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The Dynamics of a Bushmeat Hunting System Under Social, Economic and Environmental Change

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Declaration of Originality

This dissertation is the result of my own work and includes nothing which is the outcome of work done by or in collaboration with others, except where specifically indicated in the text.

James McNamara, October 2013.

Copyright Declaration

Abstract

The trade in bushmeat for human consumption is an important source of income and food for many people in tropical Africa. Yet it also represents one of the most significant threats to the persistence of wildlife. This threat has been exacerbated in recent decades as the trade has become increasingly commercial in nature, and previously pristine habitats have been degraded due to agriculture and extractive industries. These agricultural, production landscapes are increasingly the face of rural Africa, particularly West Africa. Understanding how economic and landscape-level pressures influence hunting behaviour in these production landscapes will be critical to developing effective management policies that are able to address both development and conservation agendas.

This study uses a unique 26-year dataset, collected in the Atwemonom market in Kumasi, Ghana, to examine the spatio-temporal dynamics of the bushmeat trade in the region. A multidisciplinary, multi-scale approach is adopted to present a holistic overview of the trade. Four analyses are presented. Firstly, a framework is developed to assess the degree to which the trade is driven by the demands of the consumer, or the behaviour of the hunter. Secondly, an econometric supply and demand model based on available market data is tested and implemented to analyse the drivers of supply and demand in the commercial system. Thirdly, a spatial model is designed to explore how the biophysical characteristics of the landscape influence what is harvested, from where it is harvested and how this has changed over time. Finally, the findings of these three approaches are used to inform a scenario analysis that explores the socioeconomic factors determining a hunter's willingness to adapt their behaviour in light of changing incentives to participate.

The findings highlight the importance of the production landscape for supporting the bushmeat trade in the region and present evidence that suggests the trade around Kumasi may be defined more by drivers of supply (hunter behaviour) than demand (consumer preference). This raises concerns about the effectiveness of demand side management. The results emphasise the need for

integrated approaches to bushmeat management that consider the full range of social, economic and environmental drivers.

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To my Mum and Dad, Alice and close friends, you know how much I value you, but your patience and support has been heroic! I can finally come out and play!

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Chapter 1

Introduction

1. Introduction

1.1. Problem statement

The commercial bushmeat trade in West Africa is an established livelihood activity that is deeply entrenched in the rural economy. As a financial activity, the motivations to participate in the commercial trade differ from those of the subsistence hunter and are defined both by the opportunity costs of engagement as well as environmental factors (Brashares *et al.* 2011). Thus, the context within which hunting decisions are made may be viewed as being embedded in a complex socio-ecological system (Duraiappah & Naeem 2005). There is growing awareness that if we wish to manage these systems more sustainably and more effectively, it is critical we develop holistic and interdisciplinary methods that are able to take account of the broader processes defining people's decision making (Berkes *et al.* 2003; Díaz *et al.* 2006; Nicholson *et al.* 2009). The findings of such analyses represent an important source of evidence, both to understanding complex dynamics of the system (such as feed-backs that may lead to interventions producing counter intuitive results) and to helping develop more sustainable bottom-up management policies based on empowering the user base rather than dictating to it.

The challenge of conserving biodiversity in many regions of Africa is complicated by poor governance, and high levels of poverty (Smith *et al.* 2003). Traditional reliance on natural resources, particularly among the poorest (Robinson & Bennett 2002; Adams *et al.* 2004), means that management is a priority both for conservationists and development agencies alike (Davies 2002). Forecasts for climate change in the region suggest an increase in extreme weather events, a reduction in the growing seasons of key crops, and an intensification of vector borne diseases may become more likely (Conway 2009). Such developments are likely to place additional pressure on people and resources, making the need for solutions that consider the broader contexts of these system much more critical (Young *et al.* 2006; Rands *et al.* 2010; Sala *et al.* 2000; Sachs *et al.* 2009; Watson *et al.* 2012; Warren *et al.* 2013). Bushmeat, the meat of wild animals, is a particularly valuable resource provided by tropical African ecosystems that has a long history of human use. It represents an important subsistence and economic activity, particularly for those on the edge of the cash economy, who frequently have few employment options and are less able to escape from poverty traps due to a lack of education, skills or access to capital (Robinson & Bennett 2002; de Merode *et al.* 2004; Carter & Barrett 2006). However, the bushmeat trade is largely recognised as unsustainable, and is acknowledged as among the major threats to tropical forest biodiversity (Bowen-Jones, Brown & Robinson 2003). Overexploitation by hunters has been attributed to the declines, and localised extinctions of species in a number of cases (Struhsaker & Oates, J 1995; Brashares *et al.* 2001; Barnes 2002). Many bushmeat species also play an important role in seed dispersal and pollination (Wright *et al.* 2000; Brodie & Gibbs 2009). Loss of large mammals from forest environs impacts the structure and functioning of ecosystems leading to an alteration in productivity that may have consequences for challenges of global concern, such as climate regulation and carbon sequestration (Brodie & Gibbs 2009; Morris 2010). In recognition of this fact, the trade in bushmeat been recognised by the IUCN as one of the world's most pressing conservation problems (Mainka & Trivedi 2002).

The bushmeat trade sits within a network of dynamic processes and is influenced by a range of drivers that act at multiple scales. Hunters' participation in the trade is determined by local-level drivers such as their socioeconomic profiles (de Merode *et al.* 2004) and the opportunity costs associated with their livelihood choices (Brashares *et al.* 2011; Schulte-Herbrüggen 2011). Globalisation, and the associated improvements in access to markets and technology, change the incentives associated with hunting (Kramer *et al.* 2009). Urban demand is driving the commercialisation of the bushmeat trade; as a consequence, the wealth and preferences of urban consumers exert a strong influence on the dynamics of the trade (Falconer 1992; Bowen-Jones & Pendry 1999; Brashares *et al.* 2004; Fa *et al.* 2009). At the same time, many landscapes in the tropical world have undergone dramatic changes in recent decades, with significant loss of native forests as timber and agriculture industries have expanded (Benhin & Barbier 2004; Norris *et al.* 2010). These landscape-level changes alter species composition, hunter behaviour and, ultimately, the productivity and sustainability of bushmeat extraction (Wilkie & Carpenter 1999; Jerozolimski 2003; Robinson & Bennett 2004). In addition, the personal or cultural importance of hunting may influence an individual's willingness or desire to adapt to external pressures.

The trade in bushmeat can therefore be defined by a range of drivers that influence both supply and demand. If managers are to develop appropriate strategies for managing such a complex socio-ecological system, multi-disciplinary, multi-scale approaches will need to be adopted that are able to consider the full range of drivers and their interactions (Milner-Gulland 2012). Management strategies that fail to take such an integrated approach will risk failure, as they are unlikely to be able to predict the responses of resource users to change, nor where change may be best made to encourage desirable behaviour (Albrechtsen *et al.* 2007; Carpenter *et al.* 2009; Milner-Gulland 2012). Although theoretical models have explored various aspects of the integrated socio-ecological dynamics of hunting systems (Damania *et al* 2005; Ling & Milner-Gulland 2006), empirical analyses that analyse the drivers of supply and demand are few, due often to the lack of long-term high-resolution data (Macdonald *et al.* 2011). This study aims to address this gap.

1.2. Aims and objectives

It is widely acknowledged that there is no simple solution to the problems associated with the bushmeat trade, and that successful conservation management will require an integrated approach addressing both supply and demand (Robinson & Bennett 2002; Davies 2002; Milner-Gulland, Bennett & SCB WIld Meat Group 2003; Bennett *et al.* 2007). If integrated approaches are to be successful, it is necessary to develop analyses that consider bushmeat hunting within the context of the socio-ecological systems of which it is part. To understand these systems, it is first necessary to break them down into their component parts.

In its simplest form, we break this system down into three core inter-linked components (figure 1.1): (1) the behaviour of the hunter, defined by (2) The dynamics of the market and (3) The landscape and biophysical attributes that define the trade. It should be noted that cultural and traditional uses of hunting are also likely to play an important role in defining hunting behaviour and may alter the perceived opportunity costs of participation. Although the model presented in figure 1.1 does not explicitly depict these drivers, they will be considered in a contextual manner in the following thesis.

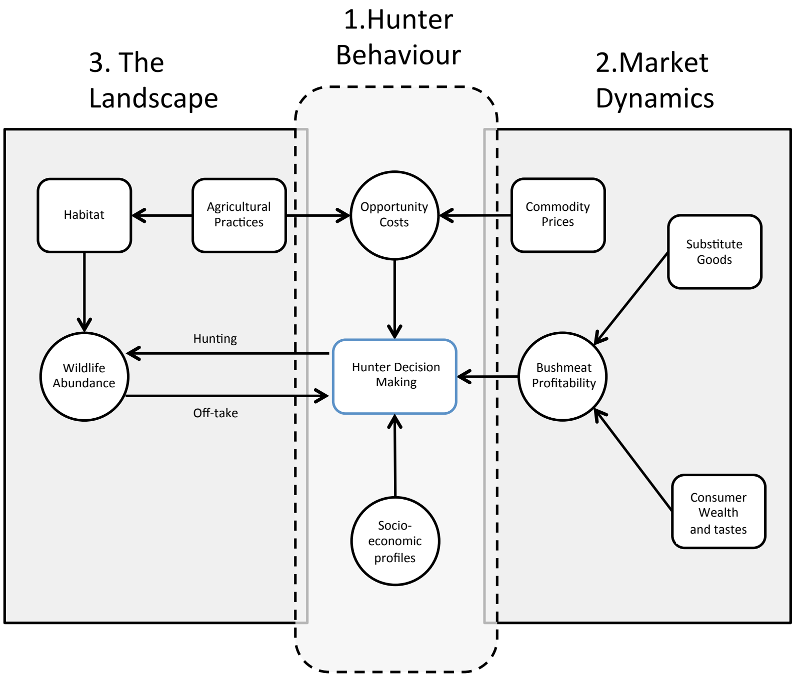

Figure 1.1: A conceptual diagram describing the fundamental processes that may define the commercial bushmeat trade in Kumasi. Circles represent incentives that influence hunter decision-making. Rectangles represent drivers, or consequences of drivers. Lines represent the direction of effect.

Using the bushmeat trade in the city of Kumasi, Ghana, as a case study, the following research aims to develop an innovative and multidisciplinary approach to analysing the socio-ecological context of bushmeat hunting, that is both dynamic (how does the trade evolve in both time and space?) and cross-sectoral (how does the broader context of the system influence behaviour?). It aims to understand the mechanics of the system in order to (1) critically analyse management options within the context of an improved understanding of system behaviour and (2) make predictions about the future evolution of the system in the light of global environmental change.

Adapting novel methodologies from the social, ecological and economic science, these research aims are addressed through the following objectives:

1. What are the drivers of the commercial trade in bushmeat?
2. How do the livelihood dynamics and socioeconomic profile of resource users influence their behaviour, and
3. How do the dynamic biophysical attributes of the landscape define the trade?

Chapter 2

Research background and case study

2. Research background and case study

2.1. Study Area

2.1.1. Ghana

Ghana, which takes its name from the ancient Kingdom of Ghana, one of the great Sudanic states that flourished in sub-Saharan Africa up to 11th Century AD, is situated in West Africa (Gocking 2005). It has three land borders: Côte D'Ivoire to the west, Burkina Faso to the north and Togo to the East. There are six primary ethnicities in the country, of which the Akan are the largest group, representing 53% of the population. Other major ethnicities include Ewe (12%), Mole Dagbani (12%), Ga-Dangme (10%), Guan (4%) and Gurman (3%). The Akan themselves consist of numerous sub-groups, of which the Asante (based in the Ashanti Region) and Fanti (in the Central region) are the largest (Ghana Statistical Service 2008). It is estimated that more than 60 local languages are spoken in the country, of which Twi, the language of the Asante and Akuapem, is the most widely spoken.

Ghana has one of the strongest economies in the west African sub-region , with a total annual GDP second only to Nigeria, and the highest GDP per capita (IMF 2013b). It has a primarily agricultural economy, with cocoa representing the main export commodity, although mineral resources, notably gold and more recently oil, are valuable components of the national balance sheet (Breisinger et al. 2009). Politically it has been relatively stable for the past 20 years, with a multi-party democratic system. This has made it an attractive option for foreign investment, particularly compared to the relatively turbulent political administrations of its neighbours (Gocking 2005). Although 30% of the population are still defined as living in poverty (living on less than $1.25 per day), the country's strong economy and stable political environment has allowed it to attain lower-middle income status, and the government has set a target to attain middle income status by 2015 (IMF 2013a).

2.1.2. Study area

This research focuses on hunting in and around the Ashanti region of Ghana, with a focus on the commercial trade that passes through the Atwemonom bushmeat market, located in the city of Kumasi. The Ashanti region is located in the tropical forest zone of southwest Ghana. It is one of the wealthiest and most populous regions in Ghana, as a result of its rich agricultural land and forest reserves that support productive cocoa and timber industries (Bediako 2008; Ghana Statistical Service 2008). In addition to Kumasi, research was conducted in four rural communities around the city. Jachie and Kwaman in the Ashanti Region (6.57N,-1.52W and 6.98N, -1.27W respectively), Anyimaye in the Brong-Ahafo Region (6.69N, -2.77W), and Kofiekrom in the Western Region (5.80N, -2.26W), see figure 2.1. The area was visited on three research trips, between April and June 2010, May and June 2011 and May to June 2012.

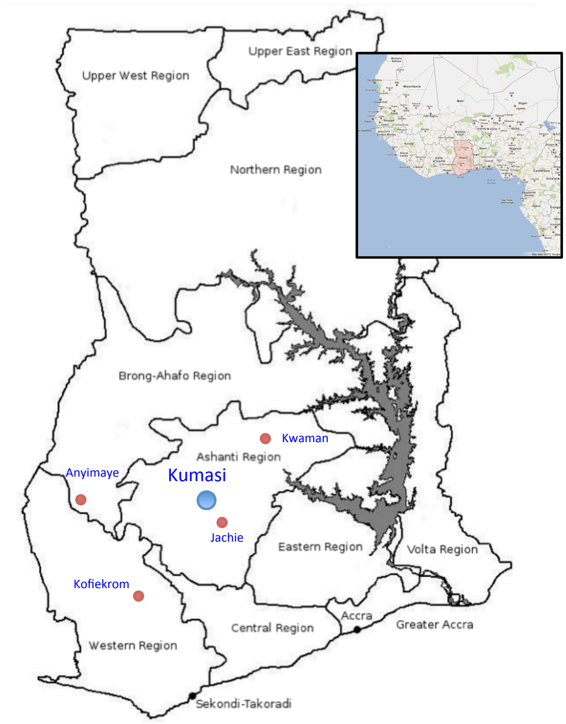

Figure 2.1 A map of Ghana and its regions, and location of the study sites, Kumasi, Jachie, Kwaman, Kofiekrom and Anyimaye

2.1.3. Climate and geography

The study area lies within the Upper Guinean Forest Global Biodiversity hotspot, which extends east from Guinea through Liberia, Cote D'Ivoire, Ghana and Togo (CEPF 2000). The ecosystem is ranked 5th among 25 global hotspots identified by Conservation International and is considered an area of high conservation and biodiversity importance (CEPF 2000; Myers et al. 2000). The climate is tropical, with average temperatures ranging from 22^{0}C to 31^{0}C, and average annual rainfall of 1,402mm with 10 days of rain per month, averaged over the past 30 years (Ghana Meterological Association 2013). There are four seasons: a long dry season (November to March) associated with the Harmattan, a dry wind from the Sahara that blows across the country from the northeast (Gocking 2005; McSweeney et al. 2008), a long wet season (from April to July), followed by a short dry season (August) and a short wet season (August to October).

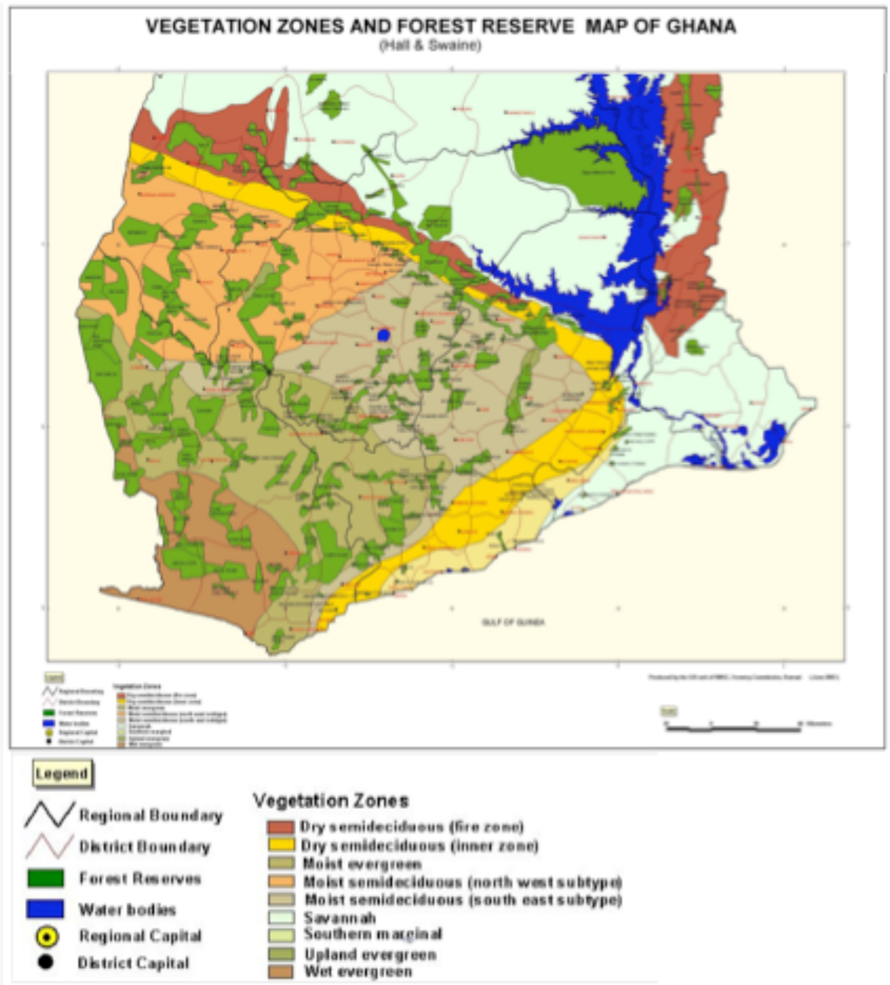

Figure 2.2 Map of the ecological zones in southern Ghana (Forestry Commission 2003)

In reality, the seasons are variable, and dominated by the Inter-Tropical Conversion Zone (ITCZ) which oscillates between the northern and southern tropic over the course of the year (McSweeney et al. 2008). The southwest of the country receives the highest level of rainfall, which declines as one moves towards the northeast. This rainfall pattern creates clearly defined differences in the ecological zones across the country (figure 2.2). The Ashanti region straddles three primary eco-zones: the dry semi-deciduous in the north; the moist semi-deciduous in the centre; and the moist evergreen in the southwest (Forestry Commission 2003).

2.1.4. Agriculture and the landscape

Agriculture is the mainstay of the rural economy. The most recent Ghana Living Standards Survey (GLSS), conducted in 2005, indicated that 61.4% of households are involved in agricultural enterprises (Ghana Statistical Service 2008), and 37% of the average household income was derived from agricultural activity (Trades Union Congress (Ghana) 2004). Cocoa and maize are the primary cash crops in the Ashanti Region, accounting for 95% of the total harvest value in 2005 (Ghana Statistical Service 2008); see table 2.1.

Table 2.1 Summary data of agricultural production of the seven main crops grown in the Ashanti region, ranked by value. Data relates to 2005. Sources, (Ghana Statistical Service 2008; SRID 2010; COCOBOD 2013)

Crop	Value (million cedi)	Production (tonnes)	Land Area (km2)	Households involved
Cocoa	405	90,535	245,685	651,009
Maize	154	183,032	113,639	1,212,037
Cassava	8.3	1,226,931	120,324	1,216,927
Plantain	7.1	600,595	65,623	1,032,758
Rice	6.0	9,926	5,264	25,952
Yam	2.5	230,367	18,146	281,583
Cocoyam	2.2	638,942	96,777	534,951

The expansion of agriculture, especially cocoa, and the timber industry has been one of the main drivers of forest loss in the region (Benhin & Barbier 2004; Braimoh 2009). Between 1977 and 2004, the area of land set aside for the cultivation of the seven main agricultural crops (including cocoa) in the Ashanti Region more than doubled, from 0.2 to 0.5 million hectares (Ghana Statistical Service 2012). This expansion has come at a price, and it has been suggested that as much as 20% of the forested land present in 1990 had been converted to other land types by 2005 (FAO 2010), while as much as 80% of Ghana's forest may have been cleared during the last century (Opoku 2006; Awanyo 2007).

Much of the remaining intact tropical forest in Ghana lies in forest reserves or protected areas. Within the Ashanti region, only 6.8% of protected forest areas are not managed for timber production. Outside of these reserves, land is largely devoted to low-intensity agricultural production (Benhin & Barbier 2004). Thus the landscape is almost entirely characterised by production and human disturbance.

2.1.5. Hunting and wildlife management

The impact of land conversion, coupled with high levels of hunting, has had a dramatic impact on wildlife across Ghana (Struhsaker & Oates, J 1995; Barnes 2002; Brashares 2003; Schulte-Herbrüggen et al. 2013). There have been a number of documented local extinctions, with perhaps the best known being that of Miss Waldron's red colobus (Oates et al. 2000; McGraw & Oates 2002), although similar, lesser known cases are available regarding other species, such as the white-neck rock fowl (Marks et al. 2004).

Despite these dramatic declines, wildlife hunting remains an important part of the livelihood portfolio for many rural households, and bushmeat a highly desired consumer good in both rural and urban markets. Household surveys conducted in communities around Kumasi in 1990 indicated that, on average, 14% of households were involved with hunting (Falconer 1992). This aligns well with surveys conducted in 2002 and 2004, also in the Kumasi area, which indicated that approximately 15% of households were involved in hunting (Crookes et al. 2007). Although estimates of the value of the trade are difficult due to its largely informal nature, research has conservatively suggested the annual trade could be worth in excess of $US350 million (Ntiamoa-Baidu 1998).

Hunting is regulated by the Wildlife Conservation Regulations (Government of Ghana 1971, 1983, 1988, 1989) which impose a strict ban on hunting of all species except the grasscutter (Thryonomys swinderianus) between 1 August and 1 December each year, a period referred to as the "closed season". For the remainder of the year, from December through to July, hunting is permitted for all species except those listed as schedule 1 in the Wildlife Conservation Regulations. For a full set of schedules and species covered by this legislation, see Appendix A. Additional controls are present in the form of hunting licences. Hunters are required to apply for a hunting licence every year. The licence stipulates the number of animals of each species that can be taken. Although Wildlife Division officials work closely with hunters to ensure that licences are up to date, monitoring offtake in line with licence requirements is extremely difficult and rarely attempted in practice. Hunting with a gun is the only legally permitted method. However, a variety of other practices are commonly used, including traps (usually wire snares) and dogs.

There are two main types of protected area that have strict conditions of use associated with them. Forests Reserves, which are managed for commercial timber extraction, and Wildlife Reserves, which include National Parks. Wildlife reserves are fully protected and no extraction of any kind is permitted. Forest reserves allow certain types of extraction in addition to commercial logging. Villagers are free to harvest forest products, such as firewood or cane, but the harvesting of commercial timber and bushmeat is strictly prohibited (Bockhorst 2010).

2.1.6. Study sites

Kumasi and the Atwemonom market

The capital of the Ashanti region is Kumasi, Ghana's second largest city, capital of the Asante Kingdom, and the throne of the Asante King, with a population of approximately 1.5 million people (Ghana Health Service 2010). Kumasi is often considered the commercial capital of Ghana, and its open-air Central Market rivals Onitsha in Nigeria as one of West Africa's largest markets. In addition to timber, it is renowned for the local trade in artisan goods and vehicle engineering (World Bank 2000). As well as the sprawling and diverse Central Market, Kumasi is also home to the Atwemonom bushmeat market. The name "Atwemonom" means "fresh duiker meat" in the local dialect, Twi, ("Otwe" is the Asante name for the Maxwell duiker, Philantomba maxwellii), and it serves as the primary market for fresh bushmeat in the city. It is also one of the oldest formal bushmeat markets in Ghana and as such is well established in the local economy (Falconer 1992). The market is primarily supplied by local hunters from the surrounding communities (Hofmann et al. 1999; Shanti-Alexander

2011). As household refrigeration is uncommon, hunters tend to bring the meat directly to market from the hunt, with the bulk usually arriving in the early morning as hunters end their night-time hunts. What is unsold is either stored for sale the following day, or smoked and dried and sold to traders at the Central Market. Atwemonom is a wholesale market, supplying restaurants and street vendors of the city as well as members of the public.

Trade within the market is controlled by a small, closely connected group of traders, many of whom are linked by family (Falconer 1992). Traders are exclusively female (the few men who work in the market are responsible for preparing the fresh meat prior to it being sold) and the market is run by a group of senior "market ladies". The traders inherit their business from their mothers, in accordance with Akan tradition and the same is true for the owners of the bushmeat chopbars (cafes) which operate from the market. For those not associated with the market through family or close business associations, entry into the trade at Atwemonom is difficult.

There is a strong patron-client relationship in which hunters will preferentially trade with specific market ladies with whom they have working relationships. The market traders will support this loyalty through loans to the hunters, either for hunting supplies or in times of hardship. These loans the hunter repays through meat. The relationships are fluid however; if a hunter's usual trading partner is not present when he arrives, he is free to sell to another trader. Hunters report that although prices vary day to day, they are broadly speaking comparable between traders. It is the relationship, rather than price competition, that bonds supplier to distributer. The market ladies and Wildlife Division officials who have worked with the market over the years claim that almost all fresh bushmeat entering Kumasi for commercial trade passes through Atwemonom. This is a claim supported by research in the market in 1990 (Falconer 1992). Consequently, a wealth of information can be readily obtained with permission of the "Queen Mother" who heads the market.

A potential lack of internal competition raises concerns about market failure, which would have consequences for the planned econometric analysis in this study if the prices set by the market were independent of supply and demand (Krugman & Wells 2006). However, there is good evidence to support the argument that, despite its dominance, the Atwemonom market is not exempt from competition. Discussions with hunters serving Kumasi highlighted that a number of alternative trade options were frequently utilised and, except in the case where bushmeat was sold directly to the consumer, that prices were equivalent or even better in alternatives markets (such as the main transport hubs and satellite towns through which the hunters passed to access the central markets). Hunters are free to and do use these trade routes. The ability of Atwemonom to shift a large amount of stock, and the relationship between hunter and trader, which provide the hunter with access to credit, maintains its prominence in the trade of the city. Although hunters may not choose traders on price alone, they are being compensated for this choice through the lenient repayment of credit, and thus there remains a degree of internal competition depending on the terms of credit provided.

Previous studies of the market have shown that prices change on a daily basis (Falconer 1992; Ntiamoa-Baidu 1998). Although no formal stock assessment was made during this study, anecdotal evidence from traders and our own casual observations during our time in the market provided no evidence of unsold stock. If anything, long-term price trends suggest that current supplies fall short of fully satisfying demand. Thus it is assumed for the purposes of this study that the market is competitive.

Study villages

Four study villages were surveyed during the course of this work: Jachie and Kwaman in the Ashanti Region, Anyimaye in the Brong-Ahafo Region, and Kofiekrom in the Western Region. All four communities were identified from the Kumasi data as suppliers of the Atwemonom bushmeat market. All communities were Akan, with Jachie, Kwaman and Kofiekrom being traditionally Asante, and Anyimaye predominantly Akuapem. Jachie and Kwaman have regular transport connections to the district capital Kumasi and are 12km and 48km from the city centre, respectively. Hunters from these communities are known to trade bushmeat regularly with the city market. The two remaining communities, Anyimaye and Kofiekrom are more remote, 130km and 120km from Kumasi, respectively. Access to large urban centres is difficult, and roads are seasonally impassable. Both Anyimaye and Kofiekrom are situated within easy walking distance of large forest reserves. Anyimaye neighboured the Bia Tano and Bonsam Bepo Reserves, while Kofiekrom bordered the Bura River Reserve. The habitat quality of the two former reserves is relatively degraded, while the quality of the latter reserve is good (Ghana Forestry Commission 2012). Hunters in Anyimaye and Kofiekrom trade almost exclusively with the local market, except on rare occasions when they travel to the city for family or work matters (figure 1.1). Communities were selected, in consultation with Wildlife Division officials, to provide a cross section of hunters, both those who regularly participated in the urban trade and those that did not, who were willing to participate in the study.

2.1.7. Market data

Species composition

Between 1978 and 2004, officials from the Ghana Wildlife Division regularly surveyed the daily trade passing through Atwemonom. Data were collected as hunters arrived at the market. The market has a central preparation area, where, following the transaction between hunter and market lady, the bushmeat is prepared and divided up to be returned to the market ladies for sale. This central processing system allowed observers to monitor efficiently the trade passing through the market. Information was recorded on the species, carcass weight, wholesale price received by the hunter and location from where the hunter had come. The dataset therefore represents a spatially explicit record of the commercial trade passing through the market over a 26-year period.

The full dataset represents 86,365 records made over 4,965 days and 268 months, covering 26 years from May 1978 to June 2004. There are a number of important caveats covering the data that need to be considered for analysis. The first of these arises due to the presence of the annual closed season. During this time, only grasscutters can be legally traded. Although other species are recorded in the data during this period, discussion with members of the team who monitored the market indicated that the recording of banned species (i.e.

illegal trade) was unlikely to be reliable. In short, as the monitoring team required the trust of the market ladies to operate, there was an incentive to ignore elements of the illegal trade. For this reason, data from the closed season was excluded from the following analysis. The resulting dataset, covering only the open season, consisted of 67,438 records, over 3,335 days and 180 months. Table 2.2 summarises the species break down of the data.

A second caveat applies to the species records. Just as observers turned a blind eye to illegal trade during the closed season, so they also reported turning a blind eye to trade in schedule 1 species, which are fully protected by law at all times of the year. During personal observation of the market in 2011, a number of schedule 1 species were openly traded, including pangolin species, *Manis spp.,* and the African civet, *Viverra civetta.* Neither of these species is common in the market data recorded between 1978 and 2004. Indeed, there is only one recorded pangolin transaction in 26 years. It is therefore unlikely that the market data represents a true record of the trade in schedule 1 species.

The final caveat relates to the composition of the trade, which is strongly skewed towards the seven most common species that constitute 94% of the trade by volume. The sharp divide between the abundance of these seven common species and the remainder presents problems for detailed statistical analysis of the long-term trade in many species. This discrepancy may be due to a number of factors such as consumer preference (demand) or local abundance (supply). It should be noted that price is unlikely to be a factor as many of the less abundant species are among the most valuable measured on both a per carcass and per kilo basis. Consequently, the following analysis is limited to analysing the trade in the seven most common species on the market, namely the grasscutter, maxwell duiker, royal antelope, bushbuck, black duiker, brush-tailed porcupine and giant rat.

Table 2.2 Summary of data of records from the Atwemonom Market, Kumasi during the open season (December – July inclusive), between May 1978 and June 2004. Species are sorted according to the number of records. All weights are fresh carcass weights. Prices are deflated to 2004 using the Consumer Price Index (CPI). Prices and weights are averaged over the entire time period.

