (function "ds" from the R package "Distance") to correct for imperfect detection. We fitted the detection function with no adjustments, using the hazard-rate and half-normal keys, and selected the best model using Akaike information criterion (Buckland et al. 2001, Buckland et al. 2004). Density was estimated using a 95% confidence interval based on the double of the standard error of the mean probability of detection within the sampled area. Densities were extrapolated to the entire area of São Tomé Island to obtain population estimates. These extrapolations were replicated for rainy and dry season, to gain a better understanding of variability, and by habitat, to correct for eventual biases in transect representativeness. Forest inventories estimate that non-forest habitats cover around 10% of São Tomé, while the remaining was equally divided between old-growth forest, secondary forest and shade plantation (INTERFOREST AB 1990, Salgueiro and Carvalho 2007). However, taking into consideration recent changes (Geoville 2013) and field knowledge, we assumed a cover of 200 km^2 of old-growth forest, 300 km^2 of secondary forest, 250 km^2 of shade plantation and 100 km^2 of non-forested habitats.

5.3.3. Extraction by hunters

Carvalho et al. (2014) identified three main types of hunters in São Tomé; commercial bird, subsistence mammal and mixed hunters. The first group lives in urban and peri-urban areas, targets mostly pigeons and is clearly motivated by commercial gain, selling to restaurants and traders close to the capital. The second group lives in rural communities, targets mostly pigs and civets, and is driven by subsistence or to exchange with other rural inhabitants. The last group is the most heterogeneous, including people of both urban and rural origin, motivated primarily by commercial gain and targeting mostly monkeys and other mammals, although many also hunt pigeons. There is a small additional group of hunters, not analysed in detail by Carvalho et al. (2014), which includes sport hunters. They live in urban areas and were pooled with commercial bird hunters in subsequent analyses.

To estimate extraction by hunters, we sampled 29 active hunters between March 2012 and February 2013. They were contacted once or twice per month to report the number of pigeons of each species captured in the previous week, and these numbers were used to estimate the number of birds caught by each hunter in each month. Detected extraction was extrapolated for an estimated population of 196 to 245 hunters, of which 48 to 59 are bird hunters, 84 to 104 monkey hunters and 65 to 81 pig hunters, assuming that at least 80% of the hunters in São Tomé were identified and that the ones who were typified (n = 119) are representative of the entire population of hunters (Carvalho et al. 2014).

5.3.4. Consumption in rural communities

We sampled ten rural communities (Fig. 5.1), two per each of the five districts with rural areas (Lembá, Lobata, Mé Zóchi, Cantagalo and Caué), to assess the extraction of pigeons for rural consumption. In this context, birds are usually captured opportunistically by farmers, forest dwellers and children, rather than targeted by local hunters. The communities sampled were scattered across the island, but tended to be close to the main forest block than the average rural community in São Tomé (Fig. 5.1). Finally, we selected communities with a minimum of 25 households and less than 250 inhabitants to ensure we could sample a significant proportion of each community. Before interviewing, we contacted each community leader and organized a public presentation of the project aims, methods and collaborators.

We sampled all households in smaller communities, and selected a random sample of 30 families in larger ones, but some were subsequently excluded because the families were not willing to participate. Sampling consisted of a semistructured interview to the head of each household, or in alternative the person responsible for preparing food. In a first interview, we identified the number of members of each household. Subsequently, we assessed household consumption of the four endemic pigeon species, using a one week recall interview, four times in a yearly cycle: main rainy season (October and November 2011), short dry season (February and March 2012); second rainy season (May 2012) and main dry season (August and September 2012). We estimated the number of birds each person consumed in one year, and extrapolated it for the population living in the vicinities of the main forest block of

São Tomé (n = 8607 – Albuquerque and Cesarini 2009) and for the entire rural population of São Tomé (n = 58,958 – INESTP 2014). These were respectively assumed as a minimum and maximum estimate of pigeon consumption in rural communities.

5.3.5. Assessing sustainability

Minimum overall extraction was estimated by summing the minimum extraction of the two groups of commercial hunters (birds and mixed) to the minimum consumption in rural communities. Given that subsistence mammal hunters are mostly rural dwellers, in this scenario we excluded them to avoid a possible overlap between their extraction and the consumption in rural communities. Maximum overall extraction was estimated by summing maximum total extraction by hunters to the maximum consumption in rural communities to define minimum and maximum values. For this maximalist estimate, we considered that there would be no overlap between hunter extraction and consumption in the rural communities.

Several algorithms may be used as indicators of sustainability (Milner-Gulland & Rowcliffe 2007, Weinbaum et al. 2013). We focused on three commonly used indicators; the *harvest model* ($P_{max} = 0.5 * D * Y * g$ - Bodmer 1994; Robinson and Bodmer 1999), the *surplus production model* ($P_{max} = 0.6 * K * F * (\lambda_{max} - 1)$ - Robinson and Redford 1991, where $\lambda_{max} = e^{Rmax}$), and the *potential biological removal model* ($PBR = 0.5\ R_{max} * D * Fr$ – Wade 1998) (Table 5.1). All of these algorithms aim to estimate the number of individuals that can be taken from a population without affecting its ability to replace the individuals that were taken; harvesting is considered unsustainable if observed extraction surpasses the value given by the models. Each of these indicators requires a specific set of population parameters, which include; population density (D), ratio of young to adult female individuals (Y), average number of gestations per female per year (g), carrying capacity (K), mortality factor (F), recovery factor (Fr), maximum finite rate of increase (λ_{max}) and intrinsic rate of population increase (R_{max}) (Milner-Gulland and Rowcliffe 2007). One drawback of these algorithms is that some of these parameters are extremely difficult to measure accurately for animal populations in tropical forests (Milner-Gulland and Akçakaya 2001, Weinbaum et al. 2013). Therefore we could only calculate some of them and had to obtain the remaining from literature on similar species (Table 5.1).

As population density values we used the pigeons' population estimates, which means that the *harvest* and *potential biological removal models* will be giving the maximum number of individuals that can be harvested sustainably for the whole São Tomé Island (Robinson and Bennett 2000). Carrying capacity was calculated by multiplying the highest densities observed for each species in each habitat by the area covered by each habitat, for which the *surplus production model* will also indicate the maximum number of individuals that can be harvested sustainably for the whole island. The ratio of young to adult female individuals was assumed to be the same as female annual birth rate (Jetz et al. 2008). Robinson and Redford (1991) suggested using mortality factors of 0.4 for species with an average life span smaller than 5 years and of 0.6 for those with an average life span between 5 and 10 years. The recovery factor, which can be made vary between 0.1, for threatened slow-breeding species, and 1.0, which is a precautionary ceiling to account for unknown bias or estimation errors, has the default value of 0.5 (Milner-Gulland and Akçakaya 2001).. We calculated the intrinsic rate of population increase (R_{max}) using an allometric equation based on body weight (W) in homeotherms ($R_{max} = 0.627\ W^{-0.27}$ - Peters 1986) and Cole's equation ($1 = e^{-Rmax} + b * e^{-Rmax * a} - b * e^{-Rmax * (w + 1)}$ – Cole 1954), which requires knowing the annual birth rate of female offspring (b), the age at which reproduction begins (a) and the age at last reproduction (w). This last parameter was not available and was assumed to correspond to the generation length. Given that some of the parameters could take a range of values, we used that range to create different possible scenarios.