Species	Latin Name	Records	Weight (kg)	Price (Cedi/kg)	Price (Cedi/ carcass)
Grasscutter	*Thryonomys swinderianus*	17470	4.03 *(1.7)*	15.91 *(5.2)*	67.0 *(22.9)*
Maxwell duiker	*Cephalophus maxwelli*	14008	7.31 *(1.74)*	12.68 *(3.8)*	90.6 *(27.0)*
Royal antelope	*Neotragus pygmaeus*	8425	2.90 *(1.42)*	15.86 *(7.2)*	33.3 *(16.2)*
Bushbuck	*Tragelaphus scriptus*	8147	36.17 *(12.8)*	8.08 *(3.2)*	271.6 *(104.9)*
Black duiker	*Cephalophus niger*	7029	19.01 *(4.7)*	9.60 *(2.9)*	179.4 *(48.8)*
Brush-tailed porcupine	*Atherurus africanus*	4637	3.28 *(1.3)*	14.65 *(5.1)*	47.9 *(16.6)*
Giant rat	*Cricetomys* gambinus.	3722	1.05 *(0.7)*	12.41 *(5.0)*	12.9 *(9.4)*
Long-nosed mongoose	*Herpestes naso*	519	0.78 (*0.5)*	12.96 *(7.9)*	9.2 *(8.6)*
Mona monkey	*Cercopithecus mona*	495	3.14 *(1.8)*	14.08 *(7.6)*	41.5 *(23.2)*
Ground squirrel spp	*Xerus* spp.	456	0.9 *(2.4)*	15.82 *(16.3)*	11.8 *(16.8)*
Francolin	*Francolinus* spp.	455	0.5 *(0.2)*	21.89 *(17.1)*	9.6 *(7.7)*
Palm civet	*Nandinia binotata*	439	2.3 *(0.7)*	16.1 *(7.2)*	35.7 *(15.7)*
African civet	*Viverra civetta*	346	7.5 *(3.8)*	13.1 *(11.4)*	92.9 *(65.2)*
Forest genet	*Genetta maculata.*	285	2.1 *(0.7)*	13.7 *(5.4)*	27.8 *(10.7)*
Red-flanked duiker	*Cephalophus rufilatus*	231	9.5 *(3.3)*	11.86 *(4.1)*	106.3 *(31.2)*
Bay duiker	*Cephalophus dorsalis*	132	12.2 *(1.6)*	10.86 *(3.18)*	125.0 *(43.9)*
Marsh mongoose	*Atilax paludinosus*	124	2.3 *(4.0)*	11.43 *(6.8)*	23.8 *(23.9)*
Spot-nosed monkey	*Cercopithecus petaurista*	122	3.6 *(1.8)*	12.4 *(4.7)*	41.9 *(19.5)*
Flying squirrel	Anomolurus pelii	67	1.41 *(0.46)*	10.8 *(6.6)*	13.5 *(6.3)*
Red river hog	*Potamochoerus porcus*	63	44.8 *(13.0)*	8.2 *(2.8)*	356.7 *(169.3)*
Gambian mongoose	*Mungos gambianus*	20	1.1 *(0.8)*	14.6 *(9.1)*	12.4 *(6.8)*
Common duiker	*Cephalophus sylvicapra*	18	7.6 *(2.1)*	13.5 *(4.7)*	99.5 *(20.7)*
Genet spp.	*Genetta spp.*	14	2.0 *(0.6)*	12.4 *(4.5)*	24.5 *(9.9)*
Slender mongoose	*Herpestessanguineus*	12	2.2 *(0.8)*	11.6 *(3.5)*	23.6 *(7.0)*
Kob	*Kobus kob*	5	35.6 *(10.1)*	12.0 *(5.5)*	429.1 *(213.2)*
Tree hyrax	Dendrohyrax dorsalis	5	1.9 *(0.3)*	9.0 *(1.8)*	16.8 *(5.6)*
Cape hare	*Lepus capensis*	5	1.8 *(0.4)*	18.0 *(5.7)*	32.0 *(8.4)*
Yellow-backed duiker	*Cephalophus sylvicultor*	4	52.7 *(46.3)*	9.0 *(5.9)*	318.3 *(225.0)*
Tree squirrel spp	*Sciuridae spp*	2	0.6 *(0.1)*	8.4 *(2.1)*	4.7 *(1.7)*
Fruit bat spp	*Eidolon spp*	2	11.0 *(4.2)*	17.5 *(NA)*	140.1 *(NA)*
Egyptian mongoose	*Herpestes ichneumon*	2	2.1 *(0.1)*	4.8 *(0.3)*	10.0 *(0.0)*
Green monkey	*Chlorocebus sabaeus*	2	3.3 *(1.8)*	14.4 *(9.0)*	38.8 *(3.9)*
Side striped squirrel	*Sciuridae spp*	2	0.2 *(NA)*	24.9 *(NA)*	5.0 *(NA)*
Oribi	*Oreibia ourebi*	1	7.0 *(NA)*	10.9 *(NA)*	76.4 *(NA)*
Pangolin	*Manis* spp.	1	2.0 *(NA)*	NA *(NA)*	NA *(NA)*
Tree pangolin	Manis tricuspis	1	7.0 *(NA)*	12.2 *(NA)*	85.0 *(NA)*

Market trends

The distribution of observation days throughout the study period is not consistent (figure 2.3). Observation effort in the latter half of data, from 1995 onwards is notably lower, with only 16 days monitored in 1997. Only two months were surveyed during the 1978 open season, hence the low observation rate.

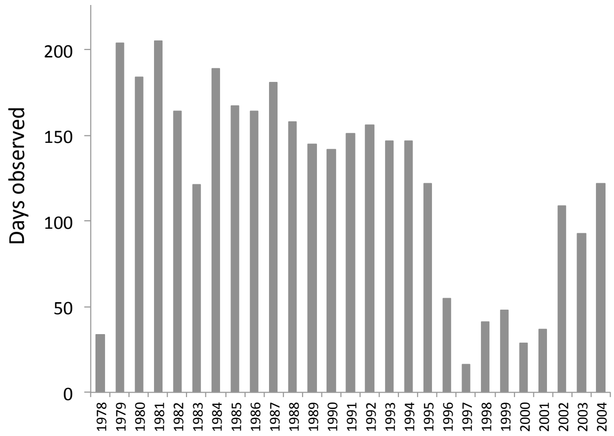

Figure 2.3: Number of days during the open season on which Wildlife Division staff visited the market

Overall trade volumes entering the market increased in the latter part of the sample period, both in terms of the average number of carcasses and biomass entering the market per day (figure 2.4).

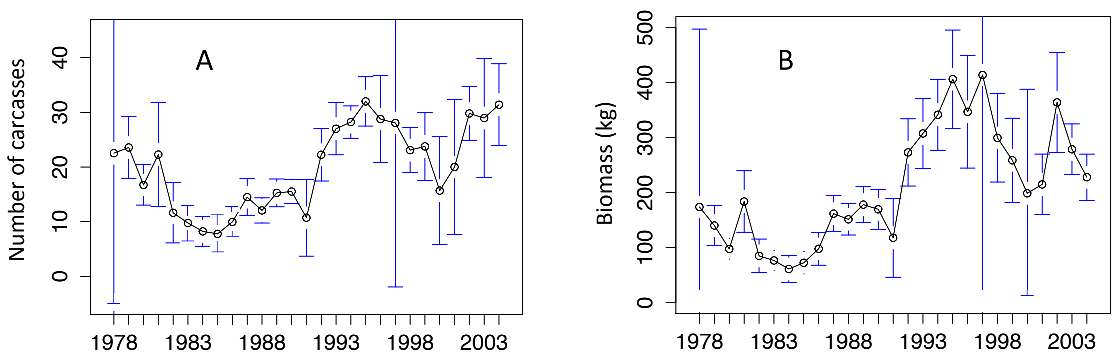

Figure 2.4: Trade passing through the market, measured in terms of A - the average number of carcasses recorded per day and B - the average weight of bushmeat entering the market per day. All data are calculated from the Open Season.

The apparent decline in biomass recorded in 2003 and 2004, which coincides with a stable trade in terms of number of carcasses, may be due to changes in the species composition entering the market, as rodent species such as the grasscutter begin to dominate and fewer ungulates are recorded. This is evident both in terms of species composition and the rodent to ungulate ratio (figure 2.5).

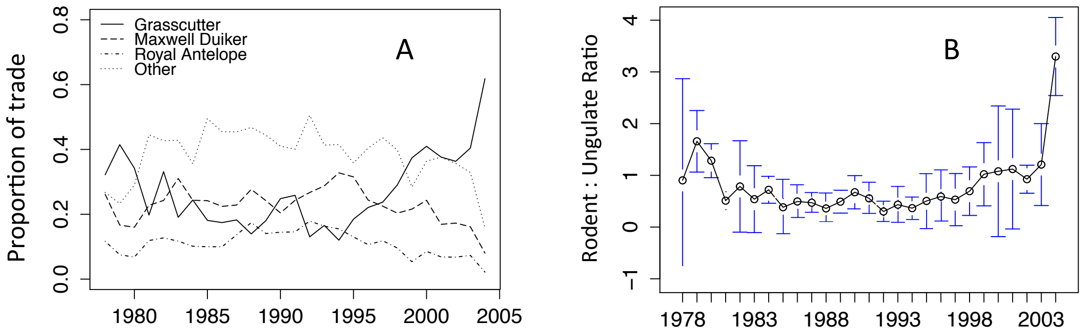

Figure 2.5: Changes in the composition of the trade. A - Ungulates and other species appear to decline in the latter stages of the survey period while grasscutters make up an increasingly large proportion of the trade (measured in terms of number of carcasses) from 1995 onwards. B – the Rodent to Ungulate ration shows a sharp increase in the latter part of the survey.

In addition to apparent changes in species composition, a clear intra-annual pattern in trade volumes in observed: notably that there are two peaks in trade volumes, a large peak in January and February, and a second smaller peak in June and July (figure 2.6).

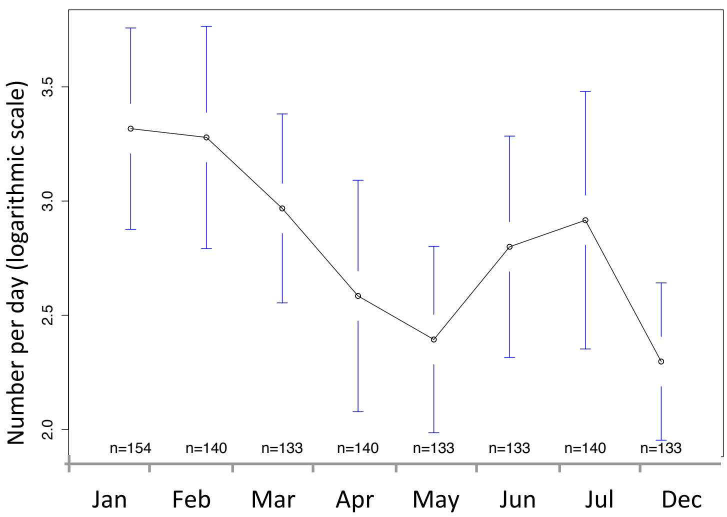

Figure 2.6: Seasonal variation in trade volumes (measured in terms of average number of carcasses passing through the market per observation day)

In terms of market prices, there was no significant change in the average price per carcass received by the hunter (figure 2.7). Such analysis is however complicated by the underlying changes in species composition that may hide significant inter-species differences. These dynamics will be explored in more detail in Chapter 4.

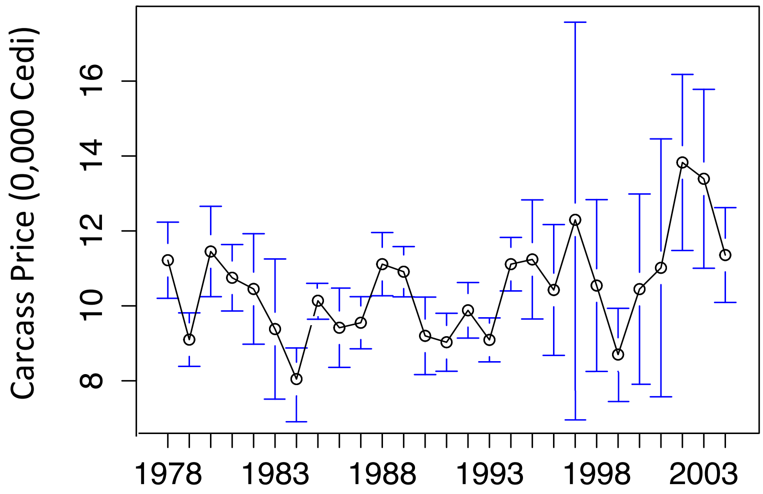

Figure 2.7: Variation in average per carcass price received by the hunter. Per carcass price is an average across all trade (total mass traded divided by the total value). Statistical testing suggested differences were not significant.

2.1.8. Urban protein consumption

101 Consumers in Kumasi were surveyed in 2011 to examine patterns of protein consumption among urban consumers to inform analysis of the drivers of demand. Fish was the most commonly consumed (86%) most preferred protein (60%) among urban consumers (figure 2.8). Although consumed regularly by a relatively small proportion of consumers (16%), bushmeat was the next most preferred protein.

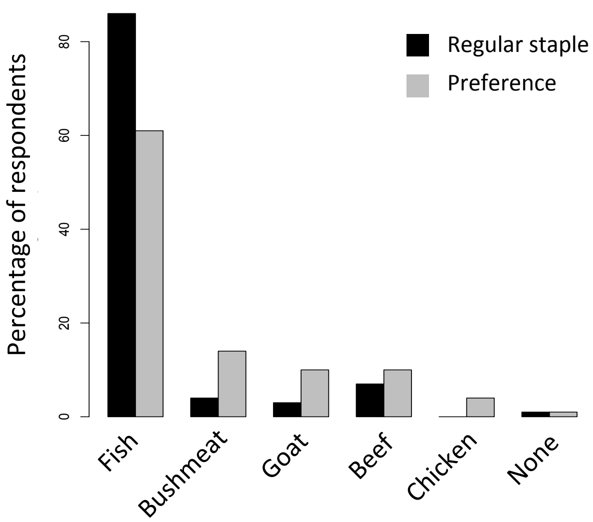

Figure 2.8: Urban consumers protein consumption behaviour. N = 101.

Breakdown of fish and bushmeat consumption behaviour highlighted the importance of marine species of fish (versus freshwater species), notably herrings and red fish (table 2.3).

Table 2.3: Most commonly consumed fish species among urban consumers in Kumasi (N = 101). The type of fish denotes whether the species is a marine (M) or freshwater (F) species.

Common name	**Scientific name**	**Type**	**Percentage of respondents**
Herrings	*Clupea spp.*	M	33
Red Fish	*Lutjanus spp.*	M	31
Mud Fish	*Protopterus, Parachanna spp.*	F	14
Mackerel	*Trachurus spp.*	M	10
Tilapia	*Cichlid spp.*	F	5
Pola	*Unknown*	M	2
Tuna	*Thunnus spp.*	M	1
Cassava fish	*Pseudotolithus spp.*	M	1
No preference	NA	NA	2

The grasscutter was the most commonly consumed type of bushmeat in line with previous research in the market (Falconer 1992; Ntiamoa-Baidu 1998), followed by the maxwell duiker, giant rat and bushbuck (table 2.4).

Table 2.4: Stated preference for difference bushmeat species among urban consumers in Kumasi (N = 101).

Bushmeat species	**Percentage of respondents**
Grasscutter	72
Maxwell's Duiker	20
Giant Rat	4
Bushbuck	2

2.1.9. Thesis outline

The thesis has the following structure:

Chapter 2: Research background and case study

An overview of hunting in the Ashanti Region, the local culture, Kumasi and the Atwemonom market are presented, in addition to background information on consumer preferences and market prices in the city.

Chapter 3: Is the Atwemonom bushmeat market supply or demand driven?

This chapter seeks specifically to address the question whether the trade in the region is defined more by the drivers of demand or supply. It sets out to do this by presenting a detailed overview of hunter and consumer behaviour, and analysing these in the context of the market.

Chapter 4: Drivers of supply and demand in a mature bushmeat market in Ghana, West Africa

This chapter presents an econometric analysis of the drivers of supply and demand, using data collected at the Atwemonom market over a 26-year period. In addition to analysing the drivers of the market, it also investigates how a major bushfire event in the 1980s affected the commercial bushmeat trade.

Chapter 5: The rise of the rodent: Spatial dynamics of a bushmeat hunting system

This chapter uses satellite imagery from two time periods, 1986 and 2002, and a time-series analysis of trends in the market data between 1978 and 2004, to investigate how landscape characteristics influence bushmeat trade volumes and trade composition. Market data from the Atwemonom market are used to characterise the trade, while classified satellite imagery is used to define features of the landscape, which might determine changes over time in the volume and type of trade emanating from particular areas.

Chapter 6: Exploitation, inflation and deforestation – What the future holds for bushmeat hunting in the Ashanti Region

This chapter analyses how the socioeconomic profiles of hunters influence their willingness to adapt their hunting behaviour in the face of changing incentives. Using scenario analysis, hunters are asked how they would hypothetically respond to future scenarios of change.

Chapter 7: Discussion

The findings of Chapters 3 – 6 are drawn together and synthesised, and their implications explored.

Chapter 3

Is the Atwemonom bushmeat market supply or demand driven?

3. Is the Atwemonom bushmeat market supply or demand driven?

3.1. Introduction

Bushmeat hunting is one of the oldest livelihoods utilised by man. However, its use sits in the context of shifting economic and environmental conditions and, as a consequence, its role for both consumers and hunters can be seen to change over time. Expansion of agricultural lands and an increasing human population have resulted in loss of habitat and increased pressure on natural resources (Fimbel *et al.* 2001; Braimoh 2009). Increasing national wealth and migration into urban centres have increased urban demand (Bowen-Jones & Pendry 1999; Breisinger *et al.* 2009), heralding a shift from traditional subsistence hunting to a trade that is now more commercial in its nature in many areas (Ntiamoa-Baidu 1998; Crookes *et al*. 2005). Meanwhile, improved access to agricultural markets, the introduction of new crop varieties and improved technology have altered the opportunity costs of hunting (Damania et al. 2005; Kramer et al. 2009).

Thus it can be assumed that the modern urban bushmeat market is characterised by a range of drivers that exert pressure on both supply and demand (Ling & Milner-Gulland 2006). If successful management strategies are to be implemented, it is critical that the processes that define these drivers are well understood (Nicholson *et al.* 2009). Much recent research in the literature has focused on trying to identify the processes governing supply (hunting behaviour) and demand (consumer behaviour). What has been missing from the literature, however, is any attempt to distinguish which of these processes (supply or demand) dominates and defines the trade. Being able to elicit such information is of particular value for managers seeking to identify where in the commodity chain interventions are best made. For example, if demand is driving the trade and hunters are responding to market prices, then initiatives to reduce demand or devalue bushmeat may be effective. This might be realised by increasing the availability of alternative protein sources to encourage consumers to switch to cheaper alternatives (Brashares *et al.* 2004; Mahama & Mohammed 2003), educating consumers through public engagement activities to attach stigma to bushmeat consumption, or flooding the market with farm-reared bushmeat to reduce its value (GTZ 2009). Conversely, if the trade were supply driven, then engaging with hunters to reduce their reliance on hunting would be more effective. Approaches often advocated include the development of alternative livelihood options (Bowen-Jones 2002) or investment in human capital to reduce poverty (Robinson & Bennett 2002). The options available to managers are well known. What are needed are novel methods to help make decisions about which interventions are likely to be effective (Ling et al. 2002).

The following analysis seeks to address this need, by developing and testing a framework based on simple concepts from the economics literature, to explore the extent to which the bushmeat trade around the city of Kumasi, Ghana, is driven by supply or demand, and to provide managers with evidence as to which interventions are likely to be effective. The bushmeat market in Kumasi provides a valuable case study for testing this framework due to a long history of bushmeat research in the region (Falconer 1992; Ntiamoa-Baidu 1998; Hofmann et al. 1999; Shanti-Alexander in press), which allows a historical perspective to be taken over three decades. The city is located in the Upper Guinean Forest Ecosystem, a biodiversity hotspot that has experienced severe degradation, such that only 15% of its original area remains intact, 1.5% in forest reserves (CEPF 2000; Myers *et al.* 2000). Thus the management of the legal hunting trade to preserve unprotected areas is of high conservation concern.

Microeconomics, which is concerned with the behaviour of producers and consumers in individual markets, posits that the relationship between price and the quantity demanded is based on a set of choices that maximizes the utility of the consumer, and that rational, profit-maximizing firms will produce at some level in accordance with demand (Besanko & Braeutigam 2010). Under this principle, changes in demand use the price mechanism to signal to firms to change what they produce. Markets that adhere to this principle are considered examples of demand driven markets (Blanchard et al. 2010).

However, the notion that individual markets are always demand driven was challenged by Ghosh (1958). He considered the case where, due either to resource limitations or some central control mechanism (such as rationing), the supply curve was inelastic and unable to respond to a change in demand. In such circumstances this led to "demand outstripping supply", where the factors associated with production (supply), rather than consumption (demand), set prices and defined consumption patterns. This proposal was highly contentious, and the technical formulation and plausibility of the model he proposed continue to be debated today (Mesnard, date unknown; Oosterhaven 1988, 2012; Dietzenbacher 1997; Guerra & Sancho 2011; Manresa & Sancho 2012). While there is as yet no agreement between the proponents and opponents of Ghosh's approach, even among the more vocal critics there is general agreement that a supply-driven approach can, under appropriate circumstance, offer value for identifying the processes that define the market Giarratani 1980; Oosterhaven 1988).

Other examples of markets that may be described as supply driven are those associated with industries that have a stable and high demand and which have few barriers to entry. Examples include prostitution and street vending. The decision to participate in these types of industries may be largely independent of price, with suppliers choosing to move in or out of the trade depending on the quality and availability of alternative income streams (Rankin 2000). Such industries are prone to considerable fluctuations in supply, despite relatively constant demand.

Traditionally, commercial bushmeat markets are often assumed to adhere to a demand driven regime, whereby hunters respond to market prices to meet consumer demand (Milner-Gulland E.J. & Clayton L. 2002). The corollary has been that if the bushmeat trade is driven by demand, then policies that seek to alter demand, and ultimately price, are a key mechanism to manage the trade. However, the trade potentially exhibits a number of characteristics associated with supply driven markets: limited exploitable resources, low barriers to entry (depending on the type of hunting adopted) and strong demand that has led to the development of a reportedly exclusive luxury market in some instances, all typify the trade, to a greater or lesser degree.

Using the bushmeat trade in the city of Kumasi, Ghana, as a case study, the following analysis presents a systematic framework, based on four key principles summarised from the economics literature, to examine the degree to which the trade is supply or demand driven (table 3.1). The characteristics are: 1) resource condition, 2) hunter behaviour, 3) consumer behaviour and 4) price behaviour.

Table 3.1: Conceptual framework for evaluating the bushmeat market under a demand and supply driven regime, broken down by resources (wildlife), producer behaviour, consumer demand and price behaviour.

Assumption	**Demand-driven** Demand determines price	**Supply-driven** Supply determines price
1) Bushmeat resources	Resources should be sufficient to meet demand	Resources may be insufficient to meet demand
2) Hunter behaviour	Hunters respond to price signals from the market, changing supply in response to price	Hunters move in an out of the trade independently of price signals from the market.
3) Consumer behaviour	Consumer choice defines patterns of consumption.	Supply-side dynamics define consumer behaviour.
4) Price behaviour	Prices are set by demand. An increase in demand will lead to an increase in price and quantity.	Prices are set by supply. An increase in supply will lead to a decrease in price.

By testing a series of predictions related to each of these four steps, and relating the findings to what we expect to observe in either a demand or supply driven market, we can draw conclusions about what is driving the trade (table 3.2). This framework is intended to use the kind of data that is commonly available in the bushmeat literature, without the need for the detailed long-term economic data that is usually required to estimate formal supply and demand relationships accurately, but which are rarely available for the informal markets system that characterise many artisanal trades. We use the framework to test whether the bushmeat trade in Kumasi is supply or demand-driven, using four general predictions. We predict that:

Table 3.2 Research structure as defined by the four framework tests. Predictions, associated tests and data sources are presented for each of the framework tests. In the data sources section, literature refers to one of the six peer-reviewed pieces of literature that form the basis for historic comparison, be it government publications or peer-reviewed articles. Primary data refers to data collected in the field as part of this study

Framework tests	Prediction	Sub predictions and tests	Data sources
Resource condition	Resources show signs of depletion.	***Trade composition***	
		1. Market level. Increase in proportion of the trade represented by less vulnerable taxonomic groups such as rodents.	Market surveys – Literature and primary data collection.
		2. Village level. First hand hunter reports reflect a comparable compositional change to one dominated by less vulnerable taxonomic groups.	Hunter surveys – primary data collection.
		Catch per unit effort	
		3. Average distance travelled per hunt increasing and catch per unit effort in decline.	Hunter surveys – Literature and primary data collection.
Hunter behaviour	Hunters move in and out of the market independently of price signals.	***Short-term (intra-annual)***	
		4. Hunting activity seasonal, defined not by the price of bushmeat, but by other factors associated with hunters' livelihoods, namely the agricultural seasons.	Hunter surveys, rural focus groups and bushmeat trader surveys – primary data.
		Long-term (inter-annual)	
		5. Participation in the trade trends independently of market signals (price) and the relative value of bushmeat (measured relative to inflation, national minimum wage and the price of alternatives).	Household and hunter surveys – Literature and primary data collection. Economic indices from national organisations.
Consumer behaviour	Consumer spending patterns defined by supply rather than demand.	***Consumer spending patterns***	
		6. Frequency of bushmeat consumption in decline due to high prices and lack of availability and frequency of consumption of cheaper alternatives increasing.	Consumer surveys – Literature and primary data collection.
Bushmeat prices	Prices are set by supply, not demand.	***Seasonal changes***	
		7. Periods of peak supply correlate to low prices and vice versa. There will be no evidence that consumer demand for bushmeat fluctuates.	Bushmeat trader surveys and market surveys from the literature.

3.2. Methods

3.2.1. Study area

Kumasi is Ghana's second largest city, with an estimated population of 1.5 million people (Ghana Health Service 2010). Kumasi is home to the Atwemonom bushmeat market, one of the oldest and largest bushmeat markets in Ghana, fed by the historically rich forests of the region (Falconer 1992). Atwemonom is the only formal market for fresh bushmeat in central Kumasi. Thus the trade passing through this market may be considered indicative of the general trade in the city. Other main central markets include Kejetia, which also doubles as the transport hub of the city, and Racecourse Market, the main market for livestock. These four markets comprise the trading centre of Kumasi and lie within easy walking distance of each other in the central business district known as Adum.

Two rural communities were surveyed, Jachie and Kwaman (Shanti-Alexander *et al.* in press), lying 20km to the southeast and 65km to the northeast of Kumasi respectively. Urban surveys were conducted in the regional capital, Kumasi (figure 3.1).

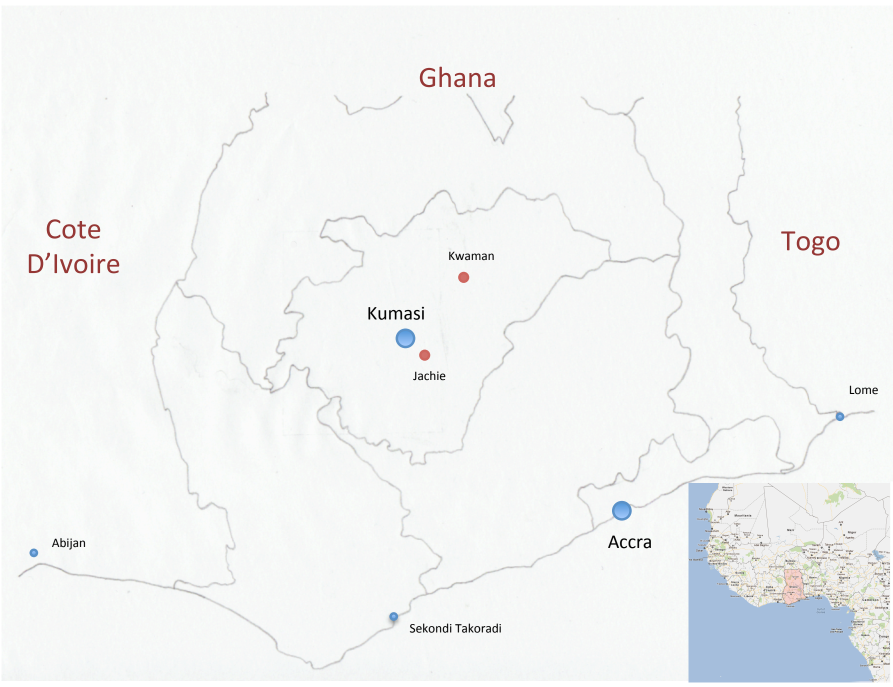

Figure 3.1: Map showing the three study locations: Kumasi and villages of Jachie and Kwaman

The decision to select the two rural communities was based on:

- Advice from Ghanaian Wildlife Division (GWD) staff (who have been working with hunters and communities in the region over may years),
- The historic involvement of each community in the bushmeat trade – the GWD conducted regular surveys of the Atwemonom market from 1978 until 2004. Jachie was ranked 12th and Kwaman 168th out of more than 1000 identified source locations.
- Willingness of the hunters and wider community to participate.
- History of research (hunting in Kwaman was studied in detail by Hoffman (1999), allowing direct comparison to be made between communities)

3.2.2. Data Collection

We used a combination of primary data (collected during two field seasons between April and June in 2010 and 2011) and secondary data from the literature, to evaluate how our four predictions had changed over time, 1) resource condition, 2) hunter behaviour, 3) consumer behavior and 4) price behaviour. Table 3.3 summarises the survey statistics.

Rural surveys

Rural surveys in Jachie and Kwaman were of two types: we used purposive sampling to obtain information from hunters, and we carried out a general survey of households within the village, selected using systematic samples.

Data were collected through structured and semi-structured interviews. Prior to commencing formal survey activities, focus groups were held in each village with a small number of individuals, typically 8 to 12. Questions focused on aspects of village life and livelihoods, such the main crops grown for cash and for food, when the associated harvest and planting seasons were and what time of the year was associated with the lean season. Individuals were selected from senior members of the hunting community, who were well placed to answer questions as the heads of their respective households. Information from the focus groups helped inform the more detailed one-on-one surveys conducted with hunters and households.

Household surveys (Appendix B1) recorded household demographics, livelihood activities, protein consumption patterns and perceptions about the bushmeat trade (Jachie N = 90, Kwaman N = 87). Surveys were conducted with the head of the household and usually took place in the early morning and early evening to fit into the daily work schedule. A systematic sampling approach was used with a sampling interval of approximately 10 households to ensure the full geographical area of the village was covered by the survey. Where the head of the household was not present, or unwilling to take part, the next available house was selected.

Hunter surveys (Appendix B2) focused on livelihood activities, trading activities and hunting behaviours (Jachie N = 23, Kwaman N= 28). Hunters were identified using three methods: household surveys, members of the hunting associations (where applicable), and the snowball method where known hunters were asked to identify other hunters. For the purpose of this study, hunters were defined as those who viewed hunting as one of their livelihood activities, whether for food or income. They hunted across a range of landscapes outside the boundaries of their own farms, using a range of techniques. Individuals who trapped on their farms as a means of pest control or for opportunistic subsistence were not included in the hunter survey, although their hunting practices were explored as part of the household survey. Such individuals seldom traded or gained direct economic benefit from their activities and usually perceived hunting to be a complement to farming (Shanti-Alexander *et al.* in press).

Urban surveys

Urban surveys were of three types. Firstly, short, semi-structured interviews based on a random sampling technique targeted general members of the public, recording meat consumption. Secondly, semi-structured interviews were targeted to bushmeat traders, both chopbar owners and wholesale market traders. Thirdly, surveys of the meat markets in the city (bushmeat, livestock and fish) were conducted to compare prices. The combination of consumer and trader was chosen to build up complementary data on the trade from different perspectives in the commodity chain.

Consumer surveys (Appendix B3) recorded patterns of protein consumption and preferences. Surveys were conducted in the four main central markets: Central Market (N = 35), Racecourse Market (N = 30), Kejetia (N = 16), and the streets between (N = 20). Surveys were kept short and simple to encourage participation, with 6–12 questions depending on whether or not an individual consumed bushmeat.

Trader surveys (Appendix B4) targeted wholesale traders in Atwemonom and chopbar owners throughout the city, and recorded information on bushmeat prices, availability and seasonal trends (wholesale traders N = 11, chopbar restaurants N = 6).

Market surveys consisted of a one-week survey of the Atwemonom bushmeat market in June 2011 to complement similarly timed surveys from earlier studies, Falconer (1992). Data were gathered on price, weight and species traded. Fish and livestock markets were surveyed in the Racecourse Market. Data were gathered on price.

Table 3.3 Summary of surveys conducted in each location. Distances and areas were calculated using Google Earth. *Consumer surveys were with households in the rural areas and bushmeat buyers in the market in Kumasi. **Includes both chopbar operators and wholesale bushmeat traders.

Location	Community Area (km^2)	Distance from Kumasi (km)	Hunter surveys	Consumer surveys	Trader surveys
Jachie	1.25	20	23	90	NA
Kwaman	0.92	65	28	87	NA
Kumasi	NA	NA	NA	101*	17**

Secondary data

Secondary data were gathered from the literature. Seven pieces of literature are used for these analyses, reporting the status of the bushmeat trade in: 1982 (Dei 1989), 1990 (Falconer 1992), 1993 (Ntiamoa-Baidu 1998), 1995 (Hofmann, Ellenberg & Roth 1999), 1999 (Hofmann, Ellenberg & Roth 1999), and 2002 (Crookes *et al.* 2007). These historical perspectives complement our own data to allow an assessment to be made of change over three decades. Additional data on economic indices, such as exchange rates and the consumer price index, were collected from international and national institutions including the International Monetary Fund, World Bank and Ghana Statistical Service.

3.2.3. Data analysis and prediction tests

Primary data are presented alongside comparable historic data selected from the literature. All information relating to 2011 represents primary data.

Resource condition

Resource condition was assessed through two metrics. 1) Trade composition and 2) catch per unit effort.

Trade composition: Changes in the composition of the trade was examined using market data collected in the Atwemonom market in three years: 1990, 1993 and 2011. This information is cross-referenced with firsthand hunter reports, gathered during our primary data collection in 2011, to validate the degree to which hunters corroborate the trends that are evident in the market data. This method was implemented to address, in so far as possible, concerns that market data may not always be an accurate measure of what is actually being harvested (Allebone-webb *et al.* 2011). As part of this process, hunters were asked to list those species that they caught frequently, and those that they used to catch but no longer did (or which were notably less frequent). Each time a species was mentioned it received a score in either the present or absent category. The totals for each species in each category (present or absent) are presented as a percentage of all scores in the relevant category. Thus an estimation of the relative scarcity of each species, from the perspective of the hunter, was made. Hunters' responses were unrestricted and they were free to list as many species as they wished (although in reality this number never exceeded 4 per category) in order to allow an honest picture of hunting at the village level.