Table 5.1 – Parameters to calculate the indicators used to evaluate sustainability of forest pigeon hunting in São Tomé. The last column shows the source of the information. Parameters in bold were directly used in the sustainability models, while the remaining were used to calculate intermediate parameters.

Parameter	STGreen pigeon	Lemon dove	Bronze-naped pigeon	Maroon pigeon	References
D- population density	37007-109255	89705-156607	47846-205079	3893-5497	Population estimates from this study
Y - young to adult female ratio	0.35 - 0.7	0.5-1	0.5-2	0.25-0.5	Jetz et al. 2008, assuming 1♀: 1♂
G - # annual gestations	1	1	1	1	Palmeirim et al 2013
K - carrying capacity	110944	176570	205079	7638	Population estimates from this study
F - mortality factor	0.4	0.6	0.6	0.6	Robinson & Redford 1991
Fr - recovery factor	0.4	0.7	0.7	0.3	Wade 1998
Allometric Rmax	0.14	0.15	0.16	0.12	Fenchel 1974
Cole's Rmax	0.15-0.47	0.36-0.68	0.36-1.10	0.11-0.36	Cole 1954
W - body weight (g)	227	185	169	440	de Lima et al. 2013
a - age at first laying (years)	1	1	1	1	Baptista et al. 1997
b - female annual birth rate (years)	0.35-0.7	0.5-1	0.5-2	0.25-0.5	Jetz et al. 2008, assuming 1♀: 1♂
w - generation lenght (years)	4.2	5.8	5.6	5.6	Birdlife international 2014

5.4. Results

5.4.1. Pigeon population estimates

We estimated that São Tomé holds about 61,511 green pigeons (37,007 to 109,255), 117,394 lemon doves (89,705 to 156,607), 114,419 bronze-naped pigeons (47,846 to 205,079) and 4,653 maroon pigeons (3,893 to 5,497) (Fig. 5.2). We consider these estimates provisional, as explained in the discussion. The green pigeons occurred at much higher densities during the dry season and in shade plantation and old-growth forest, while the bronze-naped showed much higher densities during the rainy season and chose the habitats most altered by Man. Seasonal changes may reflect differences in habitat use but also in the detectability of the birds, and were considered for the account of total estimates. The lemon dove and the maroon pigeon showed little seasonal changes in density, but the first was most abundant in shade plantation while the latter clearly preferred old-growth forest.

5.4.2. Extraction by hunters

We could not interview all the hunters we were following (n = 29) every month, so we obtained a final sample of 303 hunter-months (out of the 348 possible). These correspond to 64 commercial bird, 67 subsistence mammal and 172 mixed hunter-months, respectively. A total of 1112 pigeons was reported to have been killed by the hunters (Table 5.2). On average a commercial bird hunter extracted 13.3 birds per month, of which 59% were bronze-naped pigeons and 40% green pigeons. Hunters from the mixed group hunted 1.8 birds per month on average, of which 74% were green pigeons and the remaining bronze-naped pigeons. Finally, the mammal hunters collected an average of 0.8 pigeons per month, of which 55% were green pigeons, 40% bronze-naped pigeons and 5% maroon pigeons.

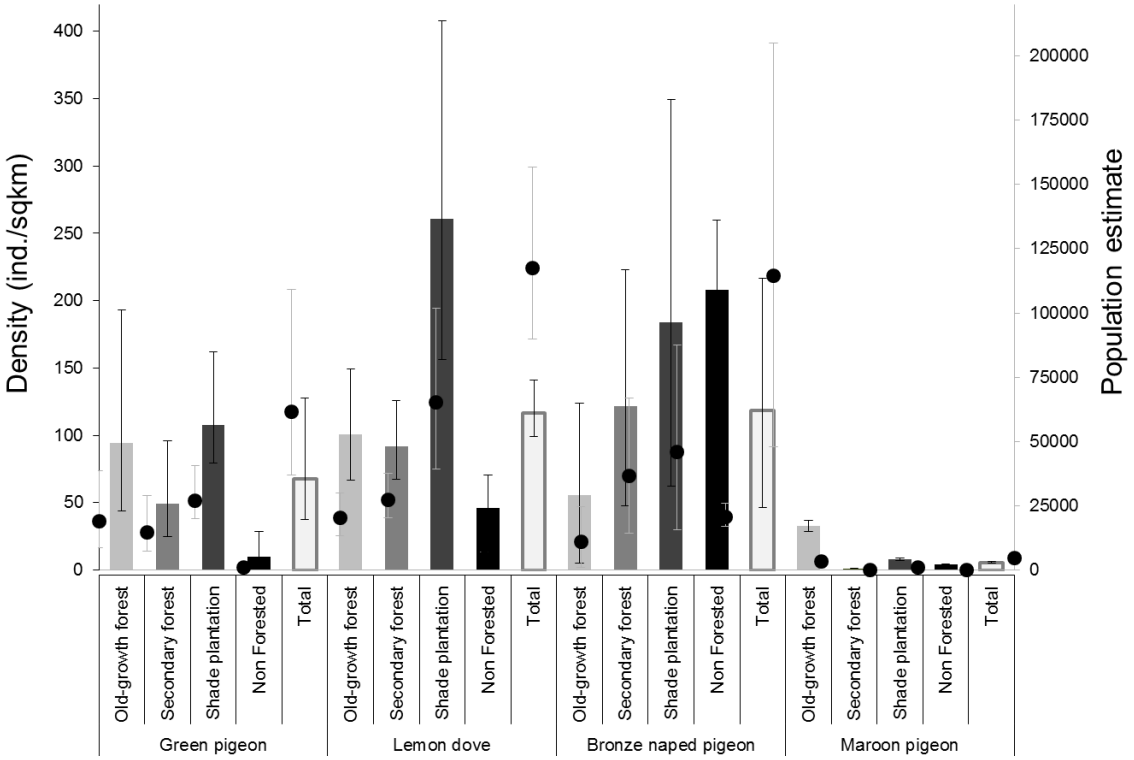

Figure 5.2 – Estimates of density and population size for the endemic forest pigeons of São Tomé. Density is represented by the coloured bars and black error lines, while the black dots and grey error lines represent population size. We performed estimates for each species, per habitat type (grade of grey, the lighest being old-growth and the darkest non-forested habitats) and in total (white). Notice the very broad confidence intervals associated to most estimates and the provisional nature of these results, as explained in the text.

Table 5.2 – Observed pigeon extraction by sampled hunters. Average is expressed in number of birds collected per hunter each month. Minimum and maximum refer to the extraction extrapolated for the period of one year.

Species	Extraction	Hunter group			
		All	Bird	Mixed	Mammal
All	**Detected**	1112	852	119	141
	Average	3.7	13.3	1.8	0.8
Green pigeon	**Detected**	507	342	88	77
	Average	1.7	5.3	1.3	0.5
Lemon dove	**Detected**	0	0	0	0
	Average	0	0	0	0
Bronze-naped pigeon	**Detected**	587	499	31	57
	Average	1.9	7.8	0.6	0.3
Maroon pigeon	**Detected**	18	11	0	7
	Average	0.1	0.2	0	0.0

Extrapolating these data for the entire hunter population (Table 5.3), we estimated that hunters extract between 10017 and 12521 pigeons per year, of which 51.6% are bronze-naped pigeons, 47.1% are green pigeons and 1.3% are maroon pigeons. Furthermore, we calculated that commercial bird hunters collect 76% of the pigeons, while hunters from the mixed group and from the subsistence mammal hunting gather 18% and 6%, respectively. Commercial bird hunters collect the majority of individuals for all species: 65% of the green pigeons, 86% of the bronze-naped pigeons and 76% of the maroon pigeons. The mixed group extracts a significant proportion of the green pigeons (28%), but very few of the bronze-naped pigeons (9%) and no maroon pigeons. Subsistence mammal hunters harvest 24% of the maroon pigeons, but a small proportion of the other species.

5.4.3. Consumption in rural communities

We sampled a total of 195 households, corresponding to 819 people and between 16 and 21 households per community. We did not managed to assess every selected household in each of the four sampling events, so we obtained a sampling effort of 716 households-weeks (out of the 780 possible), corresponding to 3043 people-weeks. A total of 66 columbids were reported to have been consumed in the rural communities: 24 green pigeons (36%), 9 lemon doves (14%), 25 bronze-naped pigeons (38%) and 8 maroon pigeons (12%). Extrapolating these data, we estimate that rural communities harvest between 10017 and 12521 pigeons per year (Table 5.3).

5.4.4. Overall extraction

We estimate that between 19114 and 73975 pigeons are harvested in São Tomé Island each year (Table 5.3). Between 40 and 45% of these are bronze-naped pigeons, and between 38 and 41% are green pigeons. Lemon doves and maroon pigeons represent much smaller proportions of the harvest (7% to 11% and 7% to 10%, respectively). Overall, rural communities harvested more pigeons than hunters; between 51% and 83% of the total number of pigeons caught in one year. This proportion varies between species; from 45% to 79% for the green pigeon, 43%

to 78% for the bronze-naped pigeon, 92% to 98% for the maroon pigeon, and 100% of the lemon doves.

Table 5.3 – Estimated pigeon extraction, extrapolated for all estimated hunters and conumers within rural communities, in São Tomé Island. Minimum and maximum values are expressed in number of birds harvested in one year.

Extraction		Pigeon species									
		All		Green		Lemon		Bronze-naped		Maroon	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Total		19114	73975	7907	28241	1327	8380	8601	29743	1278	7611
Hunter group	All	10017	12521	4716	5894	0	0	5172	6465	130	162
	Bird	7598	9497	3050	3812	0	0	4450	5562	98	123
	Mixed	1782	2227	1317	1647	0	0	464	580	0	0
	Mammal	638	797	348	435	0	0	258	322	32	40
Rural communities		9734	61454	3540	22347	1327	8380	3687	23278	1180	7449

5.4.5. Sustainability assessment

The indicators of sustainable harvesting are above the estimated extraction for the lemon dove and bronze-naped pigeon in most of the scenarios considered (96.2 and 73.1%, respectively), suggesting that current hunting pressure on these species is sustainable. In contrast, for the green or maroon pigeons most scenarios suggest a hunting pressure over the limit of sustainable extraction (Table 5.4). In fact, for the maroon pigeon only one scenario indicates sustainable levels of extraction.

Table 5.4 – Sustainability assessment of forest pigeon hunting in São Tomé, including several scenarios based on three models of sustainability with varying parameters and on different estimates of harvesting intensity (D – density; Y- yield). Notice the provisional nature of these results, as explained in the text.

Indicators of sustainability					
Model	**Parameter variation**	**Green**	**Lemon**	**Bronze**	**Maroon**
Harvest	Min (D), Min (Y)	6476	22426	11962	487
	Min (D), Max (Y)	12952	44853	47846	973
	Max (D), Min (Y)	19120	39152	51270	1374
	Max (D), Max (Y)	38239	78304	205079	687
Surplus production	Cole's Rmax	22768	35886	41495	1611
	Min (Allometric Rmax)	22512	26937	31497	1638
	Max (Allometric Rmax)	14050	13407	4783	1173
Potential biological removal	Cole's Rmax, Min (D)	1073	4809	2628	71
	Cole's Rmax, Max (D)	3167	8395	11265	100
	Min (Allometric Rmax), Min (D)	1144	11439	6030	62
	Min (Allometric Rmax), Max (D)	3376	19971	25845	88
	Max (Allometric Rmax), Min (D)	3496	21463	18373	210
	Max (Allometric Rmax), Max (D)	10321	37471	78753	297
Minimum sustainable harvesting		1073	4809	2628	62
Average sustainable harvesting		12207	28039	41294	675
Maximum sustainable harvesting		38239	78304	205079	1638
Estimated harvesting					
Minimum estimated harvesting		7907	1327	3687	1180
Maximum estimated harvesting		28241	8380	23278	7449
Percentage of sustainable scenarios		30.8	96.2	73.1	11.5

5.5. Discussion

5.5.1. Pigeons' populations and harvesting

The hunting of São Tomé pigeons has been mentioned in the literature since the early 20th century, and their consequent extirpation from ilhéu das Rolas was highlighted quite early (Bannerman 1931, Snow 1950, Amadon 1953, Naurois 1983, Collar and Stuart 1988). However, the extent and impact of hunting on pigeons was until recently considered limited and not a major threat for the species (Peet and Atkinson 1994, Jones and Tye 2006). In contrast, our results show that harvesting of forest pigeons is extensive and driven by both commercial and subsistence objectives. At least for the two least abundant and most vulnerable species, the single island endemics São Tomé green pigeon and the maroon pigeon, present harvest levels may be compromising the birds' long term survival.