Catch per unit effort: It is assumed that if the resource is depleted, hunters' catch per unit effort will be low. Estimates of the length of the average hunting trip is available from a number of studies in the Ashanti region over four periods; 1982, 1993, 2002 and 2011. Catch data are only available from one comparative study in 2002. Where possible, catch per unit effort is presented as the average number of animals caught per hour spent hunting. Comparison of the proportion of hunters in Kwaman, who believed that there had been a decline in bushmeat, between 1995 and 2011, using data from the literature, is also presented to provide a coarse perspective on the change in hunting success rates over this period.

Hunter behaviour

Short-term, intra-annual: We examined how hunters allocated their time throughout the year and explored whether variation was due to factors associated with the bushmeat market, agricultural seasons, or other external influences. Variation in hunting pressure was quantified by asking hunters to name the months when they hunted most (the peak months) and the months when they hunted least (the low months). To test whether the effort exerted was significantly different between seasons, hunters were asked to identify how many trips they might expect to engage in and how many animals per week they expected to catch in both the low and high seasons. Standard univariate statistical tests are used to analyse the differences. Hunters' motivations for acting as they did were explored through the hunting surveys. Seasonal trends reported were verified through surveys of bushmeat traders.

Long-term, inter-annual: Hunter participation (measured in terms of the proportion of active hunters in a community at any one time) was examined over three time periods: 1995, 2002 and 2011. This is contrasted with the change in the relative value of bushmeat over the same period to assess whether hunters are responding to price. An estimate of bushmeat value is made by comparing the normalised, real price of bushmeat, relative to the Consumer Price Index (a proxy for the cost of living), national minimum wage (national earnings), real price of cocoa (the most important cash crop) and the price of substitute goods (in this case, fish, the most commonly consumed protein). While not without its caveats, this "value estimation" is intended to place changes in bushmeat prices in the context of other key price indices to determine how the relative value, and hence price incentive associated with the trade, has changed.

Consumer behaviour

Consumer demand: Data are not available to accurately quantify how demand for bushmeat has changed over time. Based on our prediction that supply is unable to meet current levels of demand, we look for evidence that consumers are being priced out of the market due to shortfalls in supply. Patterns of consumption are compared over three time periods: 1990, 1993 and 2011. We measure changes in consumption behaviour using four metrics: 1) the proportion of consumers who eat any bushmeat, 2) the proportion of consumers who eat bushmeat regularly (defined as once a week or more), 3) stated preferences for bushmeat and 4) willingness to pay more for the bushmeat they consume. Changes in patterns of consumption are contrasted with changes in the real price of bushmeat. If the market is supply limited, and consumers are being priced out of the market, a reduction in consumption would likely be associated with an increase in the real price. Further, we ask consumers who report no longer eating bushmeat (but who have done so in the past) why they have made this choice, to ascertain whether price, preference, health, religion or some other factor played a role.

Bushmeat prices

We expect to see high prices associated with seasonal periods of low hunter engagement and low supply; low prices with high hunter engagement and high supply. We examine two long-term market studies conducted in Kumasi in 1990 and 1995 for evidence on price and supply peaks and hunter engagement. We reference this to reports gathered from hunters and traders during our 2011 survey season to corroborate this relationship qualitatively.

3.3. Results

3.3.1. Resource condition

Trade composition

Although differences in the timing and length of the surveys means care needs to be taken making comparisons, analysis of available historical data suggests that the profile of the trade entering Atwemonom market is relatively stable with the bulk being represented by nine species of ungulate and rodent (table 3.4).

Table 3.4: Comparison of changes in market composition (measured in terms of numbers of carcasses entering the market per day) in 1990, 1993 and 2011 at the Atwemonom Market. Data are presented for the 9 species which were most commonly traded in 1990. Falconer (1992) surveyed 12 days in April, 9 days in May and 6 in June. Ntiamoa-Baidu (1998) surveyed 6 days in March and our study surveyed 6 days in May. **Codes:** D – decrease, I – Increase in relative abundance between surveys. N/P – Not present during survey.

Species	April - June 1990 *(Falconer 1992)*			March 1993 *(Ntiamoa-Baidu 1998)*			May 2011 *(Current study)*		
	%	Rnk	Chg.	%	Rnk	Chg.	%	Rnk	Chg.
Grasscutter	48.3	1	-	26.2	1	-	62.4	1	-
Maxwell duiker	14.2	2	-	22.1	2	-	5.0	5	D
Bushbuck	10.6	3	-	12.4	3	-	6.0	4	D
Black duiker	6.9	4	-	11.0	5	D	0.7	8	D
Royal antelope	5.4	5	-	7.9	6	D	2.6	7	D
Red flanked duiker	4.0	6	-	N/P	-	D	0.2	12	D
Giant rat	3.8	7	-	4.3	7	-	9.6	2	I
Brush-tailed porcupine	3.7	8	-	11.4	4	I	4.3	6	D
Ground squirrel	0.4	9	-	N/P		-	7.2	3	I
Proportion of total	97%			95%			98%		

However, closer inspection of the data suggests an underlying shift in composition with a gradual increase in the importance of smaller species such as the giant rat *Cricetomys gambianus,* ground squirrel *Protoxerus stangeri* and grasscutter *Thryonomys swinderianus,* and a decrease in larger ungulates such as the black duiker *Cephalophus niger* and to a lesser degree the bushbuck

Tragelaphus scriptus. The ratio of ungulates to primates declines markedly between the 1990 (1.4) and 2011 (5.8).

Cross-referencing these market data with hunter observations gathered during primary surveys supports these trends. The seven most common species in our one-week market survey in 2011 were all identified as being regularly caught by hunters in our survey. The one notable decline in the market data, the black duiker, was the species most commonly reported by hunters as now being absent (figure 3.2). Primates account for just 2% and pangolins 1% of reported catch. The bushbuck was the only large ungulate (mean body mass > 20kg) reported as common by some hunters, although conflicting opinions on its presence suggest it may be becoming scarcer.

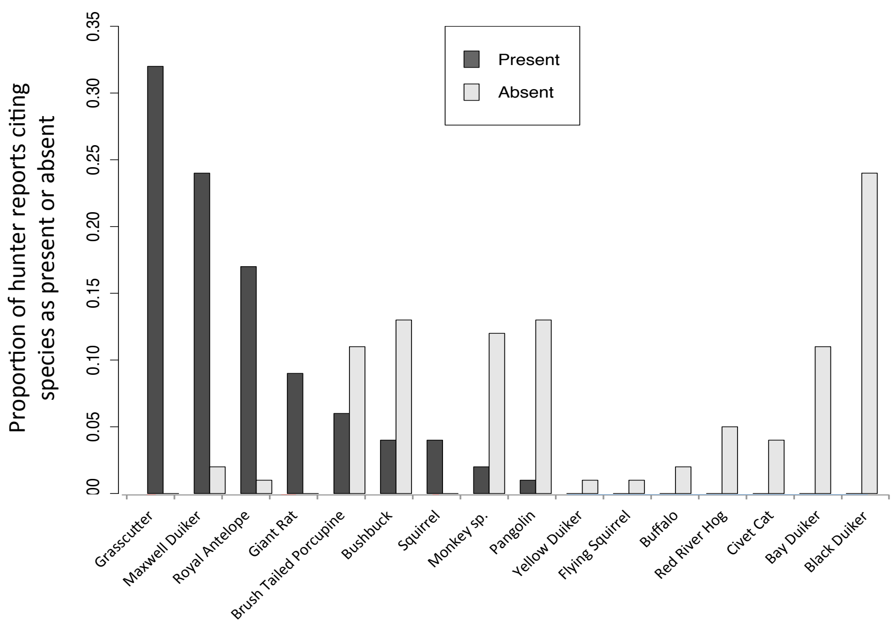

Figure 3.2: Proportion of hunter reports citing particular species as being present or absent in their catch. Present refers to species caught frequently. Absent refers to species that used to be caught regularly but are now rare or absent entirely.

A similar survey conducted in 2002 by Crookes et al. (2007) asked hunters which species they caught most regularly in three villages around Kumasi. Hunters reported a greater diversity of species, although their findings were still dominated by rodents and ungulates (78%). Four species reported in Crookes et al. (2007) but absent in our survey were the black duiker, flying squirrel, African civet and francolin.

Catch per unit effort

There was unanimous consensus among hunters that bushmeat species were in decline and that it was necessary to hunt for longer and travel further than in the past. Table 3.5 summarises estimates of average hunting trip length and, where available, catch per unit effort estimates over four time periods.

Table 3.5: Summary of average hunting trip length and catch per unit effort over time. All study locations were in the Kumasi area. Figures given in parentheses are standard deviations. * Decline in catch per unit effort is significant to the 95% level.

Period	**Average hunting trip length (hrs)**	**Catch per trip (number of animals per trip)**	**Catch per unit effort (number of animals per hour)**
1982 *(Dei 1982)*	3.6	NA	NA
1993 *(Tutu 1993)*	4.4	NA	NA
2002 *(Crookes 2007)*	5.6 *(3.3)*	1.97 *(1.2)*	0.35 *(0.15)*
2011 *(Shanti-Alexander in press)*	7.7 *(3.1)*	1.95 *(1.5)*	0.19 *(0.12)**

The average time spent hunting by hunters in the Kumasi area appears to have increased by almost 114% in the 30 years since the study of Dei et al. (1982). Catch data are only available from Crookes et al. (2007) and Shanti-Alexander (2011), thus an estimate for catch per unit effort, measured in terms of catch per hour, can only be calculated from these data. The decline in catch per unit effort of 46% from 2002 to 2011 is significant to the 95% level ($t = 0.73$, $d.f = 73$, $p = 0.02$). Further evidence that resources may be becoming stressed lies in accounts provided by other researchers. In 1995, (Hofmann, Ellenberg & Roth 1999) reported that 98% of hunters perceived bushmeat success to be in decline. 70% believed this to be due to dwindling resources. Shanti-Alexander (2011) found all hunters reported a decline in success and reported the increasing difficulty they faced in securing a successful catch. One hunter was quoted as saying:

"It used to be that before I had even left to start the hunt, they would be starting the fire to cook the meat"

While such statements need to be taken in context, these anecdotes illustrate the point that, whether entirely attributable to depletion or not, hunters perceive there to have been a dramatic change in resource availability.

3.3.2. Hunter behaviour

Short-term, intra-annual

22% of hunters surveyed in 2011 reported hunting all year round. Hunting was a strongly seasonal activity for the other hunters, and all hunters, including those who hunted all year round, reported a peak season and low season during the year (figure 3.3). Reported levels of effort and success, measured in terms of trips per week and animals caught per week, were all significantly different between peak and low hunting seasons (Kwaman trips per week, V = 196.5, P = 0.00064, Kwaman animals per week, V = 325, P = 1.29×10^{-5}, Jachie trips per week, V = 140, P = 0.0028, Jachie animals per week V = 120, P = 0.00068).

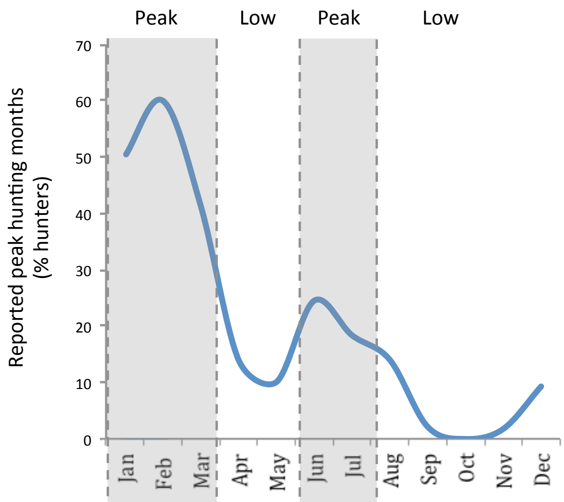

Figure 3.3: Plot of reported peak hunting months in both communities.

All hunters gained income from other sources as well as hunting, with farming being the primary income generator for most (Jachie 52%, Kwaman 71%). 94% of hunters engaged in agriculture to some degree. 80% stated that agricultural activities were the primary reason why they chose to hunt more in the peak season. This was broken down into reduced labour commitments during the months from January to March, when labour commitments associated with harvesting and planting were low (47%), and hunting to protect their crops, in particular the maize crop, which ripens in June (33%). The remaining 20% said that favourable environmental conditions linked either to the seasons or to perceived prey abundance explained their hunting strategy. No hunter mentioned any aspect associated with the bushmeat market as a reason for allocating effort as they did. Seasonal engagement in the trade appears to be driven by characteristics associated with the chosen livelihood portfolio. Bushmeat traders confirmed seasonal fluctuations in the trade in line with hunter reports.

Long-term, inter-annual

Relative engagement in hunting appears to have declined over the last decade. Household surveys in 1990 conducted in communities around Kumasi indicated that on average 14% of households were involved with hunting (Falconer 1992). This aligns well with surveys conducted in 2002 and 2004, also in the Kumasi area, which indicated that approximately 15% of households were involved in hunting (Crookes *et al.* 2007). A more recent study (Shanti-Alexander *et al.* in press) found that only 4% of households were engaged in hunting.

Over a comparable period bushmeat has consistently been the most expensive protein available on local markets (Asibey 1987; Falconer 1992; Ntiamoa-Baidu 1998). In 1990 Falconer (1992) found that fresh bushmeat was on average 39% more expensive than beef and 51% more than goat. The market surveys conducted in 2011 found this difference had increased; the wholesale value of a kilo of grasscutter meat was 67% more than the retail value of a kilo of goat, 108% more than beef and 488% more than a kilo of fresh sardines.

Data on profit margins between protein substitutes was not available. However analysis of the marginal increase in bushmeat prices between 1990 and 2011 (using the wholesale price of a single grasscutter carcass as an indicator) shows that the real price of bushmeat increased by 313%, significantly greater than the national minimum wage, 61%; the real price of cocoa, 153%; and the price of herring, the most commonly consumed protein according to our survey of 101 consumers in Kumasi, 180%.

To elaborate on these figures, in 2011 the price a hunter could expect for a single grasscutter carcass was 57% more than a worker on the national minimum wage could expect to earn in a week. In 1990 it was 30% less. According to the Ghana Statistical Service, inflation between 1990 and 2011 was 4,930%. Over the same period, the raw price of the average grasscutter carcass increased by four times this rate. While this comparison presents only a simple comparison of prices, ignoring external production costs such as fuel that might potentially impact hunters' profit margins, it highlights how the consistent rise in bushmeat price has exceeded those of similar commodities. The implication is that the relative value of bushmeat is greater in 2011 than it was in 1990 but that participation in the trade has declined.

3.3.3. Consumer behaviour

Consumer demand and spending

Comparison of historical consumer surveys suggests that the proportion of the population who regularly eat bushmeat has changed little over recent decades; in 1993 Tutu et al. (1993) found that bushmeat was the primary protein source for 2-5% of respondents, similar to our own findings of 4% in 2011. While regular bushmeat consumption appears steady, the number of people who eat bushmeat in any form appears to have declined. Preference and willingness to pay (defined simply as whether a consumer would be happy to pay more for the bushmeat they consume) have also declined sharply, while there has been a marked increase in the consumption of and preference for fish (table 3.6). Consumer preference has been shown to be linked to what is most readily available on local markets (East *et al.* 2005). The fall in preference may therefore be linked to the lack of availability and high price of bushmeat. Scarcity and price were the most frequently quoted reasons for not eating more bushmeat in 1993 (Tutu, Ntiamoa-Baidu & Asuming-Brempong 1993). In our own survey, 100% of respondents who had stopped eating bushmeat in the previous year cited cost as the reason.

Table 3.6: Comparison of consumer tastes. **1990**: (Falconer 1992) study area: Kumasi and surrounding communities; **1993** (Tutu, Ntiamoa-Baidu & Asuming-Brempong 1993) study area: Accra (capital), Mankesim (town, Central Region) and Doryum (village, Ashanti Region); **2011**, primary data collected during consumer surveys, May – June 2011, study area: Kumasi and surrounding communities.

Consumption characteristic	**1990 N = 262**		**1993 N = Unknown**		**2011 N = 278**	
	Bushmeat	Fish	Bushmeat	Fish	Bushmeat	Fish
Eat (any)	95%	NA	NA	NA	82%	100%
Eat (most freq)	NA	NA	2% - 5%	55% - 77%	4%	86%
Prefer	61%	NA	40% - 70%	10% - 32%	14%	61%
Willing to pay more	>55%	NA	NA	NA	32%	NA

Bushmeat consumption would therefore appear to remain important for a small proportion of the population, but price increases are increasingly pricing consumers out of the market, which may be reflected in a reduction in preference.

3.3.4. Bushmeat prices

Seasonal changes

Two previous studies of the Atwemonom market found supplies varied seasonally, with a peak from January to March, a decline in April and May and then a rise again in June (Falconer 1992; Hofmann, Ellenberg & Roth 1999). Falconer (1992) found prices to be correspondingly higher in the low season than in the peak season. Relative price markups in the low season for four main species were 67% (grasscutter), 29% (Maxwell duiker), 60% (black duiker) and 114% (bushbuck). Surveys of bushmeat traders in 2010 and 2011 confirmed this trend anecdotally. These seasonal fluctuations align well with allocation of effort reported by hunters in our 2011 survey of hunting communities, with periods of low hunting activity correlating with high prices and vice versa. There is no evidence among consumers that bushmeat demand follows the same seasonal pattern as hunting activity. The suggestion is therefore that seasonal price trends are driven by the seasonal participation in the trade by hunters, and hence by availability of bushmeat in the market.

3.4. Discussion

Bushmeat hunting has had a dramatic impact on wildlife in many parts of Ghana (Oates *et al.* 2000; Brashares, Arcese & Sam 2001). This loss of wildlife represents a three-fold threat, not only to the hunted species themselves, many of which are becoming increasingly marginalised in fragmented forest reserves and the few remaining patches of primary forest (Myers *et al.* 2000; Tan *et al.* 2009), but also for sections of society who rely on hunting for their incomes and wellbeing (Adams *et al.* 2004), and the ecosystem of which bushmeat species are an integral part (Brodie & Gibbs 2009). The management of hunting, as with other natural resources, is therefore necessary both from a conservation and development perspective. Understanding the processes that drive the trade is an important step in developing appropriate management strategies (Ling & Milner-Gulland 2006; Nicholson *et al.* 2009; Macdonald *et al.* 2011).

This work sets out and tests a framework that examines the bushmeat trade around Kumasi, from the perspective of the market, in order to ascertain what is driving the trade. Specifically, it aims to characterise the nature of supply and demand by explicitly considering the behaviour of the hunters and consumers involved in the trade. The tests of our predictions provide good evidence in support of our hypotheses that the trade around Kumasi is defined more by characteristics associated with supply-side dynamics than demand-side dynamics (table 3.7). The analysis also suggests that the supply-driven nature of the trade has become more marked in recent years as the resource has become more depleted.

Resource depletion is likely to be a significant contributor to the supply-limited scenario observed in the Kumasi market. The effect of resource limitation on price in hunting systems has been reported elsewhere in Africa. Hearn & Morra (2001) found that limited resources and unmet demand was likely to be responsible for high prices in Equatorial Guinea, and Kamins et al. (2011) found that vendors of bats in various locations across Ghana, including Kumasi, reported that demand frequently outstripped supply.

Table 3.7: Evaluation of results against predictions based on the market evaluation framework presented in table 3.2

Prediction	Sub predictions and tests	Result	Comments
Resources show signs of depletion.	***Trade composition*** 1. Market level. Increase in proportion of the trade represented by less vulnerable taxonomic groups such as rodents. 2. Village level. First hand hunter reports reflect a comparable compositional change to one dominated by less vulnerable taxonomic groups. ***Catch per unit effort*** 3. Average distance travelled per hunt increasing and catch per unit effort in decline.	✓ ✓ ✓	1. Dramatic increase in the rodent to ungulate ratio between 1990 and 2011. 2. Hunter reports align closely with trends observed in the market data. Rodent species and small ungulates dominate the trade. 3. Significant decline in CPUE between 2003 and 2011. Anecdotally a 114% increase in distance travelled over 30 years. It should be noted the decision to travel further may be to harvest more, however hunters' report catches are in decline.
Hunters move in and out of the market independently of price signals.	***Short-term (intra-annual)*** 4. Hunting activity seasonal, defined not by the price of bushmeat, but by other factors associated with hunters' livelihoods, namely the agricultural seasons. ***Long-term (inter-annual)*** 5. Participation in the trade trends independently of market signals (price) and the relative value of bushmeat (measured relative to inflation, national minimum wage and the price of alternatives).	✓ ✓	4. Strongly seasonal pattern in hunting effort. 80% reported this was due to agricultural commitments 5. Relative value of bushmeat has increased over the past 21 years compared to three indices (cocoa price, fish price and national minimum wage). Proportion of households engaging in hunting over the same period is in decline. Two caveats: Production costs that may reduce profit per animal were not considered and; the absolute number of hunters participating was not considered.
Consumer spending patterns defined by supply rather than demand.	***Consumer spending patterns*** 6. Frequency of bushmeat consumption in decline due to high prices and lack of availability, frequency of consumption of cheaper alternatives increasing.	✓	6. The proportion of regular consumers appears stable. The proportion of the population who eat bushmeat is in decline. Price is the main factor that defines this decision. Preference and frequency of consumption of cheaper alternatives has risen.
Prices are set by supply, not demand.	***Seasonal changes*** 7. Periods of peak supply correlate to low prices and vice versa. There will be no evidence that consumer demand for bushmeat fluctuates.	✓	7. Anecdotal evidence suggests bushmeat prices are at a premium when supplies are low. Price fluctuations are large (>100% for some species). There is no evidence from consumers that demand is seasonal. More detailed econometric modeling is needed to define the relationship between supply and demand and price.

There are a number of important caveats that should be highlighted when interpreting the results. For example, the change in composition observed both on markets and among hunters might be due in part to an increasing reliance on pest species, many of which are rodents. This reliance on pest species is reported by hunters and evidenced by the peak in hunting during the ripening of the maize crop in June. A focus on agricultural pests would influence both the seasonal participation trend and the market composition.

In addition, the supply and demand functions have not been comprehensively defined, thus precise evaluation of how the supply and demand relationship has evolved over time has not been possible. However, substantial detailed data are required for such estimations (Epple 1987), which are unlikely to be available for many bushmeat market systems. Estimates of how the relative value of bushmeat has changed over time do not consider bushmeat production costs and hence there has been no attempt to quantify how the actual profitability of hunting has changed relative to alternative income streams. Such an estimate would be extremely valuable when analysing participation in the market. Nor has it been possible reliably to estimate how long-term supplies of bushmeat entering the market have changed. Participation in the trade is measured in relative terms. However populations will have increased over the period covered by this study. Although relative engagement has declined, absolute engagement may have remained constant or increased. The data required to make such an estimate is not prohibitive; unfortunately local population data needed to make such calculations were not available for the study sites over the study period. On an individual level, the results of the tests that are presented need to be interpreted with caution. However, where possible, multiple tests have been conducted for each framework step, and collectively the results provide a robust picture of how the trade has evolved over time. The framework itself presents a systematic approach to analysing market characteristics using the kind of information that is often available for such markets.

The fact that relative engagement in hunting has declined despite significant increases in its apparent value suggests that a decline in bushmeat price, at least if these declines are marginal, may also have little effect. These findings raise doubts about whether demand-side initiatives, such as consumer education campaigns, will effectively lead to a reduction in hunting pressure. The one exception might be if government intervention formally regulated the trade, keeping wholesale prices artificially low, while inflating retail prices through the application of a bushmeat tax or similar instrument. Such a policy would almost certainly be deeply unpopular among consumers and suppliers alike, and almost impossible to enforce due to the informal, open access nature of the trade.

The logical conclusion is that supply-side interventions may be more effective; however, with limited scope significantly to alter the fundamental nature of rural livelihoods so as to break the seasonal pattern of income and labour associated with agriculture, what opportunities do these findings present? The link between agriculture and hunting suggests that hunting plays two roles: firstly, as an activity during the early part of the year when agricultural labour commitments are low and hunters have more time on their hands, and secondly, as a method of protecting agricultural incomes from losses arising from pest damage during the period around June, when crops such as maize are ripening. Crop pests tend to be abundant, fast-growing, non-threatened components of the farm-bush matrix, and therefore not as vulnerable to extirpation from over-harvest as forest-dwelling species (Rowcliffe *et al.* 2003). The importance of crop pests in Ghanaian markets has been reported previously by Falconer (1992) and Bojo (1996). Cowlishaw et al. (2005) in their study of the Takoradi bushmeat market concluded that the farm matrix might play an important role in supporting a sustainable bushmeat trade. Yet despite the recognition of the benefits of the farm-bush matrix for bushmeat in the literature, historically Ghanaian farmers have not considered crop pests to be advantageous (Bojo 1996) and although there have been calls for the production of wildlife to be explicitly considered in land planning (Asibey 1977), to date wildlife harvesting as a land-use remains off the political agenda in the forest zones of Ghana.

The small-scale individual nature of agriculture in Ghana makes the human modified landscape naturally amenable to wildlife friendly policies (Fischer *et al.* 2008), while the benefits associated with improved resilience and adaptive capacity that would be realised in multi-use landscapes are arguably of greater importance for communities heavily reliant on agriculture, where productivity and value are susceptible to environmental and economic shocks (Holling & Meffe 1996; Tscharntke *et al.* 2005). In order to integrate wildlife production into land planning, however, it is necessary to understand which components of the fauna can persist in the human modified landscape and what their characteristics are (Norris 2008). Our analysis of the trade suggests that the most valuable bushmeat species, the grasscutter, is also the most abundant in trade. It is also the species most commonly associated with crop damage and thus the ideal species for co-production of bushmeat and crops. The time at which harvesting this species is most useful from a pest control perspective is the maize season in June, which is also the lean season when agricultural income is low. Explicit consideration of the value of bushmeat in land-planning exercises would be a first step to assessing the benefits it provides and assessing any changes in land use that would be required to maximise income and reduce livelihood vulnerability throughout the year.

Policies that engage with hunters and farmers to promote the benefits of wildlife-agricultural co-production may also have the dual benefit of complementing existing policies that seek to protect and enforce the no-take status of the few remaining intact forest reserves. For example, conservationists might work with hunters to improve the efficiency of traps for crop pests, reduce the costs of transport to market (e.g. through a cooperative), or to support them in marketing them as products of wildlife-friendly farming, in return for commitments not to hunt less resilient species in forest areas. By raising the economic returns from activities that can be readily incorporated into existing livelihood strategies, conservation initiatives designed to enforce no-take zones, which are often viewed with skepticism by local communities, being associated with the loss of opportunity rather than its promotion, may be attractive to resource users.

The results of this study should not be taken as an indication that demand does not play a role. While in the short term, evidence of the market's supply driven nature is persuasive, a distinction should be made between short-term and long-term market drivers. In the long term, regardless of hunters' seasonal livelihood strategies, if the human population continues to grow and unless demand for bushmeat falls, consumption can only increase. Ultimately, management that fails to consider both sides of the trade is unlikely to provide the complete solution. However, if markets can be managed and manipulated through policies that complement rather than seek to control and dictate to existing behaviours and institutions, then the dual objectives of promoting local value from local resources while conserving scarce and endangered and species should be more achievable.

Chapter 4

Drivers of supply and demand in a mature bushmeat market in Ghana, West Africa.

4. Drivers of supply and demand in a mature bushmeat market in Ghana, West Africa

4.1. Introduction

The bushmeat trade in much of West Africa has seen significant change over the last century. While likely a primarily subsistence-based activity originally, today the bushmeat trade represents a large well-established economic activity in many countries (Falconer 1992; Bowen-Jones & Pendry 1999), providing an important source of income as well as food for hunters and their households, many of whom exist on the margins of the cash economy (Asibey 1974; Davies 2002; de Merode, *et al.* 2004; Kumpel *et al.* 2010). The economic importance of the trade is substantial. Estimates of annual bushmeat production range from 400,000 tonnes in Ghana (with an estimated value of $US350 million dollars; Ntiamoa-Baidu 1998a) to 1 – 5 million tonnes in the Congo Basin (Wilkie & Carpenter 1999; Fa, Peres & Meeuwig 2002). The scale of the trade becomes evident when one considers that, in Ghana, annual commercial production of marine and freshwater fish between 1991 and 1998 averaged 407,000 tonnes, while commercial livestock production averaged 57,600 tonnes (SRID 2010).

High bushmeat prices on the urban market are frequently considered to be one of the main drivers of the unsustainable trade in bushmeat (Wilkie & Carpenter 1999; Bowen-Jones & Pendry 1999; Fa *et al.* 2000; Fa *et al.* 2009). Despite the economic significance of bushmeat and the increasingly recognised importance of the urban trade as a driver of unsustainable hunting behaviour, there have been few analyses that have used econometric techniques (the application of statistical methods to analyse economic phenomena) for analysis of the bushmeat markets. One such example is Rentsch & Damon (2013) who presented a detailed analysis of the cross price elasticity of demand for bushmeat in the Serengeti. Although the tools of econometrics and ecology do not differ greatly in principle (Armsworth *et al.* 2009), one of the key benefits of adopting such approaches is the ability to analyse and interpret behaviour according to economic theory, offering different lines of enquiry and interpretation.

Such methods have been successfully applied in a range of natural resource markets, including local fish markets in the USA (Angrist *et al.* 2000), the ivory trade Japan (Milner-Gulland 1993) and the shark fin trade in Hong Kong (Clarke 2003). One of the biggest barriers to implementing such studies for informal markets in the developing world, such as the bushmeat trade, is the lack of long-term data necessary for robust analysis. However, the need for such analysis is great. These markets represent tightly coupled socio-economic systems, where the behaviour of the hunter, consumer and their environment are often inextricably linked. Developing models of such markets, consistent with economic theory, represents a valuable tool for improving our understanding of the processes that drive the trade; challenges that are of vital significance with regard to informing the development of appropriately targeted and effective management strategies for both conservation and development (Nicholson *et al.* 2009).

Markets can be expected to be self-regulating and in equilibrium, on the assumption that supply equals demand and that stocks clear; or in other words, under the assumption of perfect competition. Economists' interests in understanding these markets led to the development of statistical methods for modelling systems of simultaneous equations that describe both supply and demand (Tinbergen 1930; Haavelmo 1943). In their simplest form, these supply and demand relationships are linear and described in terms of the principle that supply equals demand, where the quantity of a good demanded is defined by its price and the price of an alternative, or substitute good, while the quantity supplied is defined by its price and some variable that encapsulates the production cost. In reality, many markets are highly complex, and although assumptions of perfect competition and linearity are not unrealistic (Graddy 1993; Stoker 1993) many markets may not be subject to perfect competition (for example oligopolistic or monopolistic markets) or linearity in the demand or supply functions. In practice, relaxing the requirements of perfect competition and linearity in applied systems introduces complexity in solving simultaneous supply and demand equations (Goldfeld & Quandt 1968) and requires knowledge of the true nature of competition that can be difficult to gain in real-world systems (Bresnahan 1982; Klemperer & Meyer 1989).

Bushmeat markets have been used to examine a variety of characteristics of the trade, from wildlife depletion to spatial and temporal dynamics, and consumer, hunter and trader behaviour (Falconer 1992; Juste *et al.* 1995; Fa *et al.* 2004; Crookes *et al.* 2005; East *et al.* 2005; Macdonald *et al.* 2011; Allebone-webb *et al.* 2011). These studies represent a rich source of literature from which to understand the potential drivers of supply and demand in bushmeat markets.

Using the commercial bushmeat trade in the Atwemonom market in the city of Kumasi, Ghana, as a case study, we develop a monthly simultaneous supply and demand model for the market, the first if its kind for a bushmeat system, based on the simplifying assumptions of perfect competition and linearity. Although we acknowledge that this assumption may be a simplification, it is based on knowledge of the market structure and operation, namely that the market clears and appears to operate in a competitive fashion (Chapter 2 & 3), suggesting such assumptions are a reasonable starting point for a preliminary analysis. Four models are tested. The first model considers all species traded. The second and third models focus on those two taxonomic groups that make the most important contribution to the trade, namely (2) ungulates, and (3) rodents (selected on the basis that they form the majority of the commercially traded species), which contribute 56% and 40% of the total volume of all biomass traded between 1978 and 2004 (Chapter 2). The fourth considers the most important species within the rodent subset, namely (4) the grasscutter, or giant cane rat, *Thryonomys swinderianus,* which is also the most commonly traded species on the market, contributing more than 45% of the records (number of animals) traded in 1990 (Falconer 1992) and 63% of records in a one week survey 2011 (Appendix C1). The decision to distinguish models by taxonomic group was made on the basis that while hunting is generally a non-selective activity, where specific species are rarely targeted (Hofmann *et al.* 1999), different taxa may exhibit different elasticities of supply. We may therefore expect to see difference in the ability of different stocks to respond to price signals generated in the market. For example, Rowcliffe *et al.* (2003) suggest that an index of the ratio of rodents to ungulates may be a good proxy for depletion due to the higher resilience of rodents to hunting pressures. Grasscutters are prevalent in the market, and are both the most preferred among consumers, the most valuable in terms of price per kilo and are also frequently hunted due to their being a crop pests as well as for bushmeat (chapter 3). They may therefore show different dynamics to species that are hunted specifically for trade.