Birdlife (2014) projected total population numbers for the São Tomé green pigeon and the maroon pigeon based on the known distribution within the islands' habitats, to support the attribution of the species' conservation status. We confirmed that these species are clearly more abundant in Old-growth and the mature forest, which are restricted to the island's least accessible central massif (Jones and Tye, 2005; Dallimer et al 2009; Carvalho et al in press). But this distribution may already be a consequence of hunting pressure, as birds were observed to use man altered habitats at least in some seasons (Carvalho et al, in press). Our population estimates for the two species are considerably higher than predicted by Birdlife, but the estimates indicated here should be taken as provisional, as they are extrapolated from our study sites to the full island using type of forest as the sole predictor. Further analyses are underway to refine this estimates.Bronze naped pigeons preferably use humanized habitats, with higher densities associated to shade plantations and non-forested areas. Great variations in numbers across habitats and seasonal changes in conspicuity (Jones et al, 2005; Carvalho et al, in press), may explain why this species has been described both as frequent and uncommon in the literature (Baptista et al. 1997, Birdlife 2014). The preferred use of humanized habitats by this species makes it particularly accessible to hunters, although it seems to be able to sustain the current level of extraction.

Our results highlight the differential impact of commercial and subsistence hunting. Commercial pigeon hunting focuses on the São Tomé green pigeon and the bronze naped pigeon, though it represents less than half of the total pigeon extraction in the island. Bird hunters are responsible for most of commercial extraction of the two species and particularly of bronze naped pigeons, which is consistently hunted in more accessible habitats during its conspicuous breeding period. The total commercial harvests of Bronze naped and São Tomé green pigeons are very similar, but Mixed hunters catch a higher proportion of the latter probably because they often hunt mammals in well forested, where green pigeons are more abundant. The maroon pigeon is only occasionally harvested. This is presently a relatively rare bird and is mainly distributed in less accessible forested areas, so hunting efforts directed specifically at this pigeon are no longer cost effective.

In contrast, for rural forest dwellers the occasional encounter with the maroon pigeon constitutes in an opportunity to add some protein food to the household diet.

Birds constitute an easily accessible resource in the rural context, where meat and fish are relatively scarce and often expensive. Wild birds are harvested without any costs, often with slingshots and traps, during daily routines of children and farmers (Carvalho, *com pess*.). We show that subsistence consumption of pigeons in rural communities' extent to all the four native columbids, including the lemon dove. Even occasional consumption of wild species by individual households can result in an important pressure on a species when human populations are high relative to area of natural habitat (Robinson and Bennett 2000), or where targeted species have demographic characteristics making them vulnerable (Peres 2000). Despite its opportunistic character and the small quantities consumed per household, at island level rural subsistence hunting of pigeons results in a very high harvest, which is particularly problematic for the maroon pigeon.

The Lemon dove is also hunted in this setting but it is the only endemic Columbidae not exploited commercially. This species is widely distributed in forested habitats, and although local densities seem to be influenced by human presence (Carvalho et al. *in press*), its distribution across habitats throughout the island is possibly the only one not influenced by commercial hunting.

5.5.2. Sustainability of hunting

In virtually all possible scenarios, harvest of the maroon pigeon at current levels in not sustainable, and the threat posed by hunting is very concerning. This species is classified as Endangered (IUCN 2014), because it has a single and very small population within a very small range, and is suspected to be declining due to hunting pressure, a suspicion corroborated by our results. Even the observed occasional harvest by both commercial and subsistence hunters is already above sustainable levels for the estimated population size. This may compromise the specie's capacity to recover from the pressure and its survival (Bennet and Owens 1997, Butchard et al. 2006), so conservation measures should be urgently implemented to prevent further declines. The effective legal protection of the remaining old-growth forest, combined with the listing of the maroon pigeon as a protected species under national law, is necessary to the preservation of this single island endemic.

The São Tomé green pigeon is more abundant than the previous species, but it is also probably harvested above sustainable levels. As in the case of the maroon pigeon, its distribution in mature forests of difficult access may confer some protection against hunting but a considerable demand in urban restaurants (Carvalho et al. 2014)results in a situation of conservation concern. The São Tomé green pigeon is listed as Vulnerable (IUCN 2014), because it is as a single island endemic with a population presumably declining and with very small range. Our results indicate that it is suffering the pressure of an unsustainable extraction, which needs to be controlled to avoid further declines.

Current levels of extraction may be sustainable for the two most abundant species of pigeon, the lemon dove and the bronze naped pigeon. The first is only targeted by subsistence hunting and has a wide distribution, thus specific conservation measures are not needed at this moment. As for the bronze naped pigeon, the strong pressure it suffers from commercial hunting and its frequent use of easily accessible habitats justifies, together with its small range, a conservation status of "Near Threatened". It is mostly hunted in the breeding grounds, and the impact may be underestimated by the relative conspicuity and concentration of bronze naped pigeons during this period. There is a need to enforce specific hunting regulations, to prevent the species from a potential collapse (Robinson and Bennett 2000, Butchard et al. 2006).

5.5.3. Methodological constraints

Our work has several methodological limitations, inherent to the complexity of the ecological and social systems being studied. First, it heavy relies on interviews both for consumption and extraction patterns, asking informants to recall recent events, a commonly used and increasingly important method to collect information on individual behaviours (Troter and Schensul 1987, Bernard 2006). However, numerous factors affect the reliability of the information reported in interviews, including misremembering and active misleading of the researcher (Jones et al. 2008). In our study, interviews and contacts were developed from several years of field work. Hunters had been already interviewed and collaboration was previously established without the use of incentives (Carvalho et al. 2014). Most of the communities selected were familiar with the interviewers and project personnel. The

informants had no reasons to under- or over-report activities and where contacted and interviewed by local trained assistants.

It was also not possible to randomly place the transects used to count pigeons due to generally difficult terrain and the great difficulty of doing transects outside existing trails; transect usually followed existing trails.

The estimation of biological parameters necessary for the application of sustainability models was not always possible, as biological data on the Saotomean pigeons is very scarce; we often had to use parameters from studies carried out elsewhere or with other species. The performance of sustainability algorithms is also recognizably limited (Milner Gulland and Akçakaya 2001, Weimbaum et al. 2013). All these methodological shortcomings are expressed in the uncertainty of the estimates. We attempted to partly compensate these uncertainties by using several different scenarios and sustainability models, which increases the overall confidence of the sustainability assessments conducted in this study.

5.6. Concluding remarks

The human population of São Tomé is about 180,000 people (approx. 212 inhab./km^2, INESTP 2014) and has an annual of 2.0% (CIA 2012); poverty affects 34.5% of the population (Alkire et al. 2011). In this social setting, overexploitation is likely to become an even bigger threat to the valuable fauna in the island. This risk is made worse by the insufficiency of the hunting regulations.

An average person (approximately 40 kg) needs to ingest around 106 kg of undressed vertebrate biomass per year to meet its protein needs (Wilkie and Lee 2004). Based on the levels of extraction and assuming that 66% of the birds weights are edible (Omojola et al. 2012), we estimate that pigeon harvesting contributes to between 0.01 and 0.06% of the protein needed to feed the population of São Tomé. Therefore, pigeon hunting does not make a relevant contribution to the fulfilment of the protein needs of Santomeans, despite the estimated impact that current harvest intensity is having on the conservation of the endemic pigeons. These results highlight the need to regulate and change hunting practices in São Tomé, but also

show that there are opportunities to improve the conservation status of endemic pigeon species.

Changing the focus of subsistence and commercial hunters to exotic species, such as feral pigs and monkeys, could benefit both protein intake and the economic gains of hunters, while improving conservation of native pigeons and other biodiversity. In fact, hunted exotic species tend to have larger biomass and their exploitation would help controlling their populations, thus reducing the negative impacts that they have on the native endemic-rich ecosystems (Dutton 1994, Desbiez et al. 2011, de Lima et al. 2013). Shifting hunter's priorities and developing hunting regulations are urgent issues to improve the sustainability of the island's natural resources.

Finally, it is important to note that both hunters and pigeon consumers on the island are usually unaware of the conservation problems resulting from overhunting. Controlling bird hunting and regulating the trade to restaurants should thus involve a combination of enforcement of legislation and raising awareness among all stakeholder groups.

5.7. References

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Chapter 6

GENERAL DISCUSSION: WILD MEAT HARVESTING IN SÃO TOMÉ ISLAND - EXTENT AND OPTIONS FOR THE CONSERVATION OF ENDEMIC PIGEONS

6.1. Introduction

My aim in this thesis has been to assess the impact of wild meat use in São Tomé on the conservation of the endemic forest pigeons (Columbidae). I have investigated biological as well as sociocultural aspects of the trade to develop a deeper understanding of users and their consequences of the island's wildlife. In this last chapter I present key findings of the conducted research in support of hunting policy development that can secure an adequate future for the global biodiversity values of the island, alongside the livelihood needs of the population using wild meat as a food resource in São Tomé. I start by summarizing the main results in answer of the research questions identified in section 1.1.6, focusing specifically on the potential threat posed by hunting against the endemic pigeons (section 6.4) whilst also underlining further research needs. I then consider some research constraints and limitations of the present study (section 6.5), and end with the implications of these findings for the practical management of wild meat harvesting in São Tomé and the conservation of the island's endemic pigeons (section 6.6). Some recommendations for intervention are presented and its applicability discussed in the Sao Tomé context.

6.2. Hunting as a livelihood issue

6.2.1. Who hunts wild species?

Only a few studies have examined hunter motivations and incentives (Hofer et al. 1995, Loibooki et al. 2002, Pailler et al. 2009, Kumpel 2010). However, they constitute a critical first step for developing effective wildlife conservation strategies (Bowen Jones et al. 2002). In this study I showed that three main profiles characterize São Tomean hunters, primarily associated to their main prey choice but also by their origins on the island, type of hunting gear used and main reason to hunt. Nearly half of hunters typically lived in rural areas and hunted largely for subsistence, but a large proportion hunted for commercial reasons. Most hunters used fireguns to target introduced mammals, namely mona monkeys but a small but rather specialized group (Nasi et al. 2008) were dedicated to bird hunting (with focus on the São Tomé green pigeon, bronze naped pigeon and maroon pigeon), mainly as an income generator activity.

There is broad agreement in literature that prey choice amongst subsistence hunting societies follows the foraging theory; hunters typically behave to maximize their short-term harvesting rate by hunting the biggest and most abundant animals (e.g. Alvard 1993, Bodmer 1995). However, the prey choice of human hunters operating in a primarily commercial environment, as it is the case of São Tomé bird hunters, is yet poorly dcumented (Rowcliffe et al. 2004).

Bird hunters used airguns with inexpensive ammunitions implying that hunting has low investment costs. Living in urban or peri-urban areas and on average better educated than remaining groups, bird hunters had close access to selling points but also to efficient transportation to hunting areas, frequently hunting on demand to serve the commercial pigeon trade. Bird hunting is highly profitable and represents a fallback activity for earning cash in the absence of other livelihood options, often not available. Although representing only approximately 11.2% of the total number of hunters sampled, the estimate is that they extract up to 40% all pigeons harvested in the island (including the ones informally hunted in rural areas).

Pigeons were opportunistically hunted even by the non-bird hunters. Though not preferred or not the main targeted prey, all three pigeon species suffered from extensive exploitation. The impact on each species was shown to differ according to type of hunter: commercial hunters typically harvest the more common and accesible bronze naped or green pigeons; whereas subsistence hunters would target a higher number of maroon pigeons, the larger species of the three. However, the importance of pigeon hunting most São Tomé's hunters, either as protein source or as an income generator, was negligible. Fire gun ammunition is highly priced so the costs of bird hunting are high for this type of hunting gear. Simultaneously, pigeons' biomass is comparatively low, and its contribution to protein intake of people's diets is minimal. The impacts on livelihoods of banning opportunistic pigeon hunting would thus be insignificant.

6.2.2. Who and why eat wild species?

This is the first study to document the significance of wild meat for rural communities in São Tomé Island. In particular I show the importance of the West African snail in people's diets. Rural areas are remote, have negligible lengths of

accessible roads, transportation of people and goods difficult, and poverty rife (Alkire et al 2011). Consequently, the more isolated and poorer households rely on harvesting the more accessible and free West African snail as an important source of protein. Though this type of wild meat is an inferior good, it is nonetheless a secure source of food in situations of economic hardship (Brashares et al. 2011). Higher consumption of giant snails was predicted by a lower income of the household, perhaps suggesting a reluctance to consume this food source by better-off families. Nevertheless, giant snails can represent up to 60% of protein consumption by the poorest groups. Its importance have not been recognized before e.g. Socpa et al.'s (2007) analysis of the food safety and vulnerability in the rural areas of the archipelago do not mention the enormous contribution made by giant snails to rural diets.

Wild introduced mammals and native fruit bats were seen as important in the more isolated communities, but its consumption was associated with wealthier households. For these species, demand apparently follows a "normal good" hypothesis, where household consumption increases with increasing wealth (Brashares et al. 2011). However, it is also possible that households do not switch to alternative protein sources due to their lower availability in the remote rural communities, as has been observed in rural Gabon (Foerster et al. 2011). Domestic animals produced in isolated villages are often sold alive to trade in the main human settlements, since food preservation methods are rarely available, and local sale not guaranteed. This links the consumption of wild mammals in rural communities to the interaction of wealth and availability of domestic alternatives, determined by its isolation.