Atwemonom is the primary market for fresh bushmeat in the city, and one of the oldest formal bushmeat markets in Ghana (Falconer 1992). In addition, it has been the focus of a number of previous studies on hunting in the region, and as such, represents an excellent case study for market analysis due to the relative abundance of reliable information on its structure and operation (Falconer 1992; Ntiamoa-Baidu 1998b; Hofmann *et al.*1999). Model variables are selected with reference to economic theory, the bushmeat literature and personal experience of the study site gained over three field seasons between 2010 and 2012. Data requirements for the model are underpinned using a unique 27-year dataset collected between 1978 and 2004 as part of a long-term market survey of the Atwemonom bushmeat market in Kumasi by the Ghana Wildlife Division.

In addition to assessing the drivers of the trade, we present the results of two further analyses. Firstly, we compare the relative price elasticities of supply of different species groups to test the hypothesis that if bushmeat resources are depleted as indicated by the qualitative assessment presented in Chapter 3, the supply of rodents is likely to be more elastic than the supply of ungulates, based on their faster reproduction and growth rates meaning they will be more likely to sustain high levels of hunting pressure (Robinson 2000; Rowcliffe *et al.* 2003). Secondly, we look for evidence in the market data to support the hypothesis that a major bushfire event in the 1980s dramatically impacted hunting for a number of subsequent years. Bushfires in Ghana represent a major threat, not just to agriculture and pastoralist systems, but also to native biodiversity (Kusimi & Appati 2012). Between 1982 and 1984, much of the country was affected by a series of devastating and extensive bushfires, considered by many to be the worst in living memory (Arthur & Arthur 2011). The Food and Agricultural

Organisation (FAO) estimated that as much of 50% of vegetation cover and 35% of croplands were destroyed in parts of the country. In a survey of hunters around Kumasi, bushfires were the most frequently cited threat to hunting offtakes, and many older hunters referred often to the fires of the 1980s as being at the root of the perceived decline in bushmeat today (Chapter 2). The scope of the data from the Atwemonom market presents a unique opportunity to examine evidence of the impact of major fire events on the bushmeat trade. Quantifying the impacts of such effects is particularly important in light of forecasts that predict increases in the intensity and frequency of bushfires due to climate change (Biringer 2003; Kalame *et al.* 2009).

4.2. Methods

4.2.1. General approach

The analysis is based on data collected on a daily basis in the Atwemonom market in Kumasi between 1978 and 2004 by members of the Ghana Wildlife Division. The data include records on species, trade volumes and price. The bushmeat trade in Ghana is a legal activity for non-schedule 1 species, except during a 4-month closed period between 1 August and 1 December, when the hunting of all species except for the grasscutter is prohibited (Wildlife Conservation Regulations, 1971). Due to data reliability concerns, records from the closed season were excluded from analysis (Crookes *et al.* 2005).

A monthly simultaneous supply and demand model is developed which forms the basis for subsequent analysis. The trade is broken down into four sub-groups: total trade volumes, rodents, ungulates and the grasscutter. An additional analysis investigates evidence of how a major bushfire event in the early 1980s impacted supply and demand dynamics. Our methods are broken down into four sections. First we outline a general model of the bushmeat market based on economic theory (Section 4.2.2). Secondly, we present a conceptual model of the bushmeat market based on evidence from the literature and personal experience of the study system (Section 4.2.3). Thirdly, we discuss model parameterization (Section 4.2.5), and finally, we validate the model (Section 4.2.6).

4.2.2. The General Model

Within our market, let p_t denote the price of bushmeat, q_t denote the quantity of bushmeat traded, and x_t denote a vector of covariates that characterise the market at time t. Assuming perfect competition, supply and demand are in equilibrium, and thus the supply and demand functions, which are a function of both price, p_t, and the market covariates, x_t, can be assumed to be equal:

$$q_t^s(p_t;\ x_t) = q_t^d(p_t;\ x_t) \tag{4.1}$$

Where $q_t^s(p_t;\ x_t)$ is the supply function and $q_t^d(p_t;\ x_t)$ is the demand function. On this basis, we can specify our simultaneous supply and demand model according to:

Supply: $$q_t^s = \beta_p^s p_t + \beta_x^s x_t + \varepsilon_t^s \tag{4.2}$$

Demand: $$q_t^d = \beta_p^d p_t + \beta_x^d x_t + \varepsilon_t^d \tag{4.3}$$

Market clears: $$q_t^s = q_t^d = q_t$$

Where $\beta_p^s \geq 0$ and $\beta_p^d \leq 0$, based on economic theory predicting that the gradient of the demand curve be negative, or downward sloping, while the supply curve gradient be positive or upward sloping. This is in line with the standard assumption that consumer demand will fall as prices rise, while suppliers will increase production in response to price rises. Equations (4.2) and (4.3) are referred to as the *structural equations* of our model.

When solving this system of equations, there are three primary considerations that need to be addressed: identification, endogeneity and efficiency. The problem of identification arises from the fact that if we were to simply observe a number of equilibrium positions of p_t *and* q_t, in relation to a hypothetical variable z_t which influences demand (such as income) we would only be able to reveal the supply curve and could infer nothing about the shape of the demand curve. Thus, if we are to be able to identify both the supply and demand curves, it is necessary to distinguish a set of unique covariates that are associated with shifting either demand, or supply, but not both. The vector of covariates x_t described in equations (4.2) and (4.3) can therefore be described in terms of three components: x_t^s are exogenous supply shifters that influence supply and not demand; x_t^d are exogenous demand shifters that influence demand and not supply, while x_t^c are the market controls, exogenous variables that influence both supply and demand. Thus equations (4.2) and (4.3) can be rewritten in the more specific form:

Supply: $$q_t^s = \beta_p^s p_t + \beta_{x,c}^c x_t^c + \boldsymbol{\beta_{x,s}^s x_t^s} + \varepsilon_t^s \tag{4.4}$$

Demand: $$q_t^d = \beta_p^d p_t + \beta_{x,c}^c x_t^c + \boldsymbol{\beta_{x,d}^d x_t^d} + \varepsilon_t^s \tag{4.5}$$

The second issue is that of endogeneity. A consequence of the fact that price is determined by supply is that price, p_t, is not a stochastic variable uncorrelated with the error term, ε_t. This is a violation of the assumptions of the classic linear regression model, and will result in any inferences made by ordinary least-squares being both biased and inconsistent (Maddala & Lahiri 1992). The solution to this is to use instrumental variables to estimate exogenous forms of both price and demand that can be substituted into equations (4.4) and (4.5) and solved. Based on the assumption that $q_t^s = q_t^d$, equations (4.4) and (4.5) can be set to equal each other and solved to estimate $\hat{p}_t$. Similarly, as $p_t$is equal in both equations, the same equations can be rearranged such that p_t is the dependent variable, and solved to estimate $\hat{q}_t$. The equations used to estimate $\hat{p}_t$ and $\hat{q}_t$ are known as the *reduced form* equations (equations (4.6) and (4.7)).

Price: $$\hat{p}_t = \beta_{x,c}^c x_t^c + \beta_{x,s}^s x_t^s + \beta_{x,d}^d x_t^d + \varepsilon_t^s \tag{4.6}$$

Quantity: $$\hat{q}_t = \beta_{x,c}^c x_t^c + \beta_{x,d}^d x_t^d + \beta_{x,s}^s x_t^s + \varepsilon_t^s \tag{4.7}$$

IVs: $$z_t = (x_t^c, x_t^s, x_t^d),$$

In this way, $\hat{p}_t$ and $\hat{q}_t$, – being now described purely in terms of the exogenous instrumental variables (IVs), and thus being themselves exogenous – can be substituted back into equations (4.4) and (4.5) for unbiased estimation of the structural equation coefficients, $\beta_p^s, \beta_x^s, \beta_p^d, \beta_x^d$. This process of dual estimation is known as Two Stage Least Squares (2SLS).

The final consideration with regard to estimation is efficiency. In describing the same system using two differently identified models, we have necessarily restricted the parameters in each model, and thus they cannot be thought of as being efficient (Stock & Watson 2012). Indeed, when considering how best to solve a set of simultaneous equations, it is usually not satisfactory to try and determine each of the equations separately without regard to the restrictions that each equation may impose on the other (Haavelmo 1943). A solution to this is to use Seemingly Unrelated Regression (SUR), where both of the structural equations (4.4) and (4.5) are solved jointly under the assumption that their errors are correlated. Adopting this approach ensures that the full range of regressors are considered in estimating the structural equation coefficients, thus ensuring no restrictions are placed on the model. This combination of IV and SUR methods is known as three staged least squares (3SLS) and should produce estimates of the structural equation coefficients that are unbiased, consistent and efficient (Lin 2005).

4.2.3. A conceptual model of the Atwemonom Market

To develop an appropriate model of the bushmeat market in Atwemonom, it is first necessary to define the system and distinguish those variables associated with demand, supply, and both (the market controls). In categorising the market, we make a number of assumptions to simplify the system. We consider supply in terms of those factors that influence hunter behaviour in the rural setting, while demand is defined in terms of the urban consumer. We do not consider rural demand in our analysis, as this does not play a direct role in the functioning of the Atwemonom market.

On the supply side, many hunters in the humid tropics are primarily engaged in agricultural activities (Bojo 1996; Shanti-Alexander et al. *in press*). Thus, hunting activity has been shown to be influenced by both seasonal variation in agricultural incomes (Schulte-Herbrüggen 2011), labour demands associated with harvests (Brashares *et al.* 2011) and the need to protect crops against pests at certain times of the year (Tutu *et al.* 1993; Smith 2005; Shanti-Alexander *in press*). The most significant cost associated with hunting is the purchase of a firearm. The initial capital outlay associated with this expenditure is significant (Crookes *et al.* 2007), although other, less capital intensive hunting methods are also used, such as wire-snare trapping and dog hunting (Shanti-Alexander *et al.* in press). Additional costs associated with production include the purchase of cartridges and batteries or fuel for night-time hunting (Hofmann *et al.* 1999) and the cost of transporting bushmeat to market (Brashares *et al.* 2004; Cowlishaw *et al.* 2005a). Other considerations that play a role in a hunter's decision to participate include seasonal variation during the annual wet and dry seasons, which, as well as defining the agricultural seasons, influences the penetrability of the landscape for hunters (Juste *et al.* 1995). On the demand side, in addition to the availability of alternatives such as fish and livestock (Asibey 1987; Falconer 1992; Brashares *et al.* 2004), consumer income has been shown to be a driver of bushmeat consumption (Wilkie *et al.* 2005; Fa *et al.* 2009).

Both supply and demand are likely to be influenced by macroeconomic and demographic drivers such as population growth and the cost of living. Rising urban populations are likely to increases demand and drive prices up (Bowen-Jones & Pendry 1999). Population estimates suggest that the population of the Ashanti region has more than doubled over the last 20 years (Ghana Statistical Services 2012). Although data are not available on rural population estimates, it would be reasonable to assume that this regional growth in population would be correlated in both rural and urban regions. With regard to the cost of living, bushmeat has long been considered among the most expensive forms of protein in urban centres in Ghana (Asibey 1987; Falconer 1992; Ntiamoa-Baidu 1998a; Shanti-Alexander 2011), while hunters have been shown to rely on hunting during the lean season, when income from agriculture is low and food stuffs are expensive (Schulte-Herbrüggen 2011), and during other times of hardship (Shanti-Alexander 2011). Increases in the cost of living, such as the price of daily consumables like food and fuel, as measured by the Consumer Price Index, may be expected to incentivise hunting among hunter communities while shifting urban demand towards less expensive goods. Figure 4.1 summarises these hypothesised associations in the form of a conceptual diagram of the commercial bushmeat market.

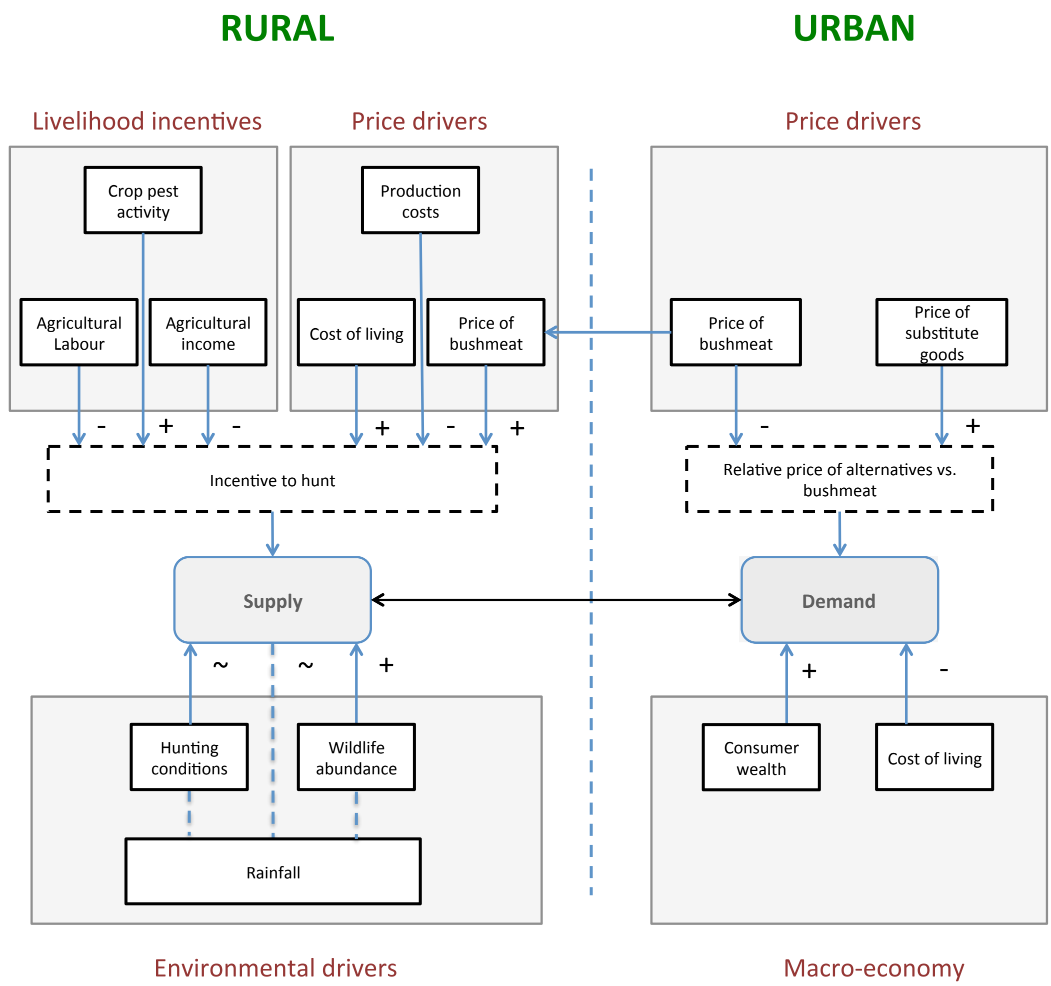

Figure 4.1: A conceptual model describing the drivers of supply and demand. Drivers are loosely grouped into different categories. Supply: (1) hunter livelihood dynamics, (2) the rural market and macroeconomy and (3) the environment. Demand: (1) The urban market and (2) the macroeconomy. Arrows show the direction of action. The symbols represent the effect of an increase in any given driver on the quantity of bushmeat supplied or demanded, be it positive, (+), negative, (-), or uncertain (~).

4.2.4. Data processing

Bushmeat data

The dataset was cleaned to remove outliers using plots of weight against price. Recorded weights were compared to the maximum reported adult weights in Silva & Downing (1995) and Huffman (2012). Allowing for regional variation in species body mass, and possible weighing errors in the market data, any entries with values over 50% greater than the maximum reported were considered individually and revised or removed accordingly. Where it was apparent that price data had been entered incorrectly (such as a misplacement of a decimal point) corrections were made, otherwise the entry was removed. The refined data set represents 60,310 records, collected over 3,331 days, 180 months and 27 years. 3,128 records, representing 4.9% of the original dataset, were deleted due to missing or incorrect data (either weight, price or both). Normalised values for price and quantity were generated to take account of variation in observer effort between months. Price was described in terms of the average price per kilogram in a given month and deflated with CPI using 2004 as a baseline. Quantity was described in terms of the average number of individuals recorded per "record day", where "record day", refers to the number of days the market was observed in the relevant month. Controlling for variation in sampling effort in this way has been shown to be appropriate for this particular dataset (Crookes *et al.* 2005).

4.2.5. Exogenous regressors

Eight exogenous regressors were defined in line with the conceptual model presented in figure 4.1 (summarised in table 4.1), and categorised according to whether they were supply shifters, demand shifters or market controls.

Supply shifters

Four variables are associated exclusively with supply side dynamics: agricultural income, agricultural labour, pest incidence and rainfall. The Ghana Meteorological Society supplied monthly rainfall data collected at weather stations in Kumasi. Agricultural income and labour were calculated with reference to production and harvest activity of the seven main cash and food crops grown in the Ashanti region: cocoa, maize, cassava, plantain, yam, cocoyam and rice (Ghana Statistical Service 2008). Agricultural income was calculated according to equation 4.8.

$$I_t = \sum_t^c A^c \emptyset_t^c P_t^c \qquad (4.8)$$

$$t = 1, \dots, T \text{ and } c = \text{ individual crops}$$

Where t represents a monthly interval, I_t is the total monthly income from all crops at time t; A^c is the annual production in kilograms of a crop c; $\emptyset_t^c$ is a production coefficient that represents the proportion of the total annual production of a crop c sold at time t and P_t^c is the deflated price per kilo of a crop

c at time t as recorded in Kumasi's Central Market. For the food crops, the Ghana Statistical Services supplied data on total annual crop production for the Ashanti region. The Statistics Research Information Directorate, a sub-division of the Ministry of Food and Agriculture, supplied monthly data on market prices, based on regular surveys of Kumasi's Central market. The production coefficient was derived from seasonal selling behaviour (the proportion of farmers selling agricultural produce in any given month) as reported in the Ghana Living Standards Survey (Ghana Statistical Service 2008). Production and price data for cocoa was supplied by COCOBOD, the state organisation in charge of the Ghana cocoa industry. Specific selling information was not available for cocoa. It was assumed that since cocoa is not stored locally it is sold shortly after harvest, and thus that selling and harvest are aligned. This assumption is in line with the findings of cocoa research in the region (Schulte-Herbrüggen 2011).

Agricultural labour commitments were calculated according to equation 4.9.

$$L_t = \sum_t^c H_t^c C^c \qquad (4.9)$$

$t = 1, \dots, T \ and \ c = \ individual \ crops$

Where L_t represents total labour commitments across all crops at time t; H_t^c is a seasonal variable representing the harvest of crop c at time t; and C^c is the total area of land under cultivation for crop c in any given year in the Ashanti region. C^c is included as a weighting factor to ascribe greater labour demands to those crops which are more widely grown. For the sake of simplicity it is assumed that the labour associated with the harvest of each crop is equal.

The relative incidence of crop pests (particularly grasscutters) is proxied by the maize season, H_t^{maize}, based on consistent reports that it is during the ripening of the maize crop that pest predation is of greatest concern to farmers (Shanti-Alexander *et al.* in press; Falconer 1992).

Demand shifters

Two variables were associated exclusively with demand side dynamics: the availability of alternatives to bushmeat, and consumer income. In the absence of long-term price data on livestock, fish price was used as a proxy for "substitute goods". Seasonal fluctuations in fish supply have been shown to be a significant predictor of bushmeat consumption and harvesting in Ghana (Brashares *et al.* 2004). Gross Domestic Product (GDP) per capita was selected as a proxy for "urban wealth" and sourced from the World Bank Data Bank (World Bank 2013). GDP per capita was only available on an annual scale, therefore intra-year fluctuations were simulated using a moving average model averaged over a period of one year.

Price per kilo of herring was selected as a proxy for fish price, based on the results of previous market and consumer surveys that highlighted it as both the cheapest and most commonly consumed protein on the Kumasi market (Chapter 2). Because herring prices in the model should be representative of fish supplies to domestic (versus international) markets, herring prices were taken from landing data at two ports close to Kumasi (in Central and Western Regions), harvested by artisanal fisheries that supplied local markets using all gear types. These data were provided by the Fisheries Commission, who also advised on the use of these landing data as the most appropriate for present purposes. Unfortunately, there were 9 months in the dataset (5% of the sample) for which herring prices were missing. In these cases, anchovy prices were used to estimate the herring prices. Monthly herring prices were closely correlated to anchovy prices (Pearson's correlation coefficient, R = 0.95), and the two-step Engle-Granger cointegration method was used for the process of extrapolation (equation 4.10).

$$F_t^s \sim F_t^a + \theta + \varepsilon_t \qquad (4.10)$$

$$t = 1, \ldots, T$$

Where F_t^s represented the logged price per kilo of sardines at time t, F_t^a the logged price per kilo of anchovy at time t, θ is a short run time trend that is the interaction between month and year and ε_t is the error. All prices were deflated using CPI to a 2004 baseline. The Engel-Granger method tests whether two time series, in this case F_t^s and F_t^a, are co-integrated, based on the fact that if they share a common stochastic drift, a linear combination must be stationary. Thus the two-step method involves regressing one variable upon the other, and testing the estimated residuals, $\hat{\varepsilon}_t$ for stationarity (i.e that their mean and variance remain statistically constant over time) using an Augmented Dickey Fuller Test for a unit root. The relationship described in equation 4.10 was shown to be stationary to the 95% confidence interval (lag = 8, DF = -3.51, p = 0.043), where DF is the Dickey Fuller test statistic and the null hypothesis is non-stationary. A lag of 8 was selected, since in the absence of the four closed season months (Aug – Nov), one "data year" covers 8 months. The predicted values of $\hat{F}_t^s$ were well correlated with the originals, F_t^s (Pearson's correlation coefficient, R = 0.97).

Market controls

Two market control variables were defined: the cost of living and population growth. The relative increase in the Consumer Price Index month on month was used as a proxy for changes in the cost of living (Mankiw 2000). The Ghana Statistical Service supplied annual population estimates for the Ashanti region, which were smoothed using a moving average model averaged over a period of one year.

Excluded variables

Two variable groups were excluded from the final analysis, both of which relate to the supply side of the market: wildlife abundance (resource condition) and hunter production costs. With regard to wildlife abundance, no suitable data were available. With regard to production costs, these can be broken down into two general categories: direct production costs (firearms, cartridges, batteries) and indirect costs (transporting produce to market). In the first case, as village blacksmiths produce most firearms locally, no long-term data were available on manufacturing costs. Nor were price data available for cartridges or batteries. However, this issue may not be as problematic as might be assumed on first consideration. In their study of hunting in the region, Hofmann *et al.* (1999), concluded that although firearms are expensive and likely to act as a barrier to those wishing to enter the trade (Crookes *et al.* 2007), once purchased the ongoing costs of participation (cartridges and batteries) are relatively low, particularly for commercial hunters where the price of bushmeat far outweighs the marginal equipment costs associated with these items. An additional consideration in this regard is the strong client-patron relationship in operation in the Awtemonom market, where traders assist hunters with short-term loans for equipment, which can be repaid in meat. Thus there are existing local finance schemes to help hunters with capital expenditure needed to hunt. Capital costs of production are therefore unlikely to represent a barrier for those already participating in the trade. They are likely, however, to act as a barrier to those who wish to enter. In reality, there are a number of lower-expenditure options available such as snare traps and dogs, which require minimum investment.

In the second case, transport costs are known to be one of the most important sources of expenditure for small-scale traders in developing countries (Badiane & Shively 1998) and the link between transport and bushmeat prices has been demonstrated previously (Cowlishaw *et al.* 2005a). There are two points worth raising in this regard. Firstly, hunters surveyed around Kumasi indicate that they are able to incorporate the costs of transport into the wholesale trade price at market. Thus, while transport is likely to be a significant determinant of price, it is unlikely to influence decisions on whether or not to participate in the trade. Secondly, a logical proxy for transport costs is the price of fuel. While data are available on global oil price, the link between global oil and regional fuel prices in Ghana is likely to be distorted due to the presence of historic fuel subsidies (Boafo-Arthur 1999). While the National Petroleum Authority of Ghana keeps records of pump prices, these records are only available on an irregular basis from 1989. Thus in the absence of reliable, long-term in-country data, fuel prices are not explicitly considered in the following analysis. Nevertheless, it should be noted that fuel prices are among the goods used to construct the monthly Consumer Price Index, which is incorporated in the model as a market control indicator of the costs of living. Model variables are summarised in table 4.1.

While the lack of data on capital costs (fuel and production), is unfortunate, it is unlikely to represent a critical exclusion in the model considering the broader context. Lack of data on wildlife populations is potentially a greater shortfall, particularly if the resource is limited. The inclusion of such data is not a strict requirement, however, and they have been excluded from similar supply and demand analyses in the fisheries sector (Angrist, Graddy & Imbens 2000)

4.2.6. Model validation

The supply and demand model described in equations (4.4) and (4.5) was parameterised according to the variables described in table 4.1. Logs were taken of bushmeat price, quantity and fish price. The endogenous relationship between quantity and price was tested with the Hausman Wu test to validate the requirement for an instrumental variable (IV) approach. The test uses an F-test to compare the distributions of two variants of the structural equations: one using the raw data for p_t and q_t, the other the estimates, $\hat{p}_t$ and $\hat{q}_t$, generated from solving the reduced form equations, (4.6) and (4.7). The null hypothesis, of no statistically significant difference between the models, was rejected (supply model: F = 0.003, p=<$2.2\text{x}10^{-16}$, demand model: F = $1\text{x}10^{-4}$, p = <$2.2\text{x}10^{-16}$), and thus endogeneity was assumed.

To validate the selected variables and test whether the IV methodology as presented in table 4.1 is likely to have adequate statistical power to identify the supply and demand functions, the reduced form relationships (equations (4.6) and (4.7)) were estimated, and F tests used to test deviations from the null model, for the model in its entirety, and the exogenous variable groupings (supply shifters, demand shifters and market controls). Results suggest that the instruments, $z_t = (x_t^c, x_t^s, x_t^d)$, are well correlated (Appendix C2) with both price and quantity, both jointly (p-value <0.001 for all models), and individually, except on two occasions where the market controls have poor explanatory power (the all-rodent and grasscutter models), suggesting that the drivers behind the rodent market (of which grasscutters make up 67%) may be somewhat independent of the macro-economic variables of population and inflation (CPI). Points of note are that on the supply side, periods with high levels of agricultural labour are associated with low trade volumes and high market price; while on the demand side, GDP per capita is positively associated with both price and trade volumes. Overall, the instruments appear strong (have good explanatory power) and credible (that their inclusion is justified in theory).

Table 4.1: Summary of model variables selected for inclusion in the monthly supply and demand model. Summary statistics are presented, along with the time trend and literature associated with the selection of each variable as a proxy for the market drivers (as identified in the conceptual model of the system). The trend is the coefficient on month when each variable is regressed on month and a constant and is included as a simple indication of the stationarity of the data over time. Figures in parentheses are standard errors. Significance codes, * 5%, ** 1% and *** 0.1%.

Category	Market driver	Model variable	Symbol	Units	Mean	S.D	Trend	Literature
Response	Bushmeat volume (all species)	Average number of animals per day	*P*	No/day	19.1	9.58	$4.4\text{x}10^{-3}$*** *($6.3\text{x}10^{-4}$)*	NA
Endogenous	Bushmeat price (all species)	Average price per kilogram	*N*	000' GHC /Kg	10.6	3.08	$-1.7\text{x}10^{-3}$*** *($3.1\text{x}10^{-4}$)*	(Wilkie & Carpenter 1999; Bowen-Jones & Pendry 1999)
Market controls	Cost of living	Relative change in CPI	*C*	None	0.03	0.04	$-1.2\text{x}10^{-4}$** *($4\text{x}10^{-5}$)*	(Falconer 1992; Brown & Williams 2003; Schulte-Herbrüggen 2011)
	Population	Ashanti region population	*A*	Millions (people)	2.74	0.69	0.01*** *(0.0001)*	(Brashares *et al.* 2001; Wittemyer *et al.* 2008)
Supply shifters	Agricultural income	Income proxy	*I*	GHC	261	121.1	1.53*** *(0.089)*	(Damania *et al.* 2005; Schulte-Herbrüggen 2011)
	Agricultural labour	Labour proxy	*L*	Km^2	293	78.6	0.71*** *(0.075)*	(Tutu *et al.* 1993; Hofmann *et al.* 1999; Brashares *et al.* 2011)
	Crop pest activity	Seasonal time trend (maize harvest)	*M*	None	0.38	0.23	$-7.1\text{x}10^{-5}$ *($2.6\text{x}10^{-4}$)*	(Tutu *et al.* 1993; Smith 2005; Shanti-Alexander, *in press*)
	Rainfall	Total monthly rainfall	*R*	Millimetres	102	89.2	0.07 *(0.102)*	(Falconer 1992; Juste *et al.* 1995; Barrett & Arcese 1998)
Demand shifters	Price of alternative	Fish price (herring, price per kilo)	*F*	000' GHC /Kg	2.93	1.20	0.24 *(1.41)*	(Brashares *et al.* 2004; Wilkie *et al.* 2005)
	Urban wealth	GDP per capita	*W*	$US / unit population	233.4	23.4	0.24*** *(0.021)*	(East *et al.* 2005; Fa *et al.* 2009; Brashares *et al.* 2011)

An augmented Dickey-Fuller test for a unit root, conducted over a lag period of 8, to align with one data year, verified that all models were stationary, for all species (supply DF = -3.76, p = 0.02, demand DF = -3.6, p = 0.04), for ungulates (supply DF = -3.3, p = 0.07, demand DF = -3.9, p = 0.02), for rodents (supply DF = -4.2, p <0.01, demand DF = 4.5, p <0.01), and for grasscutters (supply DF = -4.5, p <0.01, demand DF = -5.9, p <0.01), where DF is the Dickey Fuller test statistic and the null hypothesis is non-stationary.

Pearson's Correlation tests highlighted four potentially problematic correlations between the explanatory variables. Agricultural income and labour were positively correlated (r=0.62) and population was positively correlated with agricultural income (r=0.51), labour (r=0.56) and GDP per capita (r=0.54) (Appendix C3). Variance inflation factor tests suggested that the agricultural labour and income were likely to be most problematic (VIF labour = 3.1, income = 2.5, all other variables < 2.5). Exclusion of either income or labour from the model, however, led to a failure to identify the demand function according to economic theory ($\beta_p^d > 0$) and a marginal reduction in the explanatory power of the model as indicated by $\bar{R}^2$. Thus the original variable set was maintained. However, caution was adopted when interpreting the model relationships involving these explanatory variables.

Durbin Watson tests for serial autocorrelation indicated significant positive autocorrelation in the residuals for all models (appendix C4). Scrutiny of the auto- and partial correlation functions confirmed an autoregressive relationship, of the form AR(1) or AR(2) (Appendix C5). Although the parameter estimates should not be affected by the presence of autocorrelation, the standard errors, and hence model inference, may be biased. To take account of this effect, robust standard errors were calculated using a heteroskedasticity and autocorrelation consistent (HAC) covariance matrix, based on the "Arellano" methodology, to reduce the likelihood of a false positive (Arellano 1987; Andrews 1991; Zeileis 2004).

4.2.7. The bushfires of 1982

To test whether the catastrophic bushfires of late 1982 and early 1983 impacted the commercial bushmeat trade, a Chow Parameter Stability test was run to test for a structural break in the market data around this period. The assumption underlying this process was that the fire event would result in a sudden change in the data (the structural break) and that for a number of years after the fire, there would be prolonged impact as wildlife populations recovered, and that this break in the data would differentiate the behaviour of the model pre and post fire. Additional evidence to suggest a prolonged period of disruption post 1982 fire lies in the fact that there was a series of less major fire events in late 1983 and 1984 (Arthur & Arthur 2011). Changes in the behaviour of the model were contrasted by running a regression for the whole sample, and two sub-samples, selected according to where the break is believed to occur. The resulting model distributions are tested for evidence that the coefficients in the two subsamples differ from those of the full sample. The model used as the foundation for the test was a linear OLS regression of average monthly trade volumes against the matrix of covariates described in table 4.1 (equation 4.11). The full sample covered the period 1979 to 1985, while the two subsamples covered a period of 3.5 years each from 1979 – 1982 (mid) and 1982 (mid) to 1985. The full sample focused specifically on the period either side of the fire events so as to maximise the likelihood that any significant differences in the mode were due to the fire, and not other environmental or economic events that may be present over the period from 1978 to 2004. The decision on where to place the break was made based on literature describing the fires, reporting that they commenced in mid-1982 at the start of the dry season (Ampadu-Agyei 1988; Arthur & Arthur 2011).