The case of birds is less clear, since bird consumption in rural settings is typically opportunistic. Bird consumption is correlated with a higher number of AME per household thus reflecting the role of wild birds as an advantage food for more numerous households. Bird consumption was not related to isolation, proximity of the Park, number of hunters or wealth of the household. However, harvest and consumption of birds though culturally accepted and widespread, amounted only to a very small amount in the diets of rural peoples. Despite its lower dietary importance, numbers hunted were high enough to cause concern about the future of bird populations, especially pigeons.

6.2.3. Specific research needs

A considerable number of mona monkeys, fruit bats and pigeons are harvested annually for trade within urban or peri-urban centres and restaurants of São Tomé. Nevertheless, no data were collected on the number of urban traders and consumers or the demand fuelling the wild meat trade. Wild meat in the Island rarely makes to formal markets or pass through intermediaries, since harvested fauna is often sold directly by hunters to restaurants or for personal use/ consumption, so making it considerably less visible and difficult to quantify.

Urban demand has been frequently described as having a major impact on wildlife extraction (Fa and Juste 2001, Cowlishaw et al. 2005, Fa et al. 2006). Different from rural areas, in more urban settings wild meat is often a normal or superior good such that demand for it increases as a household's income rise (Nasi et al. 2008, Brashares et al. 2011). Taste preferences and cultural traditions may also play an important role in stimulating demand for rare species (Wilcox and Nambu 2007, Colishaw et al. 2005). The consequences of economic development may be a threat to this species, as they enter a luxury market where economic incentives are enough to stimulate the harvest, even following depletion (Bennett and Rao 2002).

From the perspective of biodiversity conservation, further research is urgently needed on the dynamics of urban consumption of wild species in São Tomé in order to effectively address the reduction of the existing commercial demand for native and endemic species as an important backup for the development of conservation policies.

6.3. Hunting as control of alien species

Introduced mammals are among the most hunted and consumed quarry in São Tomé, with most hunters primarily dedicated to hunting either mona monkeys (*Cercopithecus mona*), or feral pigs (*Sus domesticus*). The significance of hunting, trapping especially of introduced wild animals has been greatly understudied and little considered in the historical ecology of oceanic islands (Kirch and Hunt 1997, Walsh 2007). Although potentially very common in other island contexts, this unusual combination of hunting for food and control of introduced species have rarely been described (Walsh 2007, Desbiez et al. 2011, Pangau-Adam et al. 2012).

Feral pigs and mona monkeys are both the main and preferred prey of São Tomé hunters, and are also amongst the most consumed and preferred wild vertebrates in rural communities. Feral pigs are one of the few species to have caused a disproportionate share of incipient and actual extinctions in the worlds' islands (Gurevitch and Padilla 2004, Cruz et al. 2005, Nogueira et al. 2007). Introduced monkeys are also potential competitors and predators of endemic bird fauna (Dutton 1994, Furiuchi 2006). In São Tomé, the ecological impact of these introduced mammals is still poorly understood, and known native wildlife appears to have adapted to their presence without being driven to extinction (Dutton 1994). Nevertheless, hunting and consumption of pigs and monkeys, as well as other introduced mammals, generally draws attention away from hunting of native wildlife and also help in controlling their numbers.

Not less important is the control effect of harvesting West African snails for human consumption. This species was introduced a few decades ago (Albuquerque and Cesarini 2009), and has rapidly colonized most of the island. It is distributed widely ranging from the city limits to old growth forests' borders and are also very common in plantations and secondary forests. The potential devastating effects of these molluscs as pests have been previously documented (Cowie et al. 2009), and may also compete with the native endemic snail species (*Archachatina bicarinata*), but this is still understudied (Gascoigne 1994).

Understanding which management strategies are most effective in controlling alien species in Sao Tome will ensure their long term control but also maintain their value as food and income for local people. Elucidating the dynamics and long-term ecological effects generated by alien species is a crucial next step towards increasing the understanding of and more effectively managing biotic interactions in the island.

6.4. Hunting as a threat to the endemic pigeons

6.4.1. Effect of hunting in pigeon' populations

There is some evidence that all the frugivourous pigeons on São Tomé were once found throughout the entire island, including the Ilhéu das Rolas (Christy and Clarke 1998, Jones and Tye 2006). Recent studies refer to a reduced area of

distribution for the three hunted species, suggesting habitat specialization (for the maroon pigeon) and/or hunting pressure to be potential drivers of the present ranges, although little empirical data currently exist (Jones and Tye 2006, Dallimer et al. 2010). Most baseline information on the species is anecdotal. One of the most important aims of this work was to understand the patterns of distribution and abundance of pigeons throughout the islands' different habitats and analyse the impact of hunting pressure on its populations.

This study has shown that human pressure is likely to determine the abundance and distribution patterns of both the maroon pigeon and São Tomé green pigeon. These species' core distributions are presently confined to mature habitats, with their inaccessibility enabling protection for both habitat and pigeon populations. Nevertheless, development projects are expected to increase including the improvement of infrastructure and road networks throughout the island, which can affect biodiversity even in the most remote locations (Wilkie et al. 2000).

The potential hunting pressure was not shown to influence the distribution and abundance of the bronze naped pigeons as this species seems to prefer human-altered habitats. However, the hunting pressure index developed in this study also indicated that hunting was greater in such humanized habitats so effects might be confounded. Because there was a clear seasonal pattern in hunting that coincided with the birds' breeding peak, the impact of hunting on these birds can be more devastating than otherwise thought.

Hunting of pigeons and doves often takes advantage of these birds colonial breeding behaviour as described for the plain pigeon in Puerto Rico or the eared dove in Northeast Brasil (Rivera-Milan et al. 2003, Bucher 1882). Bronze naped pigeons, like the eared doves, suffer from higher pressures because they use humanized and easily accessible areas: thus they are targeted by commercial, subsistence and opportunistic hunters, harvesting young birds too, and also seasonal sport hunting (Bucher 1882, Sousa et al. 2010). Further research on the species ecology and breeding requisites is needed to develop management strategies to prevent the potential collapse of the populations.

There is growing evidence that certain pigeon species in Sao Tome are being affected by hunting. This is particularly clear from the information gathered from

interviews of hunters who consistently report less animals bagged of the three species, and particularly of the maroon pigeon and the São Tomé green pigeons, in the last decade. This may be due to an increase in the number of hunters. These results underline the urgent need to control hunting and to effectively protect all pigeon species from overexploitation.

6.4.2. Assessment of the sustainability of hunting endemic pigeons

Large numbers of endemic pigeons are hunted in São Tomé annually. Bronze naped pigeons and São Tomé green pigeons, in particular, are seasonally targeted by bird hunters for commercial trade. Demand is apparently sufficient to cover all supply, with no birds registered unsold. Furthermore, pigeons getting near the communities or occasionally found during forest activities are most often killed for food. The added impact of rural consumption is also estimated to be substantial, particularly for the maroon pigeon.

A given level of harvest is considered sustainable if it is at or below the level that permits the populations' to regenerate itself in perpetuity. Sustainable use of biological resources has been promoted as a workable solution to averting species extinctions and maintaining acceptable levels of ecosystem health and structure, while at the same time taking into account human needs (Ginsberg & Milner-Gulland 1994, Bodmer and Lozano 2001, Weinbaum et al. 2013). Sustainability assessments are however very difficult to operationalize. In chapter 5, the most commonly used mathematical algorithms were applied to population and harvest data, so as to estimate scenarios for sustainability using the observations in this study (Robinson and Redford 1991, Bodmer 1994, Wade 1998). Furthermore, a wide array of sustainability indicators may be used to evaluate sustainability of resource use (Weinbaum et al. 2013). In Table 6.1 I summarise the results of sustainability assessment of harvesting of the three exploited pigeons of São Tomé using various indicators for data collected within this research.

Table 6.1 – Application of several possible sustainability indicators to the exploitation of São Tomé endemic pigeons, in the context of the research conducted.

Sustainability indicators	Sample	Results
Population trends	Hunters' perceptions (Chapter 3)	All three species decreasing
Surplus production models	Hunting offtake; birds demographic parameters (Chapter 5)	Maroon and Green pigeons' harvest is unsustainable in most scenarios. For bronze naped pigeons, is unsustainable in just 30% of scenarios.
Comparison between sites	Patterns of distribution and abundance (Chapter 2)	Maroon and Green pigeons' distribution and abundance are determined by potential hunting pressure
Harvest rates	Hunters' perceptions (Chapter 3)	All three species decreasing
Changes in distance required for hunting	Hunters' perceptions (Chapter 3)	Maroon and Green pigeons' increasingly difficult to harvest

For the two most endangered species, the maroon pigeon and São Tomé green pigeon, harvest rates are very likely to be unsustainable. The results of the application of sustainability surplus models, even with due limitations, corroborates the observed population patterns and described trends for the two species. As for the bronze naped pigeon, birds' ecology may be confounding, with birds clustering in man altered habitats seasonally potentially over rating population estimates. With the higher recorded offtake for this species, there is an urgent need to promote hunting regulation and the effective protection of the species.

6.4.3 Ecological implications

The censuses undertaken of the endemic Columbidae in Sao Tome indicated that distribution and abundance patterns of the three hunted species are influenced by fruit availability, as described for many frugivorous Columbidae worldwide (e.g. Bancroft et al. 2000, Oliveira et al. 2006, Devi and Saikia 2010). The observed asynchronous fruiting patterns of the various tree species ensure year-round food resources for the pigeons and possibly lead to São Tomé pigeons' move across a variety of habitats to feed, but information on this is still limited. Further research is need to clarify the birds' dietary and foraging patterns, since pigeons are the largest frugivorous birds in São Tomé, and together with fruit bats (which are also extensively hunted and in need of further research) are potentially important dispersers of native forest.

The majority of the seeds of São Tomé forests are animal-dispersed (Lejoly 1995). Frugivorous fauna are one of the most affected groups by wild meat harvesting, thus compromising their ecological roles and causing a cascade effect which will reduce the regenerative capacity of native forest species (Abernethy et al. 2013). Detailed studies of fruiting tree phenology and distribution combined with research on their potential as seed dispersers of the endemic pigeons is thus fundamental to assist conservation managers on the island to ensure the long-term survival of its forests and biodiversity.

6.5. Prospects of conservation of endemic pigeons and further options for intervention

Endemic pigeons of São Tomé are exploited for both commercial and opportunistic reasons, but their unit value as a tradable/luxury good is much higher that their importance in human diets. Possible interventions for the conservation of endemic pigeons should be evidence-based and should take into account the characteristics of the different consumers and traders involved, but must also understand the feasibility of implementing adequate conservation measures. Any effort will result from a combination of activities that aim to reduce and/or regulate

demand and trade and those that specifically aim to protect habitats and populations of these species.

6.5.1. Regulation and enforcement of hunting and trade

In the developing world, resource constraints commonly limit the ability of governments to implement conservation legislation (Wilkie et al. 1992, Peres and Terborgh 1995, Wilkie et al. 2001). São Tomé and Príncipe environmental laws were largely supported by the European Programme ECOFAC, acting in the islands between 1995 and 2010. Enforcement of these laws is however low, with competent institutions often lacking the technical capability and means to effectively apply legislation. The development of a hunting law and effective regulations have been in discussion since 1995, but are still to be promulgated. The proposed document is probably too complex to effectively implement and is unlikely to be very effective, as other weakly applied environmental laws in São Tomé and Príncipe (Albuquerque and Cesarini 2009).

A key priority of this work is to communicate the findings of this research to policy makers so that they can be used as a means of regulating hunting activity and trade in São Tomé. In the short term, both livelihoods and biodiversity could be preserved by effective regulation of the trade. Hunting law should be promulgated including the ban on hunting of the maroon and São Tomé green pigeons, as present levels of harvesting are not only unsustainable but patterns of distribution and abundance of the species already reflect its long term exploitation. For bronze naped pigeons and fruit bats restrictions should be applied during breeding periods and quotas should be defined for commercial and sport hunters. For the definition of specific management and conservation plans of these species, further research and monitoring needs to be conducted so to ensure that legal harvesting is sustainable. Additionally, introduced mammals' hunting should be legalized and effectively managed, in order to ensure benefits can accrue to people's livelihoods at the same time as reducing their impact on native biodiversity.

Even if regulations are defined and promulgated, enforcement of such laws is challenging. However, unlike hunting for domestic consumption, commercial hunting is more amenable to command-and-control measures, because wild meat is

concentrated in central sales locations (Wilkie and Carpenter 1999). Short term interventions can be developed to monitor and inspect trade at urban centres during hunting restricted periods, so to influence and reduce commercial demand for pigeons, particularly during population-sensitive periods.