General equation: $$v_t = \beta'_x x'_t + \varepsilon_t \tag{4.11}$$

Test statistic: $$\frac{RSS^f - (RSS^{S1} + RSS^{S2})}{(RSS^{S1} + RSS^{S2})} \cdot \frac{T-2k}{k}$$

Where v_t represents the normalised monthly trade volumes, x'_t represents the matrix of covariates (see table 4.1), ε_t are the model residuals, RSS^f is the residual sum of squares for the full sample, RSS^{S1} is the residual sum of squares for the first subsample (1979 – 1982), RSS^{S2} is the residual sum of squares for the second sub-sample (1982 – 1985), T is the number of observations in the full sample and k is the number of regressors. The test statistic is compared against the F distribution. Differences between sub-groups were analysed by fitting the supply and demand relationships to the two subgroups, and solved according to the 3SLS methodology described previously.

4.3. Results

4.3.1. The supply and demand model

The supply and demand functions that emerge from the three-stage least-square regression appear to be well identified in all models, with $\beta_p^s \geq 0$ and $\beta_p^d \leq 0$ (table 4.2). Supply appears to be elastic in all models except ungulates, with the supply of rodents, and particularly the grasscutter, being most elastic to changes in price. This result aligns well with the hypothesis that depletion may be altering the composition of the trade away from ungulates to one dominated by rodents. It also highlights inter-taxon differences in the price elasticity of supply that may be indicative of a decline in ungulate numbers as suggested by the historical analysis of the Atwemonom market (Chapter 3). Conversely, demand in all models is elastic with the exception of rodents and the grasscutter.

Generally, the influence of the regressors on supply and demand is in line with the hypothesised relationships (figure 4.1). With regard to drivers of supply, agricultural labour is negatively associated with supply across all models. A word of caution should be expressed here due to the potentially confounded relationship between agricultural income and labour. Since these variables cannot be separated statistically, flows of income may equally be negatively correlated with hunting behaviour. However, the positive relationship between income and labour suggests that these flows are likely to materialize in tandem, and thus the evidence for the influence of the agricultural cycle on hunting behaviour appears robust, regardless of the precise mechanism involved. The model results also indicate a significant relationship between the maize season (a proxy for pest control) and both grasscutter and rodent off-take, but not all bushmeat off-take.

On the demand side, GDP per capita is strongly associated with increased demand for all bushmeat products. Interestingly, and counter to expectation, there was no relationship between fish price and bushmeat supplies.

Table 4.2: Results of three-stage least square regression. The time interval of the regression is one month. The response variable for all models is quantity, described as the ln of the mean number of animals recorded on the market per day in any given month. Four models are presented, (1) all species traded, (2) ungulates, (3) rodents and (4) grasscutter. Standard errors are given in parentheses. Significance codes * 5%, **1% and ***0.1%.

	All Species	**Ungulates**	**Rodents**	**Grasscutter**
		Supply Model		
Intercept	-12.2*** *(2.64)*	-4.34 *(3.04)*	-31.0*** *(4.26)*	-34.9*** *(4.34)*
ln(P)	1.49*** *(0.28)*	0.63 *(0.32)*	3.27*** *(0.44)*	3.62*** *(0.45)*
I (ag.income)	-7.05 $\times10^{-4}$ *(6.05* $\times10^{-4}$*)*	-6.50$\times10^{-4}$ *(5.58* $\times10^{-4}$*)*	-9.65 $\times10^{-4}$ *(6.95* $\times10^{-4}$*)*	-8.13 $\times10^{-4}$ *(7.32* $\times10^{-4}$*)*
L (ag.labour)	-2.42 $\times10^{-6}$** *(8.41* $\times10^{-7}$*)*	-2.08 $\times10^{-6}$** *(7.92* $\times10^{-7}$*)*	-3.03 $\times10^{-6}$** *(1.11* $\times10^{-6}$*)*	-3.75 $\times10^{-6}$** *(1.19* $\times10^{-6}$*)*
M (pest activity)	-0.052 *(0.21)*	-0.087 *(0.19)*	0.55* *(0.27)*	0.57* *(0.28)*
R (rainfall)	-3.05E-05 *(5.42E-04)*	-3.17E-05 *(4.98E-04)*	-6.77E-04 *(6.15E-04)*	-8.41E-04 *(6.61E-04)*
C (cost of living)	1.24 (1.19)	3.11** (1.15)	-2.28 (1.61)	-3.14 (1.60)
A (population)	8.03E-07*** *(1.22E-07)*	6.10E-07*** *(1.26E-07)*	8.57E-07*** *(1.49E-07)*	9.48E-07*** *(1.50E-07)*
		Demand Model		
Intercept	7.73* *(3.82)*	16.5** *(5.45)*	-2.58 *(5.69)*	-4.36 *(5.65)*
ln(P)	-1.07* *(0.52)*	-2.02** *(0.72)*	-0.18 *(0.72)*	-0.0546 *(0.71)*
W (wealth)	0.023*** *(0.0049)*	0.018*** *(0.0054)*	0.027*** *(0.0061)*	0.029*** *(0.0063)*
F (fish)	0.037 *(0.093)*	0.149 *(0.12)*	0.025 *(0.10)*	-0.018 *(0.11)*
C (cost of living)	1.36 *(0.88)*	4.43*** *(1.12)*	-3.05** *(1.18)*	-3.65** *(1.22)*
A (population)	-2.47E-07 *(1.73E-07)*	-4.12E-07* *(2.32E-07)*	-9.62E-08 *(1.58E-07)*	-6.91E-08 *(1.63E-07)*

Of the market controls, population growth is positively correlated with supply, but largely unimportant for demand, except in the case of the ungulate model where a significant negative correlation was reported. The cost of living, proxied by the relative change in CPI from month to month, plays a somewhat mixed role. Although it is unrelated to supply or demand in the general model, it does have taxon-specific effects. Specifically, a positive correlation with both supply and demand in ungulates, the latter being contrary to expectations, and a negative correlation with demand in rodents, in line with expectations. This rather complex relationship will be revisited in the discussion.

4.3.2. The bushfires of the 1980s

Results of the Chow Parameter Stability test confirmed a break in the market data in 1982, the first year when dramatic bushfires swept through much of the country (F = 2.43, d.f. = 25, p = 0.035), illustrated in Figure 4.2.

A Wilcoxon signed rank test of the monthly average trade volumes in the 3.5 years prior and post the bushfires highlighted a decline from an average of 20.6 (s.d=8.3) animals per day to 8.6 (2.4), (W = 573, n = 28, p <0.01). Models of the supply and demand relationships over this period were poorly identified, however, and failed to identify a positive price coefficient on the supply side, $\beta_p^s < 0$, during the 3.5 year period from mid-1982 to mid-1985 (Appendix C6).

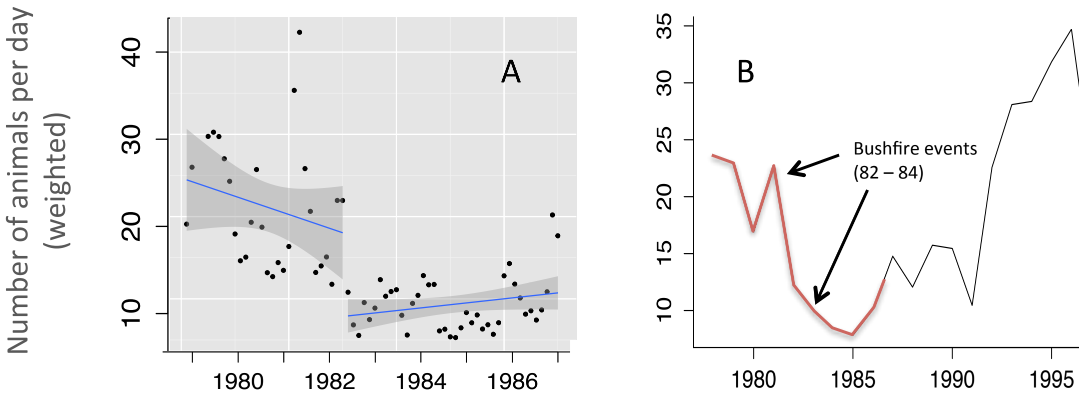

Figure 4.2: Graphical analysis of the market data during the period before and after the 1982 – 1984 bushfires. Plot A presents a monthly analysis of the 3.5 year period immediately prior to the fires and the 3.5 year period immediately following. Two linear regressions are plotted, with 95% error bars, to highlight the break. Linear regressions represent trade volumes regressed against time. Plot B highlights how the tested data sample in A appears in a larger sample of the data. Data in B are summarised annually, resulting in the differences in the scales of the y-axis on each graph.

A longer regression sample from 1982 – 1989 was better identified, and significant (p<0.05), although the significance of the individual model variables remained extremely poor. Although this latter regression suggested that bushmeat supply was less elastic in the period after the fire than before (pre-82, β_p^s = 1.87; post-82 $\beta_p^s = 1.04$) the generally poor explanatory power of the model suggests that extreme caution should be adopted when making any inferences.

4.4. Discussion

4.4.1. The model and the market

The specified supply and demand model appears robust on a number of counts. In addition to the supply and demand functions being correctly identified according to economic theory ($\beta_p^s \geq 0$ and $\beta_p^d \leq 0$), the testing of the selected instruments showed that both the supply, demand and market shifters were significant predictors of price and volume (Appendix C2). These findings suggest that the assumptions of perfect competition and linearity may not be far from reality, at least when long-term market behaviour is examined over the full period from 1978 to 2004. However, the model is not without its flaws. Data limitations restrict what can be included, particularly in regard to bushmeat alternatives (no livestock data were available), hunter production costs, and an explicit component that is able to capture the condition of the resource (i.e. wildlife abundance). Incorporating a descriptor of resource condition is not a strict requirement. Similar analyses of fisheries markets have omitted such data (Angrist, *et al.* 2000). However, these studies have often focused on resources that are considered relatively abundant. Where there are resource limitations in place, such as may be suspected in the case of bushmeat, resource condition has been found to be a significant predictor of supply (Lin 2005). In addition, our model poses inherently difficult challenges in the ability statistically to separate key variables, namely agricultural income and labour. Despite these caveats, the model appears relatively well specified and statistically robust, and highlights a number of consistent features.

4.4.2. General observations

The estimated supply and demand functions align well with commonly accepted drivers of supply and demand in the region, namely that agricultural activities and population pressure play an important role in defining supply (Tutu *et al.* 1993; Brashares *et al.* 2011; Chapter 3), while demand is most strongly influenced by consumer wealth (Bowen-Jones & Pendry 1999; Fa *et al.* 2009; Godoy *et al.* 2010). More novel trends appear when individual taxonomic groups are analysed. There are good reasons for considering different taxa in isolation. In addition to representing different resource pools, failure to differentiate taxa in any market analysis assumes that both supplier and consumer see the market in a similar way. However, this is unlikely to be true. Although hunting in the tropics is frequently non-selective (Hofmann *et al.* 1999), there are exceptions. Grasscutters, which are targeted by hunters during specific agricultural cycles are one such example (Shanti-Alexander *et al.* in press). Conversely, bushmeat consumption is highly selective, both in terms of preferences and price (Falconer 1992; Fa *et al.* 2002). Therefore, while production is generally non-selective, consumption is more discerning where bushmeat may be viewed as a range of products, differentiated by price and taste (East *et al.* 2005). Both of these factors are likely to play an important role in defining the more subtle dynamics of the trade.

In regard to this first point, that species represent separate resource pools, our results show clear differences in elasticities of supply, with grasscutters, the most commonly traded species, being most elastic. The price elasticity of supply of ungulates, whose market share is in decline, is relatively inelastic (Chapter 3). There are two possible reasons for this discrepancy. Either hunters are choosing not to trade ungulates, despite the price signals being generated by the market, or they are unable to source them in sufficient numbers. As ungulates often command higher per carcass prices than rodents due to their size (Falconer 1992; Macdonald *et al.* 2011), the former suggestion appears unlikely. Thus, it seems most likely that the variation in supply elasticities between groups is an indication of variation in the condition of the underlying resource. The analysis also supports the hypothesis that grasscutter and rodent supply is closely correlated with the maize harvest, when the protection of crops is a priority for farmers (Tutu *et al.* 1993; Hofmann *et al.* 1999).

Demand for grasscutters and all rodents was relatively inelastic, unlike demand for ungulates and bushmeat generally. One explanation may be that it reflects the strong consumer preferences for these species, particularly the grasscutter (Falconer 1992; Chapter 2). The phenomena whereby highly desired goods exhibit inelastic price elasticities of demand is a recognised phenomena in other markets (Stigler & Becker 1977). Strong demand, combined with limited supplies is arguably the mechanism that led to the wholesale price for a single grasscutter carcass more than doubling in the 12 months between June 2011 and June 2012 (Chapter 3).

There are also trends highlighted in the results that may be analysed with reference to the selective nature of consumer demand. CPI is negatively correlated with demand for rodents in line with predictions (that, as an expensive good, demand for bushmeat would decline as the cost of living rose). However, it positively correlated with demand for ungulate species. As these may represent a marginally less expensive form of bushmeat (Chapter 2), it may be possible that consumers switch species, selecting cheaper alternatives during periods when the cost of living is high. This assumption aligns with the assertion that bushmeat represents a "multi-commodity" to the consumer, but further research is needed to examine whether such a hypothesis is plausible.

The lack of a correlation between fish price and trade volumes was surprising. Evidence in the literature suggest that hunting in other parts of Ghana increases during times when fish supplies are low (and hence prices are high Brashares *et al.* 2004). Reasons may lie in differing consumer tastes in the Kumasi market, or a flaw on the part of the data to proxy accurately for monthly fish prices. It should be noted that fish represents only one alternative commodity. The inclusion of other alternatives, such as livestock, would be a valuable addition to analyses, and may represent a more accurate proxy the influence of alternative goods on bushmeat demand (Rentsch & Damon 2013).

4.4.3. The 1982 – 84 bushfires

There was good evidence of an abrupt structural break in the market data during the period of the 1982-84 bushfires. This supports the hypothesis that the fires that swept the country during this period had real and quantifiable effects on the commercial bushmeat trade, reducing the trade volume by more than 50% in the period that followed. The failure of the supply and demand model to describe the data satisfactorily during this period prevents more detailed analysis, other than to suggest tentatively that there was a reduction in the elasticity of supply following the fires, a characteristic that might be indicative of a resource under pressure. There are a number of explanations as to why the model might have failed to describe accurately market activity during this period. Firstly, the number of data points in the pre- and post-fire periods are on the border of what is statistically acceptable when one considers the number of variables in the model (Crawley 2007). Secondly, it is not unreasonable to assume that the assumptions of linearity and perfect competition may not be valid, either over the relatively short time scales under observation, or due to the potentially dramatic impact that the fires may have had on the market. In the first case, analysing the market at a finer resolution (daily as opposed to monthly) may increase statistical power, although this poses problems with obtaining comparable daily data for the other variables in the model. In the second case, implementing methods that allowed the assumption of linearity and competition to be relaxed may benefit the model.

4.4.4. Concluding remarks

This analysis represents a novel analysis of a bushmeat hunting system, which, despite the potentially simplistic assumptions of market behaviour, produces results largely in line with expectations. The study highlights the importance of considering taxon-specific effects when considering the drivers of supply and demand, and presents the first quantified evidence of the impact of extreme natural events such as bushfires on the commercial bushmeat trade. The model framework presented here indicates a number of interesting opportunities for future development, such as relaxing the assumptions of perfect competition and linearity. These may improve the ability of the model to separate the often closely intertwined drivers of supply and demand. New developments in the field of spatial econometrics (Baltagi 2008) could be combined with land-use change analysis to add a further layer of understanding of the complex dynamics that define these informal markets.

Chapter 5

The Rise of the Rodent:

Spatial dynamics of a bushmeat hunting system

5. Rise of the rodent: Spatial dynamics of a bushmeat hunting system

5.1. Introduction

Production landscapes are dynamic in both time and space. Population growth, urbanisation, changing patterns of land use and intensification of agriculture influence landscape productivity and associated ecosystem services. Understanding these dynamics is important for designing effective conservation and land management strategies that take account of the trade-offs between different ecosystem services that may be degraded or enhanced by different approaches (Anderson *et al.* 2009; Armsworth *et al.* 2012). Bushmeat is an important benefit provided by ecosystems in the tropics. However habitat loss and overhunting have modified landscapes and degraded biodiversity leading to dramatic declines in wildlife in many regions. This degradation is particularly evident in many parts of West Africa (Brashares *et al*. 2001; Norris *et al.* 2010).

In the following analysis, we explore how the spatio-temporal dynamics of a production landscape in Ghana have influenced the commercial bushmeat trade in the region over a 16 year period. We identify four landscape level patterns that are likely to influence the dynamic of the trade in time and space and be important for the management of bushmeat hunting systems. These are 1) habitat disturbance, 2) protected areas, 3) hunting pressure and 4) distance to market.

Habitat disturbance is likely to play a fundamental role in the spatial characteristics of the trade. There is evidence that disturbed landscapes such as secondary forests can, under certain circumstances, be more productive than undisturbed climax vegetation, particularly in tropical rainforests where the opening up of the canopy and improved browsing conditions can be beneficial to certain species (Robinson & Bennett 2004). Forest mosaics interspersed with food crops and mixed agricultural landscapes, can harbour a high concentration of edible foods, of particular benefit to more robust generalist species such as small ungulates, and species off-take in these semi-disturbed landscapes can surpass those of less disturbed, primary forest (Uhl *et al.* 1990; Jorgenson 2000). Robinson & Bennett (2004) provide a thorough examination of the literature in this regard and present a hypothetical framework for how supply (characterised by biotic productivity) and demand (defined in terms of off-take) may vary across a disturbance gradient.

Protected areas may also influence spatial patterns of exploitation and species-specific harvest patterns. Fa et al. (2006) found an inverse relationship between bushmeat harvests per capita and distance from protected areas in 89 urban and rural bushmeat markets in Nigeria and Cameroon. There were good indications that harvest rates of many species were greater closer to the national park boundaries, with certain species, such as primates and large ungulates, being particularly susceptible. While hunting off-reserve may represent a perfectly legal trade in many countries, the incentive for hunters in depleted landscapes to exploit relatively untapped reserves remains a real threat to wildlife conservation objectives, particularly in countries with poor governance and enforcement (Smith *et al.* 2003).

Densely populated areas are likely to experience greater levels of hunting pressure (Robinson & Bennett 2004). Unsustainable hunting reduces stocks and leads to falls in catch (Robinson *et al.* 1999; Albrechtsen *et al.* 2007). Areas exposed to sustained levels of high hunting pressure are therefore likely to experience significant declines in catch and commercial trade volumes over time.

The distance a community is from market also plays an important role in defining the spatial characteristics of the trade. Brashares *et al.* (2011) found consistent evidence that bushmeat was more expensive in settlements further from the source of capture. The effect of this price gradient was an increased incentive for hunters close to more lucrative urban markets to trade their catch, rather than consume it at home. In their study of a commercial bushmeat market in Equatorial Guinea, Allebone-Webb *et al.* (2011) found evidence of trade filters that influenced what species were brought to market depending on the isolation of the sources. Trade from isolated communities maximised trader profits, i.e. the most valuable species per kilo were sourced from such locations. Conversely, trade from communities with more direct market access maximised hunter profits, i.e. species with the greatest carcass price were more likely to be traded. If trade filters such as those observed in Equatorial Guinea were present in the Kumasi catchment area, it would be reasonable to assume there would be spatial differences in trade volumes of certain species, based on their weight – value relationship.

As urban centres expand, local resources are depleted and previously isolated communities are connected, the size of a market's catchment area, indicated by the distance meat travels to market, may grow. The change in a market's catchment area is one metric often used to describe the evolution of the trade, as hunters exploit ever more remote resources, or new actors enter the trade (Clayton *et al.* 1997; Milner-Gulland & Clayton 2002; Crookes *et al* 2005). In a detailed analysis of a commercial bushmeat market on Bioko Island, Albrechtsen *et al.* (2007) found good evidence that such increases were associated with faunal depletion, as prices, volumes, distance travelled and market composition all showed marked difference between two time periods that were broadly in line with expectations under depletion.

All four of these patterns (habitat disturbance, protected areas, hunting pressure, and distance to market) may not only affect the volume of bushmeat traded, but also the species composition of the trade, as specialist and larger, less fecund species that are more sensitive to environmental and anthropogenic pressures are extirpated (Naughton-Treves *et al.* 2003), to be replaced by smaller, more resilient, generalist species such as rodents (Fa *et al.* 2000; 2007). Such changes are evident in many commercial markets which are increasingly dominated by species of rodents and small ungulates better able to persist in human influenced landscapes (Falconer 1992; Hofmann *et al.* 1999; Crookes *et al.* 2005). Over time, locations that are susceptible to levels of human encroachment are therefore likely to experience significant shifts in species composition, relative to less heavily hunted locations (Green and Sussman 1990; Robinson *et al.* 1999; Fitzgibbon *et al.* 2000; Jorgenson, 2000; Robinson & Bennett 2004).

Thus complex processes, linking the biophysical attributes of the landscape with the socio-spatial characteristics of the human populations exploiting it, define the spatial dynamics of these hunting systems. A logical conclusion is that if the landscape defines the trade, appropriate land management has the potential to represent a powerful tool for managing it. Any management strategies that seek to alter land use to promote key benefits, however, will necessarily involve trade-offs between conflicting objectives (Armsworth *et al.* 2012). If appropriate land management decisions are to be made in the context of bushmeat hunting, it is essential that the consequences of changing patterns of land-use on wildlife, and on human use of wildlife, be understood.

Using the bushmeat trade in the city of Kumasi, Ghana, as a case study, we analyse the spatio-temporal dynamics of the commercial bushmeat trade in the region in relation to shifting patterns of land-use over a 26-year period. The landscape around Kumasi has been subject to intense conversion over the past decade, and is primarily defined by agriculture, with much of the remaining intact tropical forest confined to forest reserves and protected areas (Braimoh 2009). In addition, a long running study of the Atwemonom bushmeat market in Kumasi between 1978 and 2004 means long term spatially explicit data is available on the bushmeat trade. We test hypotheses in four key areas (table 5.1):

1. Habitat disturbance. Harvest rates may be higher in landscapes categorised by intermediate levels of disturbance. In addition, generalist species, better able to persist in more heavily disturbed landscapes, may dominate the trade from these areas.
2. Protected areas. We test whether there is any relationship between trade volumes and the presence of reserves, and whether species-specific differences exist.

3. Hunting pressure. We examine how trade volumes originating from heavily hunted areas change over time, and measure changes in species composition through changes in the ratio of rodents to ungulates.
4. Distance to market. We examine how distance from market influences the species composition of the trade, and the volume of the trade.

Table 5.1: Spatio-temporal characteristics of the landscape-bushmeat system and their associated hypotheses and predictions

Spatial characteristic	Summary description	Hypotheses and predictions	References
Habitat disturbance	Harvest rates and biological production are expected to vary with changes in human-induced disturbance in the landscape. We examine whether communities whose surrounding landscapes are categorised by intermediate levels of disturbance supply more bushmeat to the commercial market than either more or less disturbed landscapes.	1. **Bushmeat off-take will be greatest in semi-disturbed landscapes**. 1a. Bushmeat volumes will be quadratically related to level of disturbance. 1b. Trade volumes of generalist species, such as rodents, will be less sensitive to higher levels of disturbance than other species groups.	Robinson & Bennett (2004)
Protected areas	Protected areas (PAs) may act as refuges for wildlife, particularly those species that are more susceptible to disturbance. Research suggests that harvest rates of certain species, such as primates and ungulates, may be higher in communities close to PAs. Protected areas may be associated both with illegal hunting within the reserve, and spillover effects whereby hunting in neighbouring areas benefits from wildlife emigrating outside the reserves.	2. **Bushmeat off-take of certain species will be higher in communities close to PAs.** 2a. PA presence will be positively correlated to ungulate trade volumes, and uncorrelated with rodent trade volumes.	Fa *et al.* (2006)
Hunting pressure	High levels of hunting pressure may reduce standing wildlife biomass and alter species composition towards smaller bodied mammals.	3. **Heavily hunted areas will experience reduced harvest rates and altered species composition**. 3a. Trade volumes from areas with a high density of hunting communities will decline over time. 3b. The ratio of rodents to ungulates, supplied from heavily hunted areas, will increase over time.	Rowcliffe *et al.* (2003);Lopes & Ferrari (2000); Naughton-Treves *et al*. (2003); Jorgenson (2000)
Distance to market	Distance to market represents a potential barrier to participating in the commercial trade, representing a substantial cost. This may influence both the species that are brought to market and the degree to which otherwise productive landscapes participate in the trade. Over time, as resources become depleted and urban demand grows, we would expect the incentives to exploit more distant resources to increase.	4. **Over time the catchment area of the commercial market will increase.** 4a. Distance to market will be negatively correlated to trade volumes, although this effect will change reduce over time. 4b. Catchment area of the market will increase over time.	Crookes *et al.* (2005); Allebone-webb *et al.* (2011); Albrechtsen *et al.* (2007; Brashares *et al.* (2011)

5.2. Methods

5.2.1. General methodology

Bushmeat market data, collected at Atwemonom in Kumasi between 1978 and 2004 by staff from the Ghanaian Wildlife Division, were used to identify the communities (sources) supplying bushmeat to the market. Data were available on multiple individual transactions on a given day, including the species, weight, price, method of capture and location from which the traded item was sourced (see Chapter 2). For the purpose of the following discussion, a "source" is defined as a community, located within the Kumasi catchment area, that supplies bushmeat to the Atwemonom market. GIS methods were used to generate maps describing the spatial characteristics of the landscapes around each source. Data was obtained from a variety of resources (described below). The relationship between a source's spatial characteristics and associated trade volumes were then analysed using a mixture of univariate and multivariate statistical methods (figure 5.1).

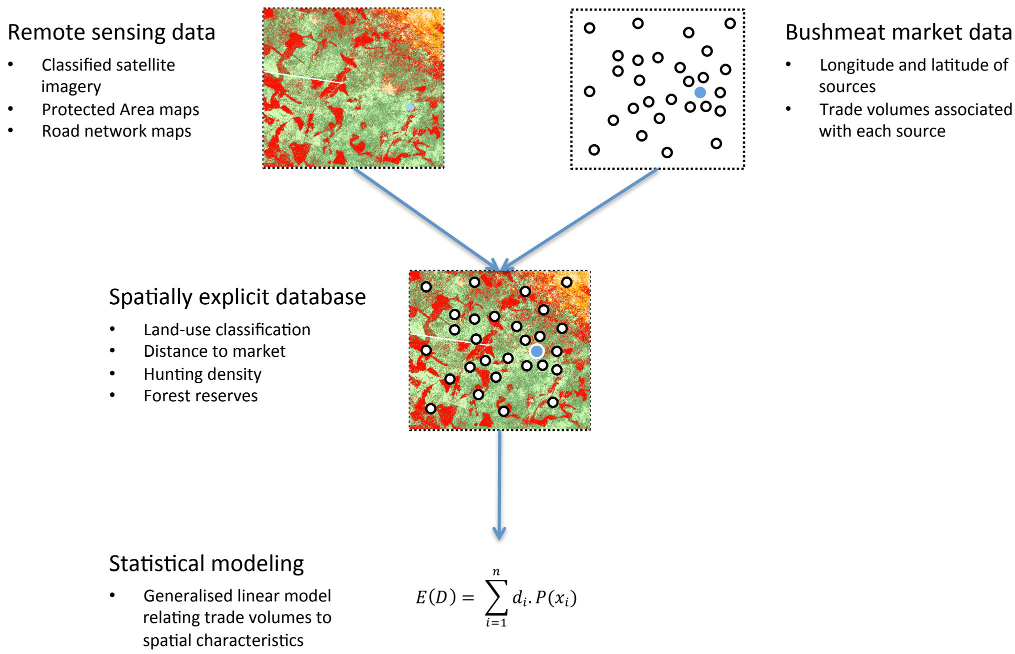

Figure 5.1: Schematic diagram of the methodology adopted underlying the statistical analysis

5.2.2. Bushmeat trade volumes

The full market dataset consisted of 67,271 records covering 3,343 days recorded over 27 years from 1978 to 2004. All data relate to the open season, which runs for 8 months from December to July, during which hunting is permitted for all species, except those classified in schedule 1 (Wildlife Conservation Regulations 1971). Each record in the dataset relates to a single carcass, for which information on species, source location, weight and price were recorded, where possible. Of these records 46,769 have sources (village names) associated with them. Sources were geographically located in a two-part process. First, the dataset was reviewed for errors in consultation with the Ghana Wildlife Division (GWD) staff member who was responsible for the original collection. With reference to a regional map, purchased from the Land Division Office in Kumasi, the geographic locations of the major sources were coarsely identified and, where necessary, ambiguous spellings and typos corrected to refine the data. Secondly, fine-grain geographic coordinates were assigned using a database of village locations in the region, compiled by the Land Survey Department and purchased from the Centre for Remote Sensing and Geographic Information Services (CeRGIS). These data were reviewed in ArcGIS, projected in UTM WGS 1984, and the boundary of the Kumasi market catchment area, representative of the entire dataset, was defined.

Ideally, the four hypotheses under test would explore the patterns of covariation between the bushmeat trade and the relevant landscape-level predictors across all years from 1978 – 2004. However, land cover and therefore habitat disturbance (hypothesis 1) could only be quantified for two years, when sufficiently high-quality satellite images were available. Meanwhile, protected area coverage (hypothesis 2) and distances to market (hypothesis 4) were expected to stay relatively constant across years. Consequently, our analysis focused on the bushmeat trade in those two years when land cover could be quantified, namely 1986 and 2002 (see below). The only exception to this approach was for the analysis of changes in catchment area (prediction 4b) and species composition, in which the full dataset could be used. Consequently, two spatially explicit databases were produced from the market data. First, a database containing all market records relevant to the 1986 and 2002 time periods; second, a general database containing records from all years, to be used in defining the long-term evolution of the catchment area over time. In both databases, records were summarised in terms of their locations, and aggregated bushmeat volumes defined by the number of carcasses at the species level.

Two hunting seasons were included for both 1986 and 2002 to align with the dates when available satellite images were taken, and to maximise data for analysis. For 1986, records cover the period from December 1985 to July 1986 and December 1986 to July 1987; similarly for 2002, records run from December 2001 to July 2002 and December 2002 to July 2003 (table 5.2). Variation in observer effort between hunting seasons was controlled for by expressing bushmeat volumes in units of carcasses per day. This method of normalising the data treats all days as equal in terms of daily observer effort, which at the seasonal scale is considered a reasonable assumption.

Table 5.2: Summary statistics of bushmeat records successfully georeferenced.

	Land-use Analysis Model		**Catchment Analysis**
Data	**1986**	**2002**	**All years**
Period covered	Dec 85 – Jul 86 & Dec 86 – Jul 87	Dec 01 – Jul 02 & Dec 02 – Jul 03	Open Season, 1978 – 2004
Total Records	4647	2875	46,769
Geo-referenced	4437	2771	43,550
Percentage of records identified	95.5%	96.4%	93.1%
Unique Sources / Locations	203	167	389
Mean volume per source, kg per day *(C.V)*	23.4 (C.V=157)	17.3 (C.V= 161)	11.7 (C.V=189)
Median volume per source, kg per day	8	5	5

5.2.3. Measuring hunting pressure

In order to calculate a spatially explicit measure of hunting pressure in the catchment (hypothesis 3), the scaled and summarised bushmeat source data were imported into ArcGIS 10 and projected in UTM WGS 1984 to produce a layer for analysis. A 7km-radius buffer zone was produced around each source to represent the effective hunting radius. 7km was chosen based on the lower boundary derived from previous surveys of 53 hunters in two communities around Kumasi where the average distance travelled to hunting grounds was 7.7 ±4.8 km (Shanti-Alexander 2011). Sources with less than 3 individual records were excluded to avoid anomalous data that might skew the model. The cut-off value was low due to the data being heavily skewed towards smaller records (table 5.2), and therefore was selected as a compromise to avoid losing excessive data, while controlling for anomalies. These data were further refined by merging sources within 2km of each other to produce more distinct sub-groups for analysis. This was done to minimise discrepancies in the data in which two or more neighbouring sources sharing more than 90% of the same catchment area (defined by the 7km buffer) might be associated with substantially different bushmeat volumes. The differences in volumes between villages in these cases was more likely to be associated with the livelihood characteristics of the communities or trader habits than differences in the landscape. Merging data for communities sharing almost identical landscapes therefore minimised data bias.

Hunting pressure was defined in terms of the overlap between the hunting zones of neighbouring sources in ArcGIS. Thus, an isolated village with no neighbours, and whose 7km hunting radius overlapped with no other source, would have a base level 1. A village with many neighbours, and whose hunting buffer intersected with many neighbours, could end up with a value many multiples of this. This approach was adopted as a measure of relative hunting intensity around a particular source. Competition for resources around hunting communities with many neighbours (who were also identified in the market data as hunting), may be expected to be greater than in areas with few hunting communities, and consequently such areas may be more depleted.

5.2.4. Measuring habitat disturbance

The assessment of spatiotemporal patterns of habitat disturbance across the catchment required the use of land cover information derived from satellite images. Based on a review of remote sensing data for the catchment area, cloud-free images were only available for two years during the study period, namely 1986 and 2002.

Semi-processed, georeferenced Landsat satellite images were obtained online for this period from the USGS Global Visualisation Viewer (Glovis). Landsat imagery is recognised as an effective basis for analysing patterns of land-use and land change (Tucker & Townshend 2000). The Kumasi catchment area, as defined by the bushmeat market data, covered an area of 39,204km^2 (198km x 198km), intersected 4 Landsat scenes, designated by path 194, row 055, path 194, row 056, path 195, row 055 and path 195, row 056. The scenes of 1986 were all captured in December 1986. One scene in 2002 was captured in January 2002, two in December 2002 and one in February 2003. The difference in dates for the 2002 image composite was necessary to find high-quality, cloud-free images. These images represented the most closely related combination in terms of season, dates and scanner for the study site in our time frame. Data for the 1986 period was from the Landsat Multispectral Scanner (MSS), and for 2002, the Landsat Thematic Mapper scanner. Once identified, these images were subject to a process of preparation, pre-classification, and classification, before a habitat disturbance index could be calculated. These four steps are described below.

Image preparation

Individual scenes were imported into IDRISI, and cropped according to the boundary conditions defined by the bushmeat market data. For 1986, three bands were selected to produce false colour composite images, band 1 (green) band 2 (blue) and band 4 (near infra-red), in line with convention for the analysis of vegetation using Landsat MSS images (De Fries *et al.* 1998). For 2002, Bands 2 (green), band 3 (red) and band 4 (near infra-red) were selected (Yiran, Kusimi & Kufogbe 2012). A single false colour composite image of the study area was produced for each time period and analysed by eye for consistency. Due to either differences in dates when scenes were taken, or haze, a single classification procedure (based on the merging of individual scenes into a single mosaic prior to image clustering and cluster labelling), was deemed inappropriate due to spectral differences between scenes. An unsupervised classification, whereby land classes are separated through the use of an automated algorithm that analyses the spectral bands, highlighted the inconsistency between scenes. Thus scenes were cropped into sub-scenes, which were classified separately prior to composing the final image, based in part on the methodology implemented in Guindon & Edmonds (2002). For classification purposes, 1986 was divided into three sub-scenes, and 2002 into four sub-scenes.

Pre-classification of land cover

Prior to classification, the spectral bands produced by the MSS scanner for the 1986 time period were assessed for signs of noise. Older detectors such as MSS can be prone to sensor and noise error that occur in the form of striping or banding. Such errors represent systematic noise in the image resulting from variation in the response of individual detectors for each band. Not all bands are therefore necessarily subject to such noise. Bands 1 and 2 exhibited such banding in all scenes. Band 4 was free from sensor error.

A Principal Component Analysis (PCA) was performed within IDRISI to reduce this error. The analysis produces three components, one for each of the bands analysed, their associated eigenvalues and the eigenvector matrix. The last few components usually represent less than 1% of the total information available and tend to hold information relevant to striping and sensor error. The output of the analysis showed that in all scenes the first component accounted for the vast majority of the variation (scene 1, 98.2%, scene 2, 97.3%, scene 3, 97.8%). Comparison of image quality with the inclusion of the second component showed a noticeable increase in noise. Thus, of the three computed components, only the first was selected for the reproduction of bands 1 and 2.

Classification of land cover

Supervised classification techniques were adopted based on their suitability for quantitative analysis of remotely sensed images (Lillesand, *et al.* 2004). Prior to classification, a ground-truthing exercise was conducted in one part of the study site. GPS markers were recorded for different land-use classes and photographs taken of the surrounding vegetation for later review purposes. 21 markers were recorded in this manner: 4 in closed canopy forest, 6 in areas of secondary forest and tree crops, 3 within settlements and areas of bare earth, 8 within farmland (both fallow and productive). This ground-truthing exercise was augmented by additional assessment methods including the use of the Google Earth application and consultation with experts familiar with the study site at the Department of Geography, University of Ghana (Kusimi 2008).

Eight classes were initially defined: Closed canopy forest, open canopy forest and tree crops, settlements and bare earth, fallow farmland, productive and recently harvested farmland, savannah and water. Cloud, which was present in a small section of one scene in 2002 (representing < 6.4% of the image area), was classified as "No Data". The signatures produced were analysed visually using the IDRISI graphical functions SIGCOMP and SCATTER. The distinction between farm classes was shown to be poor, and thus farmland was grouped into a single classification for the final analysis. The inability to distinguish farm classes reliably is not surprising when one considers the scale of many farm plots in Ghana, and the resolution of the scanners. The smallholding nature of farming means few plots extend for more than a few hectares, and are frequently multi-cropped and interspersed with secondary forest and scrub. The pixel resolution available is only 60m x 60m for MSS (30m x 30m for TM) and thus accurately describing variation in such diverse vegetation at such a small scale is likely to be problematic.

The separability of the remaining six digitised classes was quantified using the Transformed Divergence Measures of signature separability and Jeffries-Matusita Distance. These measures quantify the degree of overlap between signatures in a pairwise fashion, measured on a scale from 0 to 2 (0 – 2000 for the Transformed Divergence Measures), with 2 (or 2000) being complete separation. Values greater than 1.9 (or 1900) indicate good separability, and between 1 and 1.9 (or 1000 and 1900) moderate separability. Signature separability was satisfactory for all classified classes, falling between 1.8 and 1.98 (table 5.3).

Table 5.3: Summary of mean separability statistics associated with classified scenes for each.

Classified Classes	**Signature Analysis**						
	1986			**2002**			
	Scene1	Scene2	Scene3	Scene1	Scene2	Scene3	Scene4
1. Transformed Divergence	1959	1923	1963	1873	1902	1943	1899
2. Jeffries-Matusita	1.91	1.89	1.93	1.86	1.88	1.91	1.88

Scenes were classified according the six land classes described by the signatures, using a maximum likelihood modelling routine, where the distribution of reflectance values described by the user-defined signature is described by a probability density function, developed on the basis of Bayesian statistics. This classifier method evaluates the probability that a given pixel will belong to a particular category, and classifies the pixel to the category with the highest probability of membership. Following classification, individual scenes were composited into a single unified image. Due to differences in image resolution of the MSS and TM scanners, the 1986 image was resampled to a 30m x 30m pixel resolution in line with the native resolution of the TM scanner associated with the 2002 image. The total Root Mean Square (RMS) error describing the probability that the control points used in the resampling process vary from their true position was within acceptable limits, (RMS = 0.001, limit of acceptability = 0.5). Classified images are presented in figure 5.2.

5.2.5. Calculation of a habitat disturbance index

The Disturbance Index for each source was defined in terms of a normalised discrete probability density function based on the proportion of different land classes in each hunting buffer (see eq.1 below). Because the hypothesised

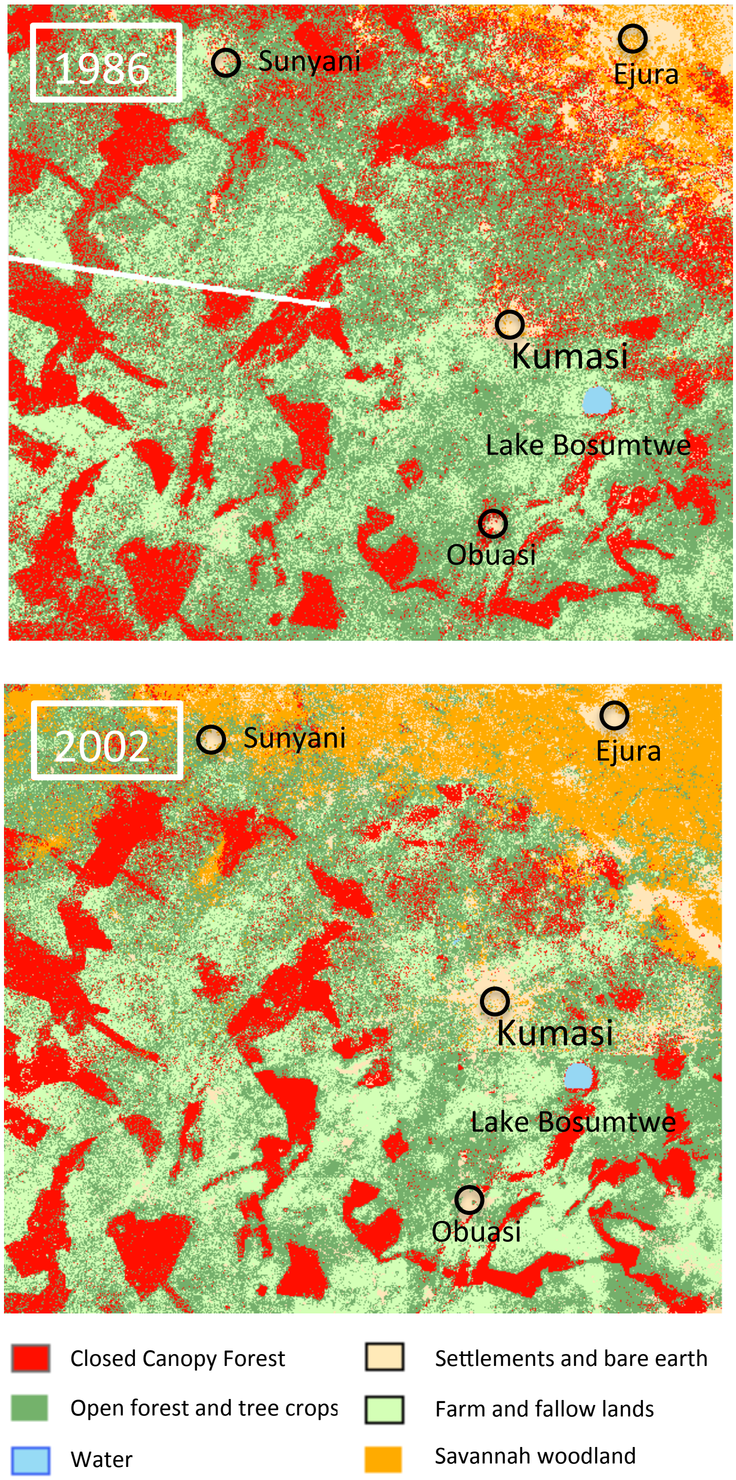

Figure 5.2: Classified images of the catchment area associated with the Atwemonom bushmeat market, Kumasi, in 1986 and 2002.

quadratic relationship between bushmeat production and habitat disturbance only applies in tropical forests (Robinson & Bennett 2004), the disturbance index was not calculated for the handful of sources supplying Kumasi from the savannah zone. In order to assign sources to tropical forest or savannah, the ecological zones in the catchment were identified using a digital image supplied by the GIS unit of the Resource Management Support Centre of the Forestry Commission (RMSC, 2003), imported into ArcGIS and geo-referenced according to the UTM WGS 1984 geographic projection system. Two sources were subsequently assigned to the savannah zone and therefore excluded. Our land cover classification highlighted significant growth in the coverage of derived savannah woodland between 1986 and 2002, which, although present throughout the catchment area, was particularly prominent in the NE of the catchment area (figure 5.2). Although communities within the formal savannah zone were excluded, derived savannah woodland reflected forest degradation or agricultural activity in the tropical forest zone and was therefore included in the analysis. Each land class was ranked in order of disturbance from 1- 4, with 1 (Closed canopy forest, relatively undisturbed), 2 (open canopy forest and tree crops together with derived savannah woodland, low-to-moderate disturbance), 3 (farm and fallow lands, moderate-to-high disturbance) and 4 (settlements and bare earth, highly disturbed). The mean disturbance index for each source was calculated according to:

$$E(D) = [\sum_{i=1}^{n} d_i . P(x_i)]/n \qquad \text{where: } \sum_{i=1}^{n} P(x_i) = 1 \text{ and, n = 4} \qquad (1)$$

Where $E(D)$is the mean disturbance index of a communities hunting buffer, d_i is the discrete disturbance index of land class *i*, $P(x_i)$ is the proportion of land class *i* in the hunting buffer and n is a normalising constant equal to the number of discrete indexes (4 in this instance).

5.2.6. Measuring protected area coverage and distances to market

In order to calculate measures of protected area coverage (hypothesis 2) and distances to market (hypothesis 4), two additional map layers were produced describing protected areas and local road networks. The designation of protected areas was completed in ArcGIS. Classified images were imported from IDRISI and a geographically referenced, digital map of the protected areas and forest reserves in the region, produced by the Ghanaian Land Survey Department, was used to define the boundaries of the protected areas in the study site. These were then cropped, re-classified, and re-integrated with the original images to produce an additional map layer that described the spatial attributes of the protected areas. A map of the local road network was obtained from CerGIS, Univerity of Ghana. Distance to market parameters were extracted using a Network Analysis approach to measure the shortest path along the local network between source and market. Information on quality of road was not available, and was likely to vary across the time period under study, therefore all roads were treated equally, and no penalties were applied for using certain routes. Access to protected areas was described in terms of the proportion of land within a given source community's hunting buffer that was protected.

5.2.7. Statistical analysis

In order to test the predictions arising from the four hypotheses (table 5.1), a general linear model was carried out using the daily bushmeat volume or species composition (indexed as the rodent: ungulate ratio) from a given source as the response variable and our measures of habitat disturbance (hypothesis 1), protected area coverage (hypothesis 2), hunting pressure (hypothesis 3), and distance to market (hypothesis 4) associated with that source as our predictor variables. Since these analyses derived data from two different years, 1986 and 2002, year was also included as a predictor, and a series of interactions between year and the other predictor variables were also explored. All variables are summarised in table 5.4).

Prior to the analyses, potential colinearity between the predictor variables was explored in a correlation matrix (Appendix D). A strong correlation (0.79) was present in one relationship, between distance to market and hunting density. However, despite concerns of colinearity, both variables were retained due to the specific hypotheses associated with each being of interest. Interpretation of the results is made with awareness of the potentially confounding issue of colinearity between these variables.

Table 5.4: Summary of model variables extracted from the data, V is the response variable and d, r, h, l, y, the independent variables

Symbol	Data	Source
V	Bushmeat volume. Estimated for: all species; rodents; ungulates; rodent:ungulate ratio	Measured in units of kg per day. This variable describes the number of carcasses originating from a given source.
d	Habitat disturbance index	A continuous variable from 0 to 1 that describes the level of disturbance in the hunting zone associated with each source.
r	Protected area coverage	The proportion of land designated as protected in the hunting zone of each source.
h	Hunting pressure	The proportion of the total area intersected by neighbouring communities' hunting zones.
l	Distance to market	The shortest distance between source and market, measured as distance along the local road network. (km)
y	Year	A categorical variable representing year associated with the data.

The general formula for the model to describe bushmeat supply at location j, excluding interaction terms, took the form:

$$\text{Log}\, V_j \sim d_j + d_j^2 + r_j + h_j + l_j + y_j + const \qquad j = 1, \ldots, J \qquad (5.1)$$

Where, based on the hypothetical relationships between bushmeat productivity, off-take, and habitat disturbance (d_j) (Robinson & Bennett 2004), bushmeat supply is described in terms of a quadratic relationship.

Interactions were selectively included based on our hypotheses (table 5.1) and knowledge of the system. One-way interactions were included between protected area and year, distance, and hunting pressure (hypothesis 2); hunting pressure and year (hypothesis 3) and distance and year (hypothesis 4). Models were tested and simplified through removal of non-significant independent variables and minimum adequate models selected by way of a stepwise model selection. Four response variables were tested using the relationship described in equation 5.1. These were the trade volumes in *(1)* all species, *(2)* rodent species, *(3)* ungulate species and *(4)* the rodent:ungulate ratio.

Finally, as a further test of hypothesis 4 (prediction 4b), changes in the spatial characteristics of the catchment area were considered for the full range of the data, from 1978 to 2004. Univariate statistics were used to examine how the mean distance of bushmeat sources, the mean distance travelled per carcass, and the changes in the rodent:ungulate ratio changed over the time period of the market survey.

5.3. Results

5.3.1. Land cover change

Changes in land cover between 1986 and 2002 indicated increased levels of human activity and disturbance; the area of closed canopy forest and open canopy forest declined by 7% and 6% respectively. Most dramatically, the area of closed canopy forest outside of reserves declined by 47%. Conversely there was an increase in land attributed to settlements and bare earth (3%) and savannah (7%). There was a marginal increase in the area of farm and fallow lands (1%; Fig. 5.3). In 2002, 71% of closed canopy forest was contained in 98 small forest reserves, with an average area of 76km^2. Of these protected areas only 6.8% (1.5% of the total catchment area) is not managed for timber production. The rural landscape of the catchment area around Kumasi is therefore strongly defined by human disturbance, with only a fraction of the landscape protected from commercial extractive activities.

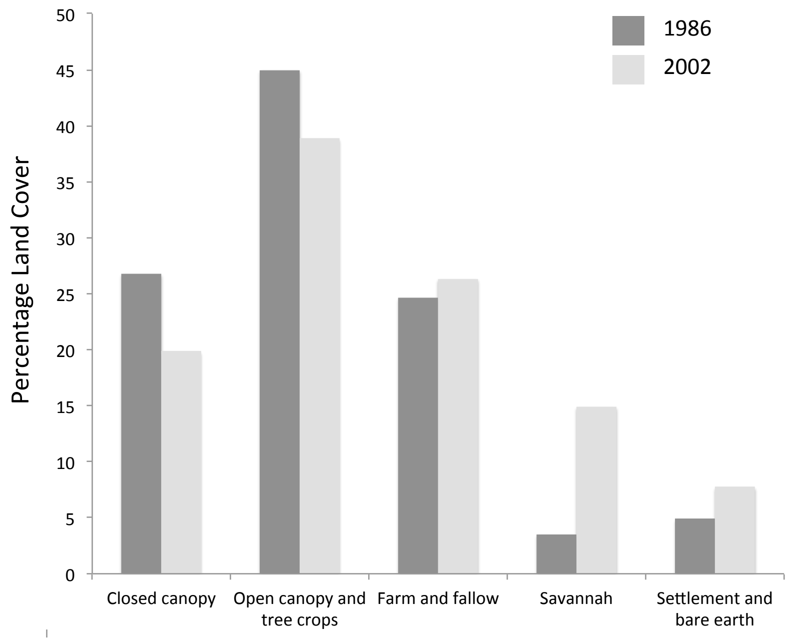

Figure 5.3: Percentage of land area defined by the 5 classified land types (excluding water bodies) in 1986 and 2002.

5.3.2. Land-use change model

Disturbance hypothesis (H1)

Total trade volumes and ungulate trade volumes were correlated with semi-disturbed landscapes, with a negative coefficient estimated for the quadratic disturbance term, and a positive coefficient for the linear disturbance term, in support of Prediction P1a (table 5.5). There was no significant relationship between land disturbance and rodent trade volumes, evidence that rodent off-take is less sensitive to high levels of disturbance than ungulate off-take, in support of Prediction P1b.

Table 5.5: Generalised liner model results showing general trends in land-use and mixed model results investigating trends in species composition over time. The dependent variable in all cases is bushmeat trade volume, kilos per day (columns represent all trade, ungulate trade, rodent trade and rodent / ungulate ratio). Standard errors values are given in parentheses; *, ** and *** represent significance at the 5%, 1% and 0.1% levels respectively.

Explanatory Variable	All Species	Ungulates	Rodents	R : U ratio
Intercept	-182*** *(-4.49)*	-120** *(-3.15)*	-267*** *(-5.89)*	-102*** *(-7.30)*
disturbance (H1)	*29.7*** (3.31)	25.0** *(3.11)*		
$disturbance^2$ (H1)	-26.1*** *(-3.38)*	-22.2** *(3.21)*		
reserve (H2)				
hunting pressure (*H*3)	53.6*** *(4.70)*	42.1*** *(3.88)*	58.7*** *(4.75)*	
distance (H4)	-7.8x10^{-3}* *(-2.03)*	-7.86x10^{-3}* *(-2.17)*		3.09x10^{-3}* *(1.67)*
year (2002)	0.08*** *(4.29)*	0.06** *(2.98)*	0.13*** *(5.91)*	0.05*** *(7.26)*
year (2002): *pressure*	-0.03*** *(-4.69)*	-0.02*** *(-3.87)*	-0.03*** *(-4.74)*	

Protected area hypothesis (H2)

No relationship between the presence of reserves and trade volumes was identified for any species group, contrary to Prediction P2a.

Hunting pressure hypothesis (H3)

Trade volumes were positively correlated with high levels of hunting pressure. In addition, over time, trade volumes of all species declined from areas exposed to heavy hunting pressure, in support of Prediction P3a. However, there was no evidence of a change in species composition in heavily hunted areas, contrary to Prediction P3b.

Distance hypothesis (H4)

Total trade volumes and ungulate volumes were negatively correlated with distance, in support of Prediction P4a. In contrast, rodent trade volumes were positively correlated with distance. There was some evidence therefore that the trade in ungulates was biased towards communities close to Kumasi, whereas rodents appeared to be harvested throughout the catchment area. The ratio of rodents to ungulates increased with distance, suggesting that trade from more remote communities was biased towards rodents.

Market catchment

Analysis of the full market data set provides strong evidence for changes to the size of the underlying catchment area. The size of the catchment area associated with the bushmeat trade in Kumasi intermittently but steadily increased from 1978 to 2004 (figure 5.4). Between 1979 (selected due to the small sample size in 1978) and 2004, there was a significant increase in both the mean distance from source to market in a given year (t=2.26,d.f =314, p=0.025) and the mean distance travelled per carcass in a given year (t=4.23,d.f=314,p=0.001). The most distant community recorded as trading with Kumasi is 190km from the city, however the majority of trade, 82%, is supplied from within 60km of the city.

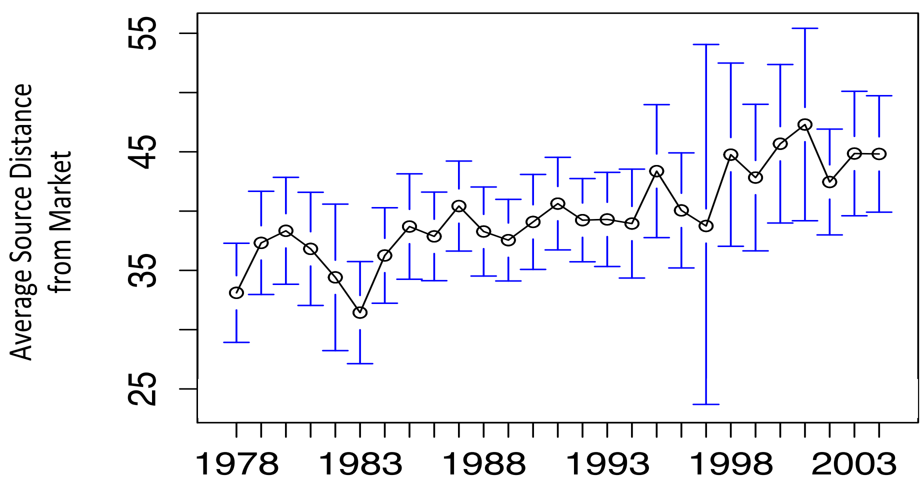

Figure 5.4: Average distance from market of communities supplying bushmeat to Kumasi.

5.3.3. General observations – species composition and time effects

Trade volumes of all species groups, as well as the rodent:ungulate ratio increased over time (table 5.5). Analysis of the full dataset shows a strong increase in the ratio in the latter parts of the market survey time period (figure 5.5). The increase in the rodent:ungulate ratio between 1979 and 2004 was signicant ($t = -2.53$, $p = 0.01$). A personal survey of the market in 2011 suggested further increases in the ratio of rodents traded on the market.

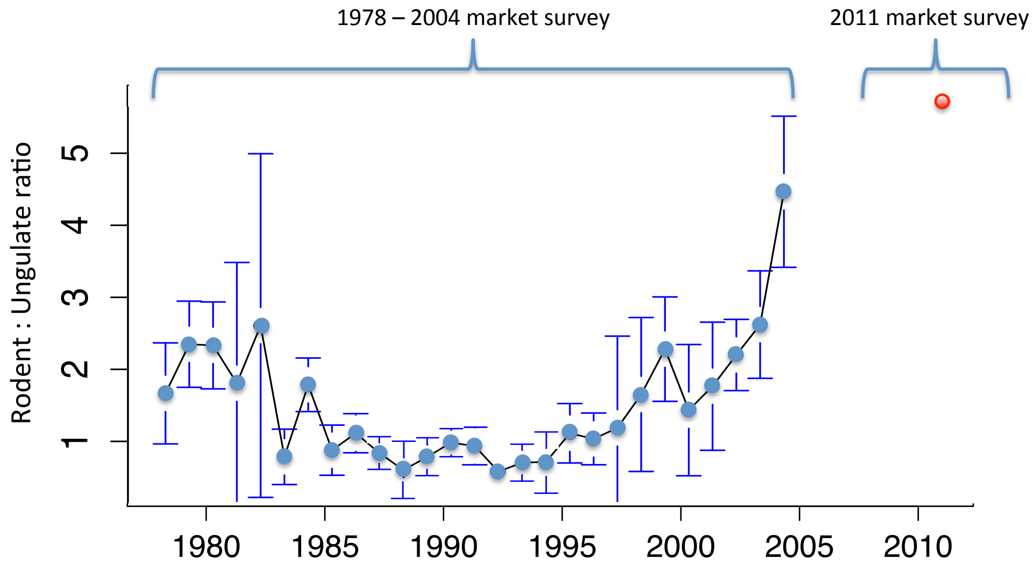

Figure 5.5: Variation in the ratio of rodents to ungulates over time. Data are drawn from both the 1978 – 2004 Atwemonom market survey, and one additional independent survey of the market, conducted by the authors in 2011.

5.4. Discussion

Using a series of hypotheses and tests, this study explored four landscape-level factors that might influence the magnitude and sustainability of the bushmeat trade, namely habitat disturbance, protected area coverage, hunting pressure, and distance to market. Our findings supported effects of these factors in three out of four cases (Table 5.6). In the first case, our results highlight the important role disturbed landscapes play in supporting the commercial bushmeat trade around Kumasi, with lower trade volumes originating from undisturbed and heavily disturbed sites compared to semi-disturbed sites. The lower trade volumes in undisturbed areas might reflect a tendency for communities that are closer to more pristine environments to experience poorer access to markets, which acts as a filter limiting trade from these locations. By controlling for distance in our model, in principle the relationship with disturbance should not be confounded with remoteness. Direct observations of hunting off-take in different landscapes have reported similar patterns (Wilkie 1989; Demmer & Overman 2001), and thus there is good reason to conclude that some disturbance is genuinely related to higher bushmeat harvests. The mechanism behind this phenomenon is likely to be a combination of habitat characteristics and hunting pressure favouring faster growing, more robust species better able to persist in and benefit from disturbed landscapes (Auzel & Wilkie 2000; Peres & Lake 2003).

In the second case, the lack of evidence linking protected areas with commercial trade volumes sits contrary to expectations. Although such findings may be viewed as positive, suggesting that protected areas are not being commercially exploited, there are other plausible explanations. Hunters from these regions may be trading with other local markets or, alternatively, the protected areas, the majority of which are managed for timber extraction as opposed to wildlife conservation (Ghanaian Forestry Commission 2010), may already be depleted,

Table 5.6: summarises key findings in relation to the over-arching research questions and hypotheses.

Spatial Attribute	Predictions	Key findings (supported)
Habitat disturbance	1a. Bushmeat volumes will be quadratically related to level of disturbance. 1b. Trade volumes of generalist species, such as rodents, will be less sensitive to higher levels of disturbance than other species groups.	1a. Semi-disturbed landscapes were the most productive. (YES) 1b. Rodents' off-take appeared independent of disturbance unlike the trade in ungulates. (YES)
Protected areas	2a. PA presence will be positively correlated to ungulate trade volumes, and uncorrelated with rodent trade volumes. 2b. No evidence that the reserves supported the trade.	2a. No evidence that the reserves supported the trade. (NO)
Hunting pressure	3a. Trade volumes from areas with a high density of hunting communities will decline over time. 3b. The ratio of rodents to ungulates, supplied from heavily hunted areas, will increase over time.	3a. Trade volumes declined in heavily hunted areas. (YES) 3b. No evidence that trade composition changed in heavily hunted areas, but the rodent-ungulate ratio increased over the full period of the data. (NO)
Distance to market	4a. Distance to market will be negatively correlated to trade volumes, although this effect will change reduce over time. 4b. Catchment area of the market will increase over time.	4a. Trade volumes declined for the trade generally and ungulates, but not rodents trade volumes, which were independent of distance effects. (YES) 4b. Catchment area of the market steadily increased between 1978 and 2004. (YES)

either through over hunting or habitat disruption due to timber extraction (Johns 1997; Auzel & Wilkie 2000; Fimbel, *et al.* 2001). The impact of land conversion, coupled with high levels of hunting has had a dramatic impact on wildlife across Ghana (Struhsaker & Oates 1995; Barnes 2002; Brashares 2003; Schulte-Herbrüggen *et al.* 2013). Indeed, local hunters surveyed during this work reported numerous species that used to be present and are no longer found (Chapter 3).

In the third case trade volumes for all species groups were correlated with hunting pressure, however there was no change in the species composition originating from these areas. The fact that species composition is unaltered, suggests that what is being harvested may be capable of sustaining relatively high levels of exploitation. Much of the market trade in Kumasi is dominated by small, rapidly reproducing mammals (Falconer 1992; Chapter 3). Ecological studies of duiker species, for example, have concluded that such species are able to exist in highly disturbed landscapes (Newing 2001). The lack of change in composition implies that much of the trade originating from these heavily hunted areas is likely composed of such individuals. The apparent ability of altered wildlife assemblages to sustain relatively high levels of exploitation has been reported previously. Cowlishaw *et al.* (2005), in their study of a bushmeat market in Takoradi, Ghana, found no evidence to support the hypothesis that the trade was unsustainable. However despite these indications of stability, there was a significant, if slight, decline in trade volumes over time from heavily hunted areas, despite trade volumes increasing overall. This suggests that despite a potentially robust species profile, heavy hunting is impacting production in these areas.

In the fourth case, our results show no evidence for a decline in the total number of carcasses entering the market; indeed there is a significant increase across all species groups. However, analyses of the spatial dynamics of the market highlight more subtle changes. Declines in trade from heavily hunted areas, the increase in catchment area, as well as a significant, if slight, change in species composition between 1986 and 2002, point to processes at work not immediately evident from an assessment of trade biomass. The direction of change of these metrics raises questions about the sustainability of the trade in its current form (Wilkie & Carpenter 1999; Milner-Gulland E.J. & Clayton L. 2002; Albrechtsen *et al.* 2007).

Differences in ungulate and rodent trade volumes with distance (namely that ungulates are sourced close to Kumasi, whereas rodents are sourced throughout the catchment area) are in line with expectations based on the "filtering" effect reported by Allebone-webb *et al.* (2011). Ungulates, which generally demand a higher "per carcass" wholesale price, were more sensitive to distance effects than the more valuable "per kilo" rodent species (Chapter 2). It seems unlikely that the reason for these differences would be that ungulate populations are depleted at the outer edges of the catchment area. The opposite would be far more logical. From an economic perspective however, it is more profitable to fill a car with grasscutters than bushbuck. For a middleman, dealing in bulk and travelling long distances, rodents represent the more valuable trade. However, middlemen are not known to be common participants in the trade around Kumasi. Alternatively, local bus drivers in Ghana charge high prices for hunters to transport bushmeat to market. The bushbuck is particularly expensive to transport due to its size and value, so rodents, which may be more easily contained in luggage or bags, may be more easily transported without incurring charges. Although the majority of hunters reported being reimbursed for transport costs by traders at Atwemonom, if a hunter has no relationship with a trader, the high costs of transporting large animals may have the potential to act as a filter when travel distances are large. Despite these caveats, it would be reasonable to suggest that a degree of depletion may be driving the observed spatial characteristics of the market, based on the combination of observed distance and hunting pressure effects.

It should be highlighted that these results can only be interpreted in the context of the commercial trade. While the growth in the catchment area suggests more hunters are participating in the market from further afield, be it in response to higher bushmeat prices or wildlife depletion (Brashares, *et al.* 2001; Crookes *et al.* 2005; Chapter 3), it cannot be interpreted as meaning that there has been an increase in absolute levels of hunting in these communities. Rather, it may reflect a shift in the proportion of the catch that is locally consumed or sold on the urban market.

But what are the implications of these findings for management? Two areas of debate that may be usefully informed by these results are how to maximise landscape productivity (i.e., how best to manage landscapes in order to reconcile the often competing objectives of conservation and development) and how to identify the optimal trade-offs in land use (i.e., what is lost or gained when making such decisions). In terms of landscape productivity, the recent focus has been on whether biodiversity is best conserved through either a 'land sparing' approach, in which agriculture is intensified on small plots of land to maximise production and allow the preservation of large areas of relatively pristine habitat (Balmford *et al.* 2005; Green *et al.* 2005), or a 'land sharing' approach, where lower-yield wildlife friendly farming practices are adopted to maximise biodiversity across the landscape (Tscharntke *et al.* 2005; Perfecto *et al.* 2005; Manning *et al.* 2006). Our results highlight the benefits of a land sharing approach, in terms of high bushmeat yields originating from the low-intensity farming practised around Kumasi (as indicated by the quadratic relationship between harvest and habitat disturbance). When one considers that the annual bushmeat trade in Ghana has been estimated to be worth as much as $350 million (Ntiamoa-Baidu 1998), the potential benefits of the trade to livelihoods should not be underestimated. Yet to date, no formal land management policies exist that explicitly consider the value of bushmeat, despite calls to the contrary (Asibey & Child 1990).