6.5.2. Alternative livelihoods

As shown in other studies, in situations where jobs are not available locally and catch per unit effort is profitable, hunting can become the most reliable activity in times of financial need and can be important during times of stress (Nasi 2008, Kumpel 2010). The high incidence of unemployment and the few occupations available in São Tomé have promoted a certain degree of professional diversification, with some people becoming hunters as a means of generating a steady income in the absence of alternatives. The contacts established during the analysis of offtake patterns analyzed in Chapter 5 corroborate the hypothesis that hunting is set aside if a secure wage activity is available, even if temporarily. Whilst hunting has the potential to provide a substantial income, households do not tend to accumulate wealth through hunting, because income from hunting is rather unpredictable, and it is rather spent as it is earned (Nasi et al. 2008).

Engaging bird hunters to search for alternative livelihoods is absolutely needed, so they can ensure for adequate income from other sources and move away from hunting. Though not many interventions to change hunters' incentives have been described, encouraging studies in Guinea (Pailler et al. 2009) showed that many hunters were willing to leave their occupation if presented with an alternative. In São Tomé, one possible strategy is shift hunting from native to introduced species, thus guaranteeing necessary income, without a change in profession. Also, and despite a global discussion on the real applicability of the wildlife farming strategy (Mockrin et al. 2005, Nasi et al. 2008), local production of native quails could be a potential response to supply for bird in urban restaurants replacing endemic pigeons, and provide an alternative livelihood to bird hunters.

Alternative livelihoods must anyhow be sufficiently labour-intensive or geographically separate from high conservation value areas, so that hunters won't continue hunting in their spare time (Kumpel 2010). The success of any specific

measure will ultimately depend on the hunters' willingness to cooperate, as effective regulation of pigeon hunting is still far from being enforced in the island and they can easily decide to hunt anyhow. These facts underline the need of combined strategies with hunting regulation, reducing demand from restaurants and traders and promoting biodiversity awareness, so that bird hunting is no longer a profitable or interesting activity to engage.

6.5.3. Biodiversity promotion and awareness

Consumers, in response to social marketing and education efforts, may be willing to change their preferences for luxury goods or for goods that contribute little to individual diets or household income (Wilkie and Carpenter 1999). Endemic pigeons constitute a luxury food for urban consumers but, on the other hand, don't represent a significant contribution for the livelihoods of rural consumers in São Tomé. It is then expectable that promoting legal restrictions together with education programmes towards endemic biodiversity could positively contribute for a wider sense of ownership and conservation of unique patrimony (Strushaker et al. 2004, Riley 2002).

During the last decade, it was observed in São Tomé an increasing concern with public awareness for environmental issues, but the extraordinary value of the unique biodiversity of the islands is still relatively unknown to local people. A considerable effort has been done on dissemination of natural values and environmental education (e.g. local NGOs, California Academy of Sciences, international cooperation educational programmes, Birdlife, etc), which are a strong basis for the development of complementary actions on biodiversity. The development of a conciliated approach of regulation enforcement, awareness and promotion of birds' other values (eg. for specialized bird tourism), could at least theoretically alleviate the pressure from opportunistic hunting of pigeons species in a long term and permanently.

6.5.4. Long term protection of species and habitats

Pigeons and doves are in general a resilient group of birds that have developed reproductive strategies characterized by certain traits and behaviours (as crop-milk production, rapid growth rates, early maturity, multiple brooding and extended nesting; Blockstein and Westmoreland 1993), that allow them to respond rapidly to environmental fluctuations and offset low survival through high recruitment rates (Bancroft et al. 2000, Rivera-Milan 2001, Rivera-Milan and Schaffner 2002). Yet, they vary in their capacity to reproduce, with some species becoming endangered or extinct because they could not cope with adverse deterministic and stochastic processes affecting their populations (Bucher 1992, Lind 1994), others have made successful recovery when impacts were removed (Rivera-Milan 2003, Oliveira et al. 2010).

There is little available information on the reproductive biology of São Tomé endemic pigeons. The maroon and São Tomé green pigeon may breed in forested habitats, but bronze naped pigeons are described to use coastal and humanized habitats seasonally in order to breed (Christy and Clarke 1998, Jones and Tye 2006).

The long term enforcement of habitat protection inside the Obo Natural Park may ensure the preservation of source populations of the maroon and green pigeons. However, with increasing development pressures on the island, these areas could come under threat of organized exploitation. With few resources available for conservation management, the danger of the Park existing only on paper is very real (Bruner et al. 2001). Where resources are limited, involving local communities directly in the monitoring, policing and decision making associated with managing a protected area can be a cost effective means of maximizing conservation gain (Shiel & Lawrence, 2004). This could also facilitate the establishment of long-term research projects that have benefits for conservation efforts and community understanding (Durant et al. 2007, Thirgood et al. 2007).

For the bronze naped pigeon, the situation is more challenging since the distribution of the bird (at least seasonally) coincides with the spatial distribution hunting effort. Evaluations of sustainability of game hunting in the Neotropics demonstrated that harvest regulation depends on the establishment of source sink dynamics which guarantees that non hunted areas are kept (Novaro et al. 2000). This

is particularly important for the effective protection of the bronze naped pigeon since that, at this point, non hunted areas do not exist and geographic limits of the island virtually allow access to all distribution area of the species. Limiting hunting effort spatially is a crucial determinant of the ecological sustainability of the system (Van Vilet et al. 2010).

6.6. Final remarks

Despite strong experimental design and the execution of a pilot survey to improve methodologies, several constraints and limitations were encountered during field work. For example, it was not feasible to census the entire island due to its inaccessibility. The wild meat trade, despite not being illegal, is elusive and the commodity chain rarely includes intermediates or formal markets, making it less detectable. Hunters were most of the time cooperative, but spread all over the island and not always reachable. They also often exhibit on and off patterns of collaboration, making particularly challenging the collection of regular data. Urban sellers and consumers were generally suspicious and mostly were reluctant to cooperate so for that reason dropped off this first approach.

However, it is acknowledged that long-term studies should develop "better questions and more accurate answers" (Godoy 2001), and that the understanding of complex systems of wild meat exploitation considerably improve with time (Coad et al. 2013). This was the first study to broadly analyse the different components of the wild meat exploitation in a São Tomé, a geographically limited area with high conservation value. It pretended to assess the extent of a potential conservation issue, but also to develop on further research questions that filled the necessary gaps to effective wildlife management.

Close cooperation with local institutions was an essential step in the development and proper execution of this study. This relationship should also open opportunities to integrate the results of the study in local capacity to manage natural resources. It highlights the urgent need to have baseline regulation for commercial hunting with a focus on the preservation of endemic birds, but also to integrate collected data within a decentralized net of local stakeholders and cooperatively

promote the implementation of hunting management, combined with public awareness and education. Results from a well-controlled situation such as São Tomé Island may help develop new models to improve the techniques for the scientific management of populations of harvested species elsewhere in Africa and other oceanic islands around the world.

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