The benefits of promoting and enhancing the value of existing patterns of land-use, rather than radical manipulation, are clear given the inevitable difficulty of achieving the latter. Patterns of land use are the product of local socio-economic and bio-geographical conditions which cannot easily be changed (Fischer *et al.* 2008). In countries such as Ghana, where more than 60% of rural inhabitants rely on agriculture for their livelihoods, intensifying agricultural production systems without radical socio-economic reform is likely to be realistic only in the long term. In the interim, adopting approaches such as those advocated by Vandermeer & Perfecto (2007) are likely to represent the most viable way forward. These authors suggest that in landscapes where much of the native habitat has already been converted, ignoring the potential benefits of conservation in production landscapes is to miss an opportunity to promote a generally richer bio-diverse landscape with the associated benefits of resilience and ecosystem services.

With production landscapes such as those present in Ghana increasingly likely to be the face of many tropical landscapes in developing countries (McNeely & Scherr 2003; Balmford, Green & Scharlemann 2005; Norris *et al.* 2010), and agriculture forecast to remain the backbone of the Ghanaian economy as it moves towards Middle Income status (Benhin & Barbier 2004) there is an urgent need to develop conservation policies that work with existing institutions and patterns of land use to promote the dual benefits of development and conservation. If bushmeat production is to be successfully incorporated into land-use policies, more information is needed to understand its value in the agricultural matrix. If realised effectively, however, such policies should lead to the promotion of beneficial ecosystem services and the enhancement of both ecological and livelihood resilience.

Chapter 6

Exploitation, Inflation and deforestation – What the future holds for bushmeat hunting in the Ashanti region.

6. Exploitation, Inflation and deforestation – What the future holds for bushmeat hunting in the Ashanti region.

6.1. Introduction

The economies and landscapes of many developing countries are changing rapidly. These changes offer new opportunities, but also bring consequences, particularly for biodiversity. Agriculture, for example, is expanding faster in the developing world than elsewhere (Balmford *et al.* 2005), yet the conversion of natural habitats associated with agricultural expansion represents one of the greatest threats to biodiversity in many parts of world (Green *et al.* 2005). Globalisation and associated improvements in access to markets and technology are also changing the way in which people use their natural resources (Kramer *et al.* 2009). As previously remote communities are connected to urban markets, agricultural production costs tend to be driven down, while the value of locally produced goods is driven up (Jacoby 2000). Such changes may manifest in a number of ways, including agricultural intensification and the associated loss of native forests and biodiversity (Geist & Lambin 2002). Increased levels of hunting pressure may also occur, either in response to increased urban demand or easier access to remote locations (Bowen-Jones & Pendry 1999; Auzel & Wilkie 2000; Peres & Lake 2003; Poulsen *et al.* 2009; Brashares *et al.* 2011). In addition to the increasingly intense socio-economic drivers of biodiversity loss, awareness of the potential impacts of climatic variability on ecosystems and livelihoods is also increasing (Fischlin *et al.* 2007). For example, some studies have suggested that the range and viability of maize in West Africa, one of the region's primary food and cash crops, may be severely impacted under predicted future climate scenarios (Conway 2009). The failure of such an important crop would have significant impacts on local economies. The knock-on effects of such failure would largely depend on how local communities responded and adapted;

yet to date efforts to explicitly incorporate human behaviour into climate adaptation assessments have been limited (Watson *et al.* 2012).

Clearly, economic development and climate change have the potential to dramatically impact biodiversity, both separately and in concert (Rands *et al.* 2010). The challenge to predict and manage such impacts is particularly pressing in the humid tropics where poverty, community remoteness, high levels of biodiversity and aggressive forecasts for economic development and climate susceptibility make these biologically valuable yet economically impoverished regions particularly susceptible to change (CBD 2003; Fisher & Christopher 2007; Breisinger *et al.* 2009; Kramer *et al.* 2009; IMF 2013). In addition, the poorer regions of the world are likely to be affected by the loss of biodiversity (Adams *et al.* 2004; Díaz *et al.* 2006). Such impacts may be mediated by the behavioural responses of the individuals affected by the change. That is, the decisions taken at the household level in response to change define the implications of the change at the landscape level (Black *et al.* 2010). Understanding decision making at the level of the individual is therefore key if managers are to understand how global change will impact biodiversity on a local and regional scale, and what the consequences of such impacts will be for both people and nature (Liu *et al.* 2007; Nicholson *et al.* 2009).

Approaches that attempt to model and predict human behaviour in the context of natural resource use have frequently based themselves on utility theory, assuming that actors in the system will respond rationally to economic costs and benefits, choosing to adapt their effort according to the most profitable options (Bjørndal & Conrad 1987; Bulte & Horan 2003; Damania *et al.* 2003; Damania *et al.* 2005). Such approaches have a strong foundation in the economics and natural resource literature, yet these approaches do not take account of non-monetary considerations and the heterogeneity that characterises decision-making among resource users (Cooke *et al.* 2009). More recently, approaches based on scenario analysis techniques have been adopted to ask groups of resource users and other stakeholders how they would behave under certain policy scenarios, in an attempt to capture a broader picture of the variety of behaviours that the group comprises (Cinner *et al.* 2009; Black *et al.* 2010). Such approaches are not without compromise. For example, respondents may over or under-estimate their response due to personal agendas or a failure to appreciate the true ramifications of the question. There is therefore arguably a risk of bias in the results. However, they do represent a novel and valuable method of gaining a more nuanced perspective on the underlying motivations in decision-making. Free from the requirement of historic data, or the assumption that past observations will be valid in the future, such analyses nevertheless allow a specific set of developments or turning points to be targeted in a precise manner, and allow contrasts to be made between different sets of scenarios, while leaving the nature of the response open to the respondent. The findings can inform where management intervention should be targeted, and allows important features of the system to be identified, such as tipping points (at what point will a little change become too much), resistance (to what degree are people unable or unwilling to adapt despite intense pressure to the contrary), and feedbacks (both those that align with logical behavioural responses, and those that are unexpected). For example, Cinner *et al.* (2009) targeted fishers in coastal communities in Kenya to examine their willingness to exit a declining fishery. They found that poorer members of the community and those with less income security were less likely to exit a severely declining fishery. This highlighted the need for management to focus on addressing poverty to empower resource users and reduce pressure on natural resources.

A key example of where the interface between people and their natural resources is particularly strong, and where management is urgently required, is the bushmeat trade (Milner-Gulland *et al.* 2003). The behaviour of hunters, and the livelihood decisions they make, have the potential to directly and rapidly impact local wildlife populations (Brashares *et al.* 2001; McGraw & Oates 2002; Fa & Brown 2009). It is also an industry that has experienced numerous changes in recent years, in terms of developing technology, changing patterns of land-use (Norris *et al.* 2010), growing urban demand (Bowen-Jones & Pendry 1999), improved market connectivity, population growth (Barnes 2002) and dramatic changes in wildlife abundance and species composition (Crookes *et al.* 2005). These changes are unlikely to abate in the future. Understanding how households will respond is crucial, not only for anticipating the future development of the trade, but also for designing effective management policies that incentivise desirable behaviour change and which anticipate non-linear or unexpected responses.

We use the case study of a bushmeat hunting system in Ghana and apply scenario analysis techniques to explore how actors in the system are likely to respond to changing incentives to participate in the trade, based on the principle of stepping in, stepping out or stepping up (Dorward *et al.* 2009; Cinner *et al.* 2009). The scenarios are designed to reflect hypothetical future developments in the local economy, landscape and climate, based on existing literature and personal knowledge of the study area developed through multiple field visits.

6.1.1. Scenario 1. Improved accessibility to urban centres

The connectivity of isolated communities to local and national markets has been shown to impact resource use, as people respond to increasing commercial incentives and shift livelihood strategies from risk mitigation to profit maximisation (Queiroz & Gautam 1992; Fafchamps 1992; Angelsen & Kaimowitz 1999; Jacoby 2000; Kramer *et al.* 2009). Road networks in many parts of Ghana are poor quality, restricting access. This is likely to change in the future as government investment in the transport infrastructure begins to materialise (Ministry of Finance 2012). Understanding whether hunters are likely to respond to these changes will be important to understanding whether such developments represent an unforeseen risk to already depleted wildlife stocks (Wilkie *et al.* 2000; Willcox & Nambu 2007; Poulsen *et al.* 2009). We examine hunter responses to the opening up of markets through direct questioning on behavioural responses to quicker journey times.

6.1.2. Scenario 2: Reduction in agricultural productivity

Agricultural productivity will be influenced by climate variability and soil exhaustion. Cocoa, the primary cash crop grown in the study region, has a recognised lifetime before depleting soil nutrition, and increases in disease, reduce productivity to levels where existing plantations are no longer economic (Ruf & Schroth 2004). In addition, some future climate predictions suggest maize, the second most valuable cash crop in the region, may cease to be viable in parts of West Africa (Conway 2009). As hunters are primarily farmers (Shanti-Alexander 2011), loss of agricultural income may drive them to seek alternative sources of income. Understanding whether a decline in agricultural productivity will result in increased pressure on wildlife, which may either be unable to provide adequate support, or lead to further degradation of regional biodiversity, is important for assessing the resilience of the system to future shocks and informing management priorities (Gallopín 2006).

6.1.3. Scenario 3. Increasing bushmeat prices

High bushmeat prices, whether due to an increase in demand or increasing resource scarcity, are a recognised driver of hunting activity (Bowen-Jones & Pendry 1999). Analysis of the bushmeat trade in Ghana shows that the real price of bushmeat is increasing at a greater rate than many other comparable economic indicators, such as the national minimum wage, producer price of cocoa and price of fish (Chapter 3). As human population grow, and with little scope for recovery of wildlife resources, it is a reasonable assumption that these price increases will continue in the future. Evaluating how hunters' will respond to price rises is of particular concern to conservation.

6.1.4. Scenario 4. Increased travel time to hunting grounds

Consensus surveys conducted with hunters in 2012 identified deforestation and changing patterns of land use as among the greatest threat to hunters' livelihoods in the study region (Appendix E1). Such changes deplete local resources, increasing the effort that must be expended for a successful hunt. With forecasts for agriculture to continue to expand or intensify in the coming years (Balmford *et al.* 2005; Green *et al.* 2005), it is likely that the effort required to access hunting areas will increase. Understanding how hunters are likely to respond to an increase in the physical and time demands associated with hunting is therefore an important component to understanding the future evolution of the system.

6.1.5. Scenario 5. Decline in bushmeat catch

In addition to increased effort, it is also likely that catches will continue to decline. Data from our study (Chapter 3) highlights a significant decline in catch per unit effort between 2002 and 2011. All hunters surveyed in the study region reported that catches had declined in recent years (Shanti-Alexander *et al.* in press). With no management strategy in place it is reasonable to assume, based on historic trends, that catches will continue to decline in the future. Understanding how hunters will adapt their behaviour in light of continued declines in their catch is critical for understanding future system dynamics and developing effective management strategies.

6.1.6. Scenario 6. Decreasing bushmeat prices

If rising bushmeat prices potentially incentivise hunting, it is logical to assume that falling prices may have the opposite effect. The manipulation of bushmeat prices represents a potentially interesting management intervention. Previous research has highlighted how price, changing tastes, and the availability of alternatives may influence demand (Brashares *et al.* 2004; Wilkie *et al.* 2005; Rentsch & Damon 2013). Exploring the response of hunters to falling prices can help inform whether price manipulation strategies are likely to be effective.

Two groups of individuals were targeted in the survey: hunters and non-hunters. Both surveys collected data on socioeconomic profiles and on how the anticipated hunting behaviour of each group might change in response to the selected scenarios. Hunter surveys were concerned with assessing whether hunters would increase, decrease or stop hunting. Non-hunter surveys examined the circumstances under which those outside the trade would consider entering it. Hunter surveys also targeted two subgroups, those with regular access to urban markets (termed “market hunters”) and those with poor access to urban markets (termed “rural hunters”), to assess whether the presence of an urban market influenced hunting decision-making.

We ask two fundamental questions:

1. How will hunters and non-hunters respond to future landscape and market level change, and what are the socioeconomic characteristics that define this response?
2. Do individuals in communities that are connected to, and trade with, urban markets make different decisions compared to those who are not?

6.2. Methods

6.2.1. Sampling

Four communities were surveyed in the Ashanti and Brong-Ahafo regions in southwest Ghana. Two communities, Jachie and Kwaman, had regular transport connections to the district capital Kumasi. Hunters from these communities were known to trade bushmeat regularly with the city market. The two remaining communities, Anyimaye and Kofiekrom, were more remote. Access to large urban centres was difficult, and roads were seasonally impassable. Hunters traded almost exclusively with the local market, except on rare occasions when they would travel to the city for family or work matters. All communities were primarily of Akan heritage (89%) and had lived in the community for longer than one generation (87%). The trading behaviour of the hunters associated with each community was verified in two ways. Firstly, using official surveys of the main fresh bushmeat market in Kumasi, collected by officials from the Ghana Wildlife Division over a 27-year period from 1978 to 2004, which contained information on the names of the villages supplying the market, and secondly, from personal observations and field research conducted over three field seasons between 2010 and 2012. Anecdotal reports gathered from hunters during research trips confirmed that wholesale bushmeat prices in the rural communities were lower than those in the market connected communities, in line with findings from other research (Brashares *et al.* 2011). Communities were selected based on the profile of the hunters in each, i.e. whether the hunters regularly traded with urban markets, whether communities could be considered "typical" of the area (verified in so far as possible through discussions with Wildlife Division staff familiar with the area and through personal observations) and based on the willingness of hunters to participate in the study (verified from discussions held with senior members of the hunting communities during pilot trips in 2010). Non-hunters were surveyed in three of the four villages, Jachie and Kwaman (good market connectivity) and Anyimaye (poor market connectivity). A map of the study area is presented in figure 6.1.

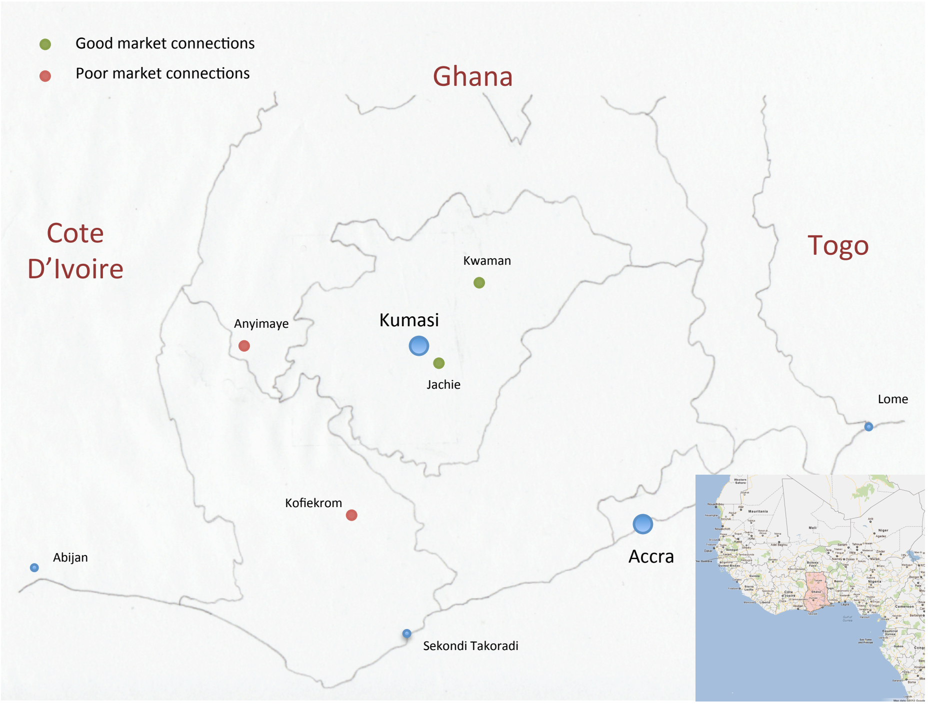

Figure 6.1: A map of the study area and four communities surveyed as part of this work.

Hunters were defined as those members of the community who considered hunting to be a formal livelihood activity, that is, that they identified it as an integral component of their livelihood strategy. This included firearm hunters, dog hunters and hunters who trapped in the forests (Shanti-Alexander *et al.* in press) but excluded farmers who trapped casually in their fields to control pests. In practice, this distinction was easily made, as hunting as a livelihood practice is well recognised in the study communities. Since only men adopt hunting as a formal livelihood activity, our study focused on male decision-making and behaviour for both hunters and non-hunters. Different approaches were necessary to identify our respondents in each case. Men who were currently non-hunters but could potentially become hunters in the future, i.e. males of working age (out of full time education), were identified through a randomised household interview process. The distribution of households was selected to cover the full geographical area of each community. Based on a coarse estimate of the number of households, an interval of every i^{th} household was chosen for interview. The one exception was Anyimaye, where, due to its small size, 92% of households were surveyed. Due to time constraints, no general household survey was undertaken in Kofiekrom. Hunters were selected through three approaches. Firstly, senior members of the community were asked to identify those who hunted. Secondly, after initial identification, the snowball method was used, whereby each hunter was asked to identify other hunters. Thirdly, during the household surveys, household members were asked whether they hunted or knew of others nearby who did. Overall, a total of 94 hunters and 121 non-hunters were surveyed in this fashion (table 6.1).

Table 6.1: Details of communities and surveys conducted. Community areas are calculated using Google Earth diagnostic tools. Distances are straight-line distances from each community to the main transport hub in Kumasi.

Village	**Community area (km^{2})**	**Distance to Kumasi (km)**	**Hunters**	**Non-hunters**
Jachie	0.90	12	29	40
Kwaman	0.85	48	36	40
Anyimaye	0.12	130	18	41
Kofiekrom	0.07	120	11	0

6.2.2. Data collection

Data on six general socioeconomic indicators were collected that might potentially be related to an individual's willingness to enter or leave the hunting trade (Appendix E2). The selection of variables was adapted from similar studies in the bushmeat literature (Kumpel *et al.* 2010), and fisheries literature (Ikiara & Odink 1999; Stewart *et al.* 2006; Cinner *at al.* 2009). Six of these were collected at the individual level: age, education (number of years respondent was in full time education), family size (the number of people in the household), material assets (as a proxy for wealth), income diversity (number of income generating livelihoods undertaken) and the market connectivity of the home community. For market connectivity, Jachie and Kwaman were considered well connected (71% of hunters traded with Kumasi) and Anyimaye and Kofiekrom were poorly connected (no hunters traded outside of their local communities). Data on two material assets were collected: whether the participant owned a vehicle (car or motorbike), and whether they had access to electricity. Hunters were asked two further questions to better understand the motivations behind hunting: (1) what was their primary reason for hunting, and (2) was hunting their main source of income. Non-hunters were also asked two further questions: (1) whether farming was their primary source of income, since the majority of hunters are farmers, and thus farming and hunting may be considered closely linked (Shanti-Alexander 2011) and (2) whether they had any previous experience of hunting (defined as either none, trapping or gun hunting).

Three key variables defined the scenarios (Appendix E2): journey time (to market/hunting ground), production (of bushmeat/agriculture), and the price of bushmeat. The first represents a physical incentive, while the latter two represent economic incentives. In each case, the key variable could either increase or decrease, leading to six scenarios in total (three in which the incentive to hunt was increased, and three in which the incentive to hunt was reduced). The key variables were identified on the basis that each is likely to play an influential role in the decision making of hunters and potential hunters alike, and can be considered a 'critical uncertainty', i.e. an area where change is likely to occur in the future, and thus where information on behavioural responses will be of greatest value. All six scenarios were put to the hunters, while only those three relating to an increase in incentives to hunt were put to non-hunters.

Each scenario asked a specific question about a single change that could be quantified with reference to a standard "index" in order to relate the change to the personal experience of the respondent. For example, when asking a hunter how he would respond to a 50% increase in the price of bushmeat, he was first asked how much money he usually received for a single grasscutter carcass (the most common species of bushmeat caught and traded). The questions would then be framed in relation to the figure, i.e. the 'index', he provided. Table 6.2 summarises the scenarios, indexes and categories.

Three different levels of change were associated with each scenario in order to assess how respondents adapted their choices with the severity of the change, and identify any non-linearities in the responses. Consistent levels of change were used across all comparable scenarios (increased incentive and decreased incentive) to aid with administration of the questionnaire.

Table 6.2: A summary of the six scenarios. Three levels of change were associated with each scenario, 25%, 50% and 100% for increasing incentives to hunt and 25%, 50% and 75% for declining incentives to hunt. Change for each scenario was quantified relative to the index. Scenario 2, declining agricultural productivity, was only asked to those engaged in agriculture.

Scenario	Index	Target Group	Hypothesised Hunting Incentive
1) Improved accessibility to urban centres	Travel time (hours)	Hunter & Non-hunter	Increased
2) Reduction in agricultural productivity	Number of bags of main cash crop produced in a season.	Hunter & Non-hunter	Increased
3) Increasing bushmeat prices	Grasscutter price (Cedi) (single carcass)	Hunter & Non-hunter	Increased
4) Increased travel time to hunting grounds	Travel time (hours)	Hunter	Decreased
5) Decline in bushmeat catch	Average monthly catch (number of animals)	Hunter	Decreased
6) Decreasing bushmeat prices	Grasscutter price (Cedi) (single carcass)	Hunter	Decreased

Levels were selected to reflect a combination of optimistic, pessimistic and realistic levels of change. In addition, there needed to be great enough separability between levels such that they represented noticeably different choices for the respondent. Where possible, data on changes over the past few decades were used as a basis for selecting realistic step changes. Such data were available for bushmeat price, which increased by 313% between 1990 and 2011, length of time spent hunting, which increased by 114% between 1982 and 2011, and catch rates, which declined by 46% (Chapter 3). Historical data were not available on crop productivity or market connectivity, therefore the same incremental levels of change were used to maintain consistency.

Thus, hunters were asked a total of 6x3 = 18 questions, and non-hunters 3x3 = 9 multiple-choice questions. Hunters were given four options: to continue as normal, to decrease effort, to increase effort, or to stop. Non-hunters were given two choices: to continue as normal or to start hunting. Additional discussion relevant to the questions was encouraged to help frame the responses. With regard to a decline in agriculture, both groups were asked how else they might adapt to such a change. Hunters were also asked to identify what they perceived to be the greatest threats to hunting in the future. There were no restrictions on responses to these questions (Appendix E1).

6.2.3. Data analysis

Comparing scenarios

Chi squared tests for count data were use to test whether the proportion of hunters willing to stop hunting or increase hunting, differed between scenarios. Willingness to increase hunting was compared between scenario 1 (improved accessibility to urban centres), 2 (reduction in agricultural productivity) and 3 (increasing bushmeat prices). Willingness to stop hunting was compared between scenario 4 (increased travel time to hunting grounds), 5 (decline in catch) and 6 (decreasing prices). All levels were tested on a like for like basis (i.e. a 50% decline in catch was compared with 50% decline in price).

Market access and behaviour

To examine whether better access to an urban centre affected hunters' willingness to adapt their behaviour, chi squared tests were also conducted to contrast different groups. Hunters were grouped according to the market connectivity of the home community (section 6.2.2), so that the behaviour of hunters from Jachie and Kwaman was contrasted with that of hunters from Anyimaye and Kofiekrom. Tests examined how the willingness of hunters to stop, decrease or increase hunting varied between the two community groups, under identical scenarios and levels of change.

6.2.4. Socioeconomic drivers

Specific scenarios were selected for further analysis using a binary logistic regression to explore how the probability of an individual's willingness to adapt was related to their socioeconomic profile, as described by the socioeconomic indicators (section 6.2.2). Model variables and hypothesised effects are summarised in table 6.3.

Three sets of models were fitted:

1. Hunters' willingness to exit the trade.
    a. 50% drop in market price (Scenario 6)
    b. 50% decline in catch (Scenario 5)
    c. 50% increase in distance to hunting grounds (Scenario 4)
2. Hunters' willingness to increase hunting.
    a. 100% rise in price (Scenario 3)
    b. 50% decline in agricultural production (Scenario 2)
3. Non-hunters' willingness to enter the trade.
    a. 100% rise in price (Scenario 3)

Scenario 1, improved accessibility to urban centres, was not modelled due to the homogenous nature of responses (see results). The 50% threshold was selected as a compromise to ensure adequate response diversity for modelling procedure, while also remaining within the bounds of realistic real-world change under extreme conditions. Price rises were the exception, where recent historic evidence suggests that increases of the order of 100% are highly likely (Chapter 3). Due to the relatively low number of non-hunters willing to enter the trade, model 3 (willingness to enter), suffered from quasi and complete separation of independent variables. To address this issue, Firth's penalized likelihood estimation was used to estimate the models (Firth 1993). Models were simplified on the basis of a stepwise model selection process, where non-significant terms were removed and nested F tests used to contrast the significance of the removal.

Response variables were two level factors. As hunter responses consisted of four choices (no change, increase, decrease or stop), these were simplified according to the model, such that for model 1 (willingness to exit), 1 indicated a willingness to exit, 0 all other responses; and for model 2 (willingness to increase), 1 indicated a willingness to increase, 0 all other responses. In model 3 (non-hunter willingness to enter), non-hunter responses were already binary in nature (start, 1 or don't start 0) and did not need to be transformed. A summary of model variables is provided in table 6.3.

Table 6.3: Summary of response and independent variables included in the logistic regressions.

Model	Variable	Type	Description
Response	Willingness to exit	Binary response	Success, 1, is defined as stop. All other responses are defined at failure, 0.
	Willingness to increase	Binary response	Success, 1, is defined as increase. All other responses are defined at failure, 0.
	Willingness to enter	Binary response	Success is defined as entering the trade, and 0, failure, is to continue as normal.
Independent (all models)	Age	Continuous	Individual's age
	Education	Continuous	Number of years an individual was in education.
	Family size	Continuous	Number of individuals supported financially by the respondent in his household.
	Income diversity	Continuous	Number of livelihoods providing income.
	Wealth	Two level factor	Did the respondent own his own transport or have access to electricity, yes / no.
	Market connectivity	Two level factor	Defined by the village. Either "good access" (Jachie and Kwaman) or "poor access" (Anyimaye and Kofiekrom).
Independent (Hunter models)	Primary reason for hunting	Two level factor	Income or food
	Primary income	Two level factor	Was hunting the primary cash earner, yes / no.
Independent (Non-hunter model)	Primary occupation	Two level factor	Was farming the primary source of income, yes/ no.
	Hunting connection	Three level factor	Did the respondent have direct links to the trade? Either no links at all; used to hunt but does no longer; or traps on farmland, but does not travel to specifically hunt.

6.3. Results

6.3.1. Hunting behaviour

Comparing scenarios

Of the three scenarios associated with declining incentives, hunters were more likely to continue hunting in the face of falling market prices, than when their catch declined or their hunting journey time increased (price decline vs. catch decline, 50% level, n = 94, χ^2= 7.04, p <0.01; price decline vs. hunting journey time 50% level, n = 91, χ^2 = 6.32, p = 0.01). This was true across all step changes. Comparison of smaller catches and longer journeys revealed no difference between scenarios in the willingness of hunters to reduce or stop. Overall, the majority of hunters reported that they would continue hunting as normal in the face of all but the most extreme changes (figure 6.2). With regards to improving incentives, hunters were always more likely to increase effort in response to improved prices, than in response to a reduction in agricultural production or better access to urban markets. This was true across all levels of change (price increase vs. travel time to an urban centre, 50% level, n = 93, χ^2 = 13.8, p < 0.01; price increase vs. agricultural production decline, 50%, χ^2 = 13.7, p < 0.01).

Market access and behaviour

For between-hunter differences, market hunters were more likely to stop hunting in response to falling prices than rural hunters at the 75% level (n = 64:29, χ^2 = 3.27, p = 0.04) and more likely to stop hunting in the face of increased travel time to hunting grounds at both the 25% (n =61:29, χ^2= 51, p = 0.02) and 75% levels (n=61:29, χ^2 = 4.08, p = 0.04). Responses to declining catches were similar in both groups. It should be noted that mean journey times to hunting grounds, reported at the time of surveying, were already longer for market hunters than rural hunters, (Wilcoxon Rank Test, W=514, p=0.043) (calculated from data reported in Chapter 3).

Rural hunters were more likely to increase hunting effort in response to rising prices at both the 25% (n = 64:29, χ^2 = 4.9, p = 0.03) and 50% level (n = 64:29, χ^2 = 3.90, p = 0.04). Interestingly a small proportion of hunters in both communities indicated that they would decrease effort if prices were to increase. This effect was particularly noticeable among market hunters: 18% would cut back on hunting if prices rose by 50%, either in order to focus their attention on other pursuits, or to rest. Although a greater proportion of rural hunters reported that they would increase hunting effort if access to markets improved (figure 6.2), this relationship was not significant. Neither group viewed declines in agricultural production as a strong incentive to increase hunting effort.

General hunter perspectives

The open-ended discussion that accompanied the specific scenario questions, in which respondents were encouraged to raise anything of relevance to their responses, highlighted a number of interesting points. In terms of adaption, there were two comments regularly made by all hunters. Firstly, that if access to urban centres improved, it would not affect how much they hunted, but would influence how much they traded. Secondly, that if agricultural production declined, they would adapt their farming strategies, be it through crop selection or weed/pest control, rather than turn to hunting. This was because hunting was simply not viewed as a sufficiently reliable income source to replace agriculture. Only 1.2% indicated that they would leave agriculture entirely, even at a 75% decline in production.

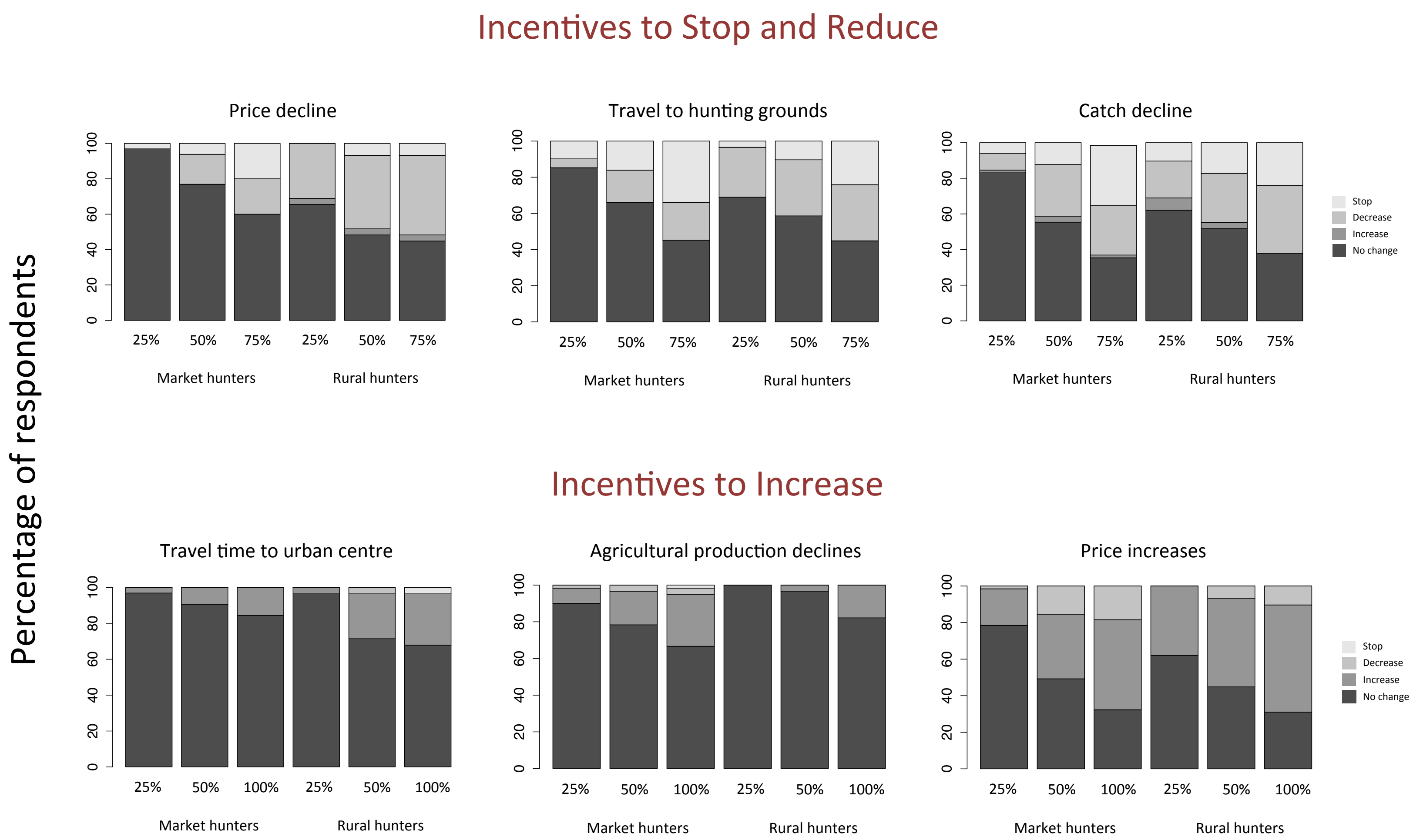

Figure 6.2: Hunter responses to hypothetical scenarios based on changing economic and physical / environmental incentives. Hunters are divided into two groups. Market hunters – those who have easy access to an urban bushmeat market; and rural hunters – those in more isolated communities with little access to urban bushmeat markets.

Non hunters

Increasing bushmeat price was the only scenario that generated a positive hunting response. Respondents were more likely to consider starting hunting in response to rising bushmeat prices than agricultural declines (n = 80, 25%, χ^2=5.88, p=0.02; 50%, χ^2=14.06, p < 0.01; 100%, χ^2 = 15.06, p < 0.01). A total of 22% of non-hunters expressed a willingness to start hunting if bushmeat prices doubled. There were no significant differences in the responses of non-hunters based on whether they lived in a community with good connections to an urban centre. 57% of non-hunters were engaged in farming activities and therefore questioned on their likely behaviour in response to declining agricultural production. Generally, non-hunters were reluctant to start hunting regardless of the type and magnitude of change (figure 6.3). Changes in agricultural production and journey time to urban centres, created little incentive for non-hunters to enter the trade. Indeed, many non-hunters expressed strong views on the subject of hunting. If it was something they had no training in, there was a general consensus that they would not do it, simply because it *"was not their job"*. Many spoke about how it was difficult and thankless work. Due to the low number of positive responses, the effects of improved urban access and declines in agricultural production are not tested statistically, nor included in the logistic model. Similarly to hunters, only a small proportion, 6%, of those who farmed, suggested that they would consider leaving agriculture even under 75% reductions in production.

6.3.2. Socioeconomic drivers

Hunters

Four socioeconomic variables were associated with the decision to stop hunting across the three scenarios tested. These were: whether the community to which the hunter belonged had good connections to the urban market; whether the primary reason for hunting was for food or income; family size and wealth (table 6.4). The same variables were associated with the decision to increase hunting, except there was no wealth effect and education was an important predictor.

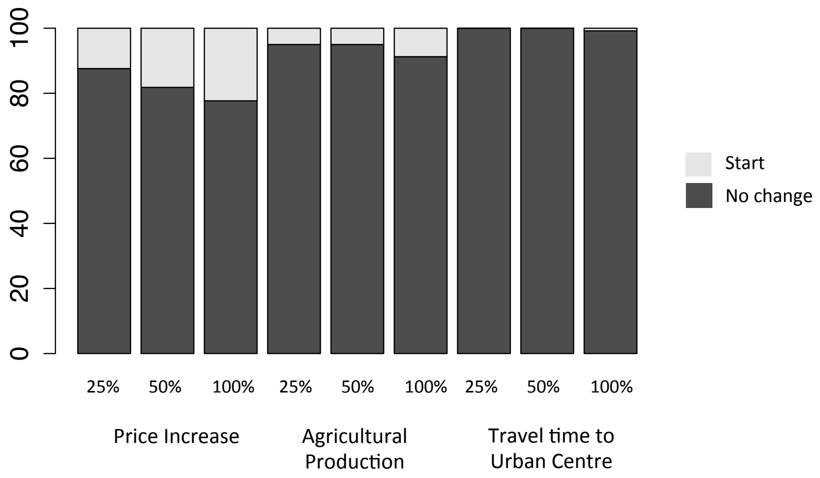

Figure 6.3: Non-hunter responses to hypothetical scenarios based on changing economic and environmental incentives.

General observations - hunters

In interpreting these results, it is useful to distinguish between those scenarios linked to economic incentives (price changes, catch declines) versus physical hardships (journey time increases; Fig. 6.5). Five key points emerged from the logistic model. (1) Hunters who hunted for income, regardless of their other attributes, are less likely to stop hunting and more likely to increase effort, whether in the face of changing economic returns or greater physical hardship. (2) Hunters with a large number of dependents were most likely to stop if economic returns declined (price and catch). (3) Hunters who hunted primarily for food were most likely to stop if the physical hardship of hunting increased. (4) Wealthier hunters (those with high value material assets) were more likely to quit under reduced economic incentives, or increased physical hardship. (3) Hunters with a better education were less likely to increase hunting if economic incentives improved. Variables that showed no effect were, age, income diversity and whether hunting was a primary livelihood activity.

Location specific observations - hunters

Two location specific patterns emerged. (1) Hunters in rural areas were more likely to increase effort if prices rose and less likely to stop hunting if the hardship of hunting (journey time to hunting grounds) increased, and (2) market hunters were more likely to use hunting to support themselves if agricultural production were to decline.

Table 6.4: Results of the logistic model examining how the behaviour of hunters and non-hunters is related to their socioeconomic profiles. Three scenarios are associated with hunters choosing to stop hunting: scenario 4, increased travel time to hunting grounds, scenario 5, decline in bushmeat catch, and scenario 6, decreasing bushmeat prices. Two scenarios are associated with an increase in hunting effort: scenario 2, reduction in agricultural productivity and 3, increasing bushmeat prices. Non-hunters willingness to enter the trade is modelled against scenario 3, increasing bushmeat prices. All level changes are 50% except scenario 3, increasing bushmeat price increase, which is 100%. Response variables are binary, with 1 (success) representing either exiting the trade, increasing effort or entering the trade (depending on the model being tested), and 0 (failure) represents all other responses. Where the independent variable is a factor, the level is given in italics. Figures in standard formatting are coefficient estimates; figures in parentheses are Standard Errors; significance levels are indicates by asterisks, at the * 0.05, **0.01 and ***<0.001 levels.

		Hunter					**Non-hunter**
Variable category	**Hunter response**	**Stop**			**Increase**		**Enter**
	Scenario	4.Increased travel time to hunting grounds	5. Decline in bushmeat catch	6. Decreasing bushmeat prices	2.Reduction in agricultural productivity	3.Increasing bushmeat prices	3. Increasing bushmeat prices
General variables (all models)	**Intercept**	-0.69 *(0.43)*	-4.75*** *(1.25)*	-3.76*** *(0.83)*	-0.54 *(-0.50)*	0.33 *(0.61)*	-2.04*** *(0.43)*
	Education				-1.02** *(0.36)*	-0.66* *(0.28)*	
	Family size		0.32* *(0.13)*	0.12* (0.08)			
	Wealth: *Yes*		1.94* *(0.80)*				-2.32* *(0.89)*
	Market connectivity: *Rural*	-1.47* *(0.75)*			1.23* *(0.51)*	1.23* *(0.60)*	
Hunter	**Primary reason for hunting**: *Income*	-2.28** *(0.84)*	-5.39* *(2.31)*		1.06* *(0.31)*	1.06* *(0.56)*	
Non-hunter	**Primary occupation**: *Farming*						1.21* *(0.51)*

General observations – non-hunter

Farmers were more likely to consider hunting than non-farmers. In terms of the likelihood of entering the trade, being a relatively poor (no high value assets) and a farmer was the profile most likely to consider engaging in hunting. There was no relationship between willingness to enter the trade and whether the respondent had previous experience of hunting.

6.4. Discussion

Understanding how and why natural resource users respond to change is a pressing concern for conservation, and represents an area where the need for more information is frequently highlighted in the literature (Nicholson *et al.* 2009; Warren *et al.* 2013). In the context of bushmeat hunting, there are also important development and health angles: bushmeat can represent an important component of household income, particularly for the rural poor (Robinson & Bennett 2002; Davies 2002; de Merode *et al.* 2004; Schulte-Herbrüggen *et al.* 2013), while also representing a valuable source of nutrition (Golden *et al.* 2011). As the pace of globalisation quickens, and the economic incentives that drive the behaviour of resource users change, understanding the human component of linked socio-ecological systems is increasingly important if we are to promote their resilience and adaptability and understand how they may respond to future change (Young *et al.* 2006). We discuss the implications of our findings for the bushmeat trade, in relation to three areas that underpin the scenario analysis: market development, landscape change and environmental change.

6.4.1. Market development

Bushmeat is the most valuable protein traded on the urban market in Ghana. High prices are often seen as a driver of unsustainable hunting behaviour (Bowen-Jones & Pendry 1999) and consequently, managing the trade through price manipulation is frequently discussed (Brashares *et al.* 2004). Our results suggest that rising bushmeat prices are likely to represent a significant incentive not only for hunters to increase their hunting effort, but also for a small proportion of those outside of the trade to enter it. The incentive for existing hunters appears to be particularly strong in those rural communities that are most remote from the urban commercial trade. Such findings are in line with expectations, based on the observed effects of connecting previously remote communities with lucrative local and national markets (Kramer *et al.* 2009). Conversely, falling prices elicited relatively indifferent responses, and were less likely to result in hunters quitting than declining catches or increased journey times. Commercial hunters, i.e. those who hunted primarily for income, were least responsive to price declines. These results question the degree to which reducing prices will translate to a reduction in hunting, particularly as the target demographic for such action (commercial hunters) is the group least likely to respond. In addition, the level of change required to generate meaningful responses is likely to be beyond the remit of any realistic price-reduction policy.

Education would appear to play a mediating role in hunters' willingness to increase effort, while wealthier individuals were both more likely to stop, and less likely to start. The mechanism behind this is not clear, but may reflect improved access to alternative livelihoods, and/or a better appreciation of the high physical demands of hunting in a relatively depleted landscape.

Amongst non-hunters, it is overwhelmingly agriculturalists that are most likely to consider entering the trade. The relationship with wealth (vehicle ownership) provides some indication that it is the poorer households for whom hunting may represent an attractive option, in line with previous observations (Crookes *et al.* 2007; Kumpel *et al.* 2010). Nevertheless, only 22% of non-hunters indicated they would consider hunting if prices were to double. Thus, hunting appears to be an unattractive livelihood option for the majority outside the trade.

6.4.2. Landscape change – increasing journey times and falling catches

Declining catches and increased journey times are more likely to stop hunters from hunting than falling market prices. Socioeconomic analysis highlights some important trends within the hunter groups that help understand the social dimension. Hunters motivated by income are less likely to stop regardless of the incentive, than those who hunt for food. Market hunters, in communities with good access to urban centres, are more likely to stop in the face of longer journey times to their hunting grounds than their rural counterparts. This may be a consequence of the fact that such hunters are already travelling further than rural hunters. Communities with better market access are, by definition, closer to Kumasi and likely to be more populated, more developed and characterised by more depleted wildlife populations. Such communities may be closer to a tipping point, whereby the demands of hunting are already nearing critical levels for some members of the community.

Hunters in larger households were more likely to stop hunting if the economic incentives declined (falling catches and declining prices). One mechanism through which family size might influence hunting decisions is income multiplicity. Cinner *et al.* (2009) found that income multiplicity (i.e., the number of household members generating an income) was a determinant of an individual's willingness to exit a declining fishery. Kumpel *et al.* (2010) found that large family sizes were associated with greater annual income per reference adult (defined as adults over 16). Data on income multiplicity are not available, but a larger family may be synonymous with a more diverse livelihood portfolio that the family can turn to in times of difficulty.

These results suggest that 1) the activities of commercially orientated hunters are likely to be more difficult to manage that subsistence hunters; 2) that the connection of remote communities to urban markets will increase hunting pressure on local resources, as has been reported elsewhere in the literature (Ruiz-Pérez *et al.* 2004; Young *et al.* 2006; Crookes *et al.* 2007); and 3) that income stability may play a role in allowing actors to exit a declining trade.

6.4.3. Environmental change – Agricultural production

Declines in agricultural production were shown to be poor drivers of hunting behaviour among both hunters and non-hunters. The unwillingness of both hunters and non-hunters to rely on hunting if their primary livelihood failed, may be a consequence of the commonly held belief that hunting is simply not viable as a main source of income. This latter observation is supported by the fact that hunting was the primary source of income for only 19% of hunters surveyed in the study region (Shanti-Alexander, in press).

6.4.4. Concluding remarks

Although similar studies have been conducted with fishing communities (Cinner *et al.* 2009), this study represents the first of its kind to be conducted with hunting communities. Our results highlight how socio-economic differences within groups, influences their response to change.

Analyses of competing and inter-related drivers in isolation, while valuable for assessing individuals' motivations and for identifying sweet spots (i.e. those policy levers likely to generate the biggest response), needs to be interpreted with caution. For example, declining catches and rising prices are directly related; change one and you will almost certainly change the other. On this basis, there would appear to be a fine balance present in the hunting system around Kumasi. When one considers how the value of bushmeat has increased many-fold in recent decades, it would be reasonable to assume based on our results that hunting engagement would have increased in this time. However, this is not the case, and engagement appears to be in decline (Shanti-Alexander *et al.* in press; Chapter 1). In reality, the increased incentive offered by higher prices is likely to be offset by declines in catch or increased hardship due to longer hunting trips.

The potential for price rises to stimulate hunting activity where resources are less limited would appear clear. This may explain, in part, the differing responses of rural hunters compared to market hunters, with the former being more likely to increase effort in response to price rises, and less likely to stop if travel times to hunting grounds increase.

There are implications in our findings that education and wealth play a role in limiting hunting. This is in line with the literature on poverty traps (Costanza 1987). The reluctance of many hunters to adapt, despite declining catches and increasing effort, suggests an unwillingness or inability to change, behaviour typical of poor households with few options (Barrett *et al.* 2006). Meanwhile, the conviction of farmers to stick with agriculture, even in the face of drastic declines, means that policy makers and managers tasked with mitigating the future consequences of regional climatic disruption, should examine opportunities to encourage greater livelihood diversity to develop these agricultural system's resilience to shocks. Management interventions that target poverty, through education or seed financing, may increase actors' socio-economic mobility and their ability to find alternatives to hunting in the face of declining returns.

Further research is required to explore the complex socio-economic drivers of the trade, and to knit together the competing incentives into a more holistic model that can inform management. In the interim, social analysis techniques such as scenarios analysis represent a powerful tool for the analysis of behavioural patterns amongst resource users and represent a valuable source of information for conservation and development practitioners seeking to understand the dynamics of socio-ecological systems.

Chapter 7

Discussion

7. Discussion

The findings in this thesis make a number of important contributions to knowledge in regard to understanding the dynamics of bushmeat hunting systems and, notably, the urban bushmeat trade. Firstly, they challenge the assumption that the trade is demand driven, presenting two analyses that take different approaches to understanding the drivers of the urban trade around Kumasi (Chapters 3 & 4). Secondly, it presents a novel spatio-temporal analysis of bushmeat hunting in the study area, using market data to explore how the biophysical characteristics of the landscape define the urban trade (Chapter 5). Finally, based on the findings in Chapters 3, 4 and 5, it investigates how actors in the system are likely to respond to future change, and examines the socioeconomic characteristics that define these responses (Chapter 6).

The following discussion debates the key findings of the thesis, explores what these findings mean for management, both in the context of the trade around Kumasi and more generally, and discusses what the implications are for the future evolution of the trade in the study area.

7.1. Managing the urban bushmeat trade

7.1.1. What drives the urban trade around Kumasi?

Tests of the conceptual framework evaluated in Chapter 3, present evidence that the bushmeat trade around Kumasi is supply driven. All four of our framework tests were upheld (Chapter 3). Evidence that bushmeat resources are becoming depleted, and unable to respond to consumer demand, was demonstrated by the fact that both market analysis and hunter surveys showed a change in the composition of the trade, in line with expectations under depletion (Rowcliffe *et al.* 2003). In addition, a review of historical hunting surveys in the region suggested there has been a decline in catch per unit effort. Hunters' participation in the trade appeared to be independent of the price signals coming from the market, at both short-run and long-run time scales. There was evidence that increasingly, urban consumption was limited by supply, with consumers being priced out of the market as bushmeat has become progressively more expensive in recent years. Finally, there was evidence, anecdotally at least, that seasonal fluctuations in wholesale market prices are driven by seasonal variation in supply.

However, the results of the econometric supply and demand model (chapter 4) and the scenario analysis (chapter 6), produced results that both supported and challenged the premise of a supply driven market. In support of the supply-driven hypothesis, there was a significant increase in the rodent: ungulate ratio between 1978 and 2004 (Chapter 4 & 5), an indication that bushmeat resources are being depleted. In terms of hunter participation, the seasonal agricultural predictors (labour and the maize season) were significant predictors of trade volumes, in agreement with hunter and trader reports and previous assertions in the literature (Falconer 1992). In regard to consumer demand, while demand generally was elastic, demand for rodents, notably the popular grasscutter, was inelastic, suggesting that in this instance demand might be outstripping supply. Finally, in terms of price behaviour, the instrumental variable regression (Chapter 4, Appendix C2) demonstrated that high prices, and low supply, were correlated with periods of high agricultural demand. These findings support the predictions on resource condition, hunter behaviour and price behaviour outlined in the conceptual framework (Chapter 3). However, the general price elasticity of supply and demand (considering the trade as a whole) were elastic (Chapter 2), implying that consumers and hunters alike are responding to the price signals generated by the market in line with economic theory (Besanko & Braeutigam 2010; Blanchard *et al.* 2012). While one would expect consumers to respond elastically to price (Wilkie & Godoy 2001; Apaza *et al.* 2002), the fact that hunters do so, sits contrary to prediction 5 in Chapter 3 on long-term, inter-annual hunting behaviour. The implication from the econometric analysis is that while supply-side drivers may dominate the trade in the short-term, the general market, ignoring inter-species differences, conforms to a traditional demand driven structure. A conclusion that may be drawn from these findings is that

Table 7.1: Summary of evidence from all chapters, summarised according to the frameworks tests, presented in Chapter 3, to test the supply-driven nature of the market.

Prediction	Sub predictions and tests	Chp.3	Chp.4	Chp.5	Chp.6	Comments
Resources show signs of depletion.	***Trade composition*** 1. Evidence for depletion	✓	✓	✓	NA	1. All evidence suggests that bushmeat resources are becoming increasing scarce, in terms of hunter reports (Chp.3), changes in market composition (Chp.3 & 5), a decline in trade volumes from heavily hunted areas (Chp.5) and differing elasticities of supply for ungulates and rodents (Chp.4).
Hunters move in and out of the market independently of price signals.	***Short-term (intra-annual)*** 2. Hunting activity seasonal, defined not by the price of bushmeat, but by other external factors.	✓	✓	NA	NA	2. Hunter surveys and econometric analysis highlight the seasonal nature of the trade and importance of agricultural influences on participation (Chp.3 & 4).
	Long-term (inter-annual) 3. Participation in the trade trends independently of market signals (price)	✓	✗	NA	✓ / ✗	3. While long-term participation appears out of sync with price rises (Chp.3), econometric analysis suggests that supply is generally elastic (Chp.4). Scenario analyses suggest hunters will not change behaviour is prices fall but will increase effort if prices rise (Chp.6).
Consumer spending patterns defined by supply rather than demand.	***Consumer spending patterns*** 4. Consumption defined by supply limitations	✓	✓ / ✗	NA	NA	4. Consumers report being increasingly priced out of the market (Chp.3). Econometric analysis suggests that while demand is generally elastic, on a species level the supply of rodents is indicative of unmet demand (Chp.4).
Prices are set by supply, not demand.	***Seasonal changes*** 5. Periods of peak supply correlate to low prices and vice versa.	✓	✓	NA	NA	5. Anecdotal evidence from traders, and reports in previous studies of the Atwemonom market suggest seasonal price variations in line with supply trends (Chp.3). This is supported by the econometric analysis (Chp.4, Appendix C2)

there is a distinction between short-term and long-term market drivers.

However, bushmeat markets are dynamic, and it is worth asking the question, whether the market of the 2010's, is the same as that of the 1980's and 1990's analysed in Chapter 4? For example, there is evidence that since 2004, the rate of change of increase in the rodent: ungulate ratio has become more marked in the years since 2004 (Chapter 3 & 5). The implication is that the condition of local wildlife populations is worse today than it was during the period covered by the econometric analysis; a factor likely to exacerbate the supply-driven nature of the market (Ghosh 1958; Rankin 2000). In addition, participation in the trade appears to have declined only fairly recently, falling from approximately 15% in 1990 and 2004, to 4% in 2011 (Chapter 3). Evidence of how hunters may respond to price in today's market is examined through the scenario analyses presented in Chapter 6. Hunters were unwilling to reduce hunting effort if prices declined, in agreement with the supply-driven price prediction (Chapter 3), but indicated a willingness to increase effort if prices rose (in agreement with the demand-driven dynamics highlighted in the econometric analysis). Generally, those outside of the trade were unlikely to hunt regardless of the incentive (Chapter 6). The implication is that reducing prices is unlikely to reduce hunting pressure, but rising prices may exacerbate the situation, even if it represents a marginal incentive to new participants.

Thus, there is something of a mixed bag of evidence depending on the time-scale at which you choose to observe the market, and the degree to which the focus is on individual species, or the trade as whole. There is also evidence that the dynamics of the trade have changed since 2004 (the temporal limit to our econometric analysis), based on declining rates of participation and shifts in the composition of the trade. Overall however, the system appears strongly characterised by dynamics that can be attributed to characteristics of supply, rather than demand (table 7.1).

7.1.2. Assessing management priorities

So what do these findings mean for management and how can they help inform the selection of appropriate policies? Previous research has suggested that many of the tools available to manage hunting systems are well known, the carrot, the stick, or the diversion, and that what is needed are systems to allow the selection of the right strategy for the right place (Ling *et al.* 2002). Assessing whether the market is supply or demand driven, in the manner undertaken in this thesis, represents a valuable tool for informing such decisions, particularly in relation to urban markets. Systematically appraising the behaviour of the hunter and consumer in light of the operation of the market, allows an informed perspective on where in the system intervention is best focused in the short term (what drives the market over seasonal time frames) and the long-term (what drives the market over years or decades). Management options can be categorised as to whether they represent demand or supply side initiatives, and prioritised accordingly, depending on management objectives. Sub criteria could be included to further refine options depending on the resources available. For example, is local, national or international governmental support required? Or, what are the investment requirements of different options relative to the available budget? Table 7.2 represents a simple categorisation of possible management options in light of the Kumasi bushmeat market based on a priority for short-term wins.

There are few win-win management strategies for the bushmeat trade. While our analysis of the Kumasi bushmeat market highlights the importance of supply side dynamics, it also suggests that in the long-term price is an important determinant of supply (Chapter 4 & 6). It has been estimated that there is a limit to human population density in regard to sustainable hunting of approximately 1 per km^2 (Ling *et al.* 2002). Although the precise point at which population density becomes unsustainable will be variable, depending on local socio-ecological characteristics, such findings highlight the fact that in all but the most sparsely populated tropical forests, bushmeat extraction cannot be sustainable.

Table 7.2: A simple table summarising a number of management interventions according to whether they are categorised as supply or demand side interventions. Management priorities are based on the Kumasi bushmeat market, under the assumption that the trade is supply driven over short time periods (seasonally), but demand driven over longer periods (years and decades). Management priority is to develop policies that focus on near term wins, and thus supply-side initiatives.

Management	Supply or Demand	Priority
Cap. Investment (poverty alleviation)	Supply	1.
Education – land management strategies	Supply	1.
Alternative livelihoods	Supply	1.
Enforcement	Supply	1.
Exclusion	Supply	1.
Direct payment (PES)	Supply	1.
Education – consumer behaviour	Demand	2.
Alternative protein	Demand	2.
Farmed bushmeat	Demand	2.
Taxation	Demand	2.

Therefore, while we may realise short-term wins through supply-side intervention in the case of the Kumasi market, ultimately consumer demand for bushmeat cannot be met through the harvesting of wild species (Wilkie & Carpenter 1999; Fa *et al.* 2000; Fa *et al.* 2002; Albrechtsen *et al.* 2007; Nasi *et al.* 2008) and it will be critical to address the issue of demand in the long term.

7.2. The Kumasi bushmeat market

7.2.1. Supply-side dynamics

If one accepts that the bushmeat trade around Kumasi is largely "supply-driven", the logical corollary is that supply-side management interventions will be more effective than demand-side interventions (table 7.2). Supply-side interventions may be broadly categorised according to whether they 1) seek to manage the resource (protected areas, wildlife corridors etc.) or 2) manage the hunters (alternative livelihoods, direct payments etc.). This thesis presents two analyses in this regard. Firstly it explores how the biophysical characteristics of the landscape influence the dynamics of the trade, in order to assess whether appropriate land management can support the trade and conserve wildlife (Chapter 5). Secondly, it examines the socio-economic determinants of hunting behaviour to identify the socio-economic profiles of resource users who are either least able to adapt to change, or most likely to use hunting as a livelihood support mechanism (Chapter 6).

With regard to the landscape, our results highlight some important features. Firstly, the bulk of the trade appears to be sourced from semi-disturbed habitats rather than primary forest or protected reserves (Chapter 5). Although many primary forests in Ghana are likely to be degraded, with only 1.5% of forest reserves in the Kumasi catchment area not managed for commercial timber extraction, such findings agree with the theorised relationship between supply and disturbance proposed by Robinson & Bennett (2004). They also emphasise the valuable role the farm bush matrix plays in the bushmeat trade around Kumasi. Such findings emphasise the need to consider bushmeat production when assessing ecosystem service priorities in landscape and conservation planning exercises (Vandermeer & Perfecto 2007; Fischer *et al.* 2008; Anderson *et al.* 2009). Secondly, there appears to be a degree of stability in the trade originating from areas of high hunting pressure (areas which also supply the bulk of the trade), with no significant change in the species composition from such areas between 1986 and 2002. There was however a small, but significant decline in total trade volumes from such sites over this time period (Chapter 5). Lastly rodent trade was independent of disturbance, and correlated to the seasonal maize season (Chapter 5). The implication is that, at least as far as the trade in rodents in concerned, farmlands can be as productive as forestlands. Economically this is important. Rodents make up the bulk of the commercial trade, and are among the most valuable species on a per-kilo basis, and the most popular among consumers (Chapter 2 & 3). In addition, the price elasticity of the supply of rodents is elastic (Chapter 4) implying that the underlying resource base is in better condition than other species groups, such as ungulates whose supply is inelastic, despite the intense hunting pressure. It may be concluded that harvesting rodents from farmlands can supply significant trade volumes, be resistant to high levels of hunting pressure, and represent a valuable economic proposition for hunters while equally satisfying the demands of the consumer.

The economic incentives needed to promote the preferential off-take of rodents, i.e. high prices, would appear to be already in effect, and have likely been so for decades (Falconer 1992; Ntiamoa-Baidu 1998; Hoffman 2008; Bockhorst 2010). Why then has the trade continued to be so destructive, as demonstrated by well documented declines in a number of vulnerable species (Struhsaker & Oates, J 1995; Oates *et al.* 2000; Barnes 2002; McGraw & Oates 2002; Brashares 2003; Schulte-Herbrüggen *et al.* 2013)? Although hunters' insensitivity to price in the short-term may be part of the answer, a major contributor likely lies in the non-selective nature of hunting (Bowen-Jones 2002; Milner-Gulland 2003; Nasi *et al.* 2008). While consumer demand is species specific, hunting is rarely so. Snares and dogs are selective only in size, and firearm hunters are largely opportunistic harvesters (Hofmann *et al.* 1999). While hunters may be selective in terms of what they sell (Shanti-Alexander *et al.* in press), this is often not the case for the family pot. How then, can this be addressed? Exclusion and enforcement is one option. However, such regulations are already in place through the Wildlife Conservation Regulations (Government of Ghana 1971) and, judging by historic declines in wildlife in the region, have a poor track record of success. An alternative is to engage directly with the hunting community, promoting the benefits of the farm-bush matrix, supplying evidence of the economic productivity that can be achieved from such landscapes compared to forests. If combined with improved enforcement, and educational activities at the broader village level, that promote wildlife friendly farming practices and seek to attach stigma to illegal hunting activities, then such measures are arguably more likely to drive desirable behavioural change, than comparable demand side interventions. Developing such initiatives with the hunting community may not be unrealistic. Hunters in a number of communities around Kumasi have recently started forming hunting associations in response to the perceived decline in bushmeat resources on which their livelihoods depend (Shanti-Alexander *et al.* in press). These associations are actively engaged with members of the Wildlife Division to find solutions to their loss of livelihood. Galvanising these sentiments represents a valuable opportunity to develop solutions at a grass-roots level.

The clear reality however is that hunting cannot be a viable livelihood choice in modern Ghana, except, perhaps for the few. There have been marked changes in the urban market in recent years (Chapter 3 & 5), indicative of a steady, but definite, decline in resource condition. Our analysis of the socioeconomic drivers of hunting behaviour suggests that wealth, education and income stability increase the probability that hunter will exit a declining bushmeat trade, and reduce the probability that they will increase effort in response to price rises (Chapter 6). There is also evidence that hunters may be caught in poverty traps (Chapter 6), unable to mobilise the necessary resources to overcome either shocks or chronic low-income situations and consequently remain tied to hunting as a livelihood choice (Chapter 6). The reluctance to the exit a declining bushmeat trade, among certain sectors of the community, may be linked to entrenched cultural or traditional values. However, the fact that only 24% of hunters surveyed in Jachie and Kwaman wanted their sons become hunters (Shanti-Alexander 2011), and the lack of interest from non-hunters to participate, suggests cultural values are unlikely to represent a majority perspective. These findings highlight the importance of appropriately targeted investment in social and human capital to empower hunters, and communities in general, to facilitate desirable behaviour change.

7.2.2. Recommendations

The evidence presented in this thesis suggests that in the short term, demand side initiatives are unlikely to lead to a reduction in hunting pressure. Whether due to poverty or tradition, hunting appears deeply embedded in the livelihoods of those who participate, and there is a reluctance to change. No single policy is likely to be successful. A suite of measures is required that drives different components of the system, hunter behaviour, ecosystem conservation and social empowerment. For example, promoting the benefits of hunting in the farm-bush matrix will only be effective at conserving threatened landscapes if accompanied by more rigorous enforcement of existing wildlife regulations. Equally, so long as hunters are socially and economically constrained, they may have few options but to hunt. Alternative livelihood initiatives, education, or micro-finance schemes that help build local capacity should be a priority.

In the long term however, demand needs to be addressed. Commercial hunters are far less likely to stop or reduce hunting even in the face of a dramatic decline in the trade (Chapter 6). A bushmeat trade that is non-selective and sourced, by definition, from wild stocks cannot be sustainable. Consumer education and investment in alternative protein markets (livestock, fisheries etc.) will be necessary to supply the protein demands of consumers. Farmed bushmeat may play a role in this future market, however great care would need to be taken that such actions do not stimulate the unsustainable harvest of wild species.

7.3. Future evolution of the system

Although few hunters in rural communities reported that faster journey times to market would act as an incentive to hunt, rural hunters were significantly more likely to increase effort in response to price rises (Chapter 6). It is logical to assume therefore, that economic and structural development is likely to drive biodiversity loss in remote communities at a greater rate than in those communities where access to lucrative urban markets is already relatively easy (Kramer, Urquhart & Schmitt 2009). Climate change is also likely to have substantial, if unpredictable consequences on these tightly coupled socio-ecological systems. There is a growing body of literature that suggests extreme temperature events, such as the decade-long drought in the Sahel, including Northern Ghana, may become more commonplace (Meehl *et al.* 2000; Rosenzweig *et al.* 2001). Such events are likely to raise the risks of large-scale fire events such as those witnesses in the early 1980's. During this period bushfires decimated more that a third of the agricultural lands in the Ashanti region (Ampadu-Agyei 1988; Arthur & Arthur 2011). Our results suggest these fires were also associated with a dramatic decline in bushmeat productivity that took years to recover (Chapter 4). Climate change may also influence crop production in many regions of Africa (Christensen *et al.* 2007; Conway 2009). Although our results imply that farmers around Kumasi are unlikely to turn to bushmeat hunting to support themselves in the event of crop failure (Chapter 6), nevertheless, with rural communities heavily reliant on their natural resources, and constrained in terms of alternative opportunities, as indicated by the reluctance of farmers and hunters to adapt in times of crisis (Chapter 6), any decline in human wellbeing driven by a degradation of the agricultural sector, will only serve to reduce economic mobility and increase pressure on natural resources. These findings serve to underpin the recommendations for investment in human capital in these communities, to alleviate poverty, and generate new income streams, both as a measure to reduce hunting pressure, and to increase system resilience against future climatic shocks.

7.4. Concluding remarks

Our results highlight the importance of understanding the drivers of bushmeat markets if appropriate management strategies are to be adopted. Contrary to often-assumed wisdom, our analyses suggest the commercial bushmeat trade is not always driven by consumer demand, at least in the short term. The dynamics of bushmeat hunting systems will differ from place to place. Wildlife abundance, rural livelihood profiles, and consumer tastes will vary. The conceptual framework outlined in Chapter 3 however, represents a powerful and universal tool for systematically analysing market dynamics and assessing management options. In addition, the importance of the farm-bush matrix for bushmeat production should not be overlooked. As an industry that is valued in in the hundreds of millions of dollars per year, incorporating bushmeat production into landscape planning and ecosystem service mapping exercises should be standard in systems where bushmeat is exploited. Ultimately, there are no easy solutions to the bushmeat crises. Unified approaches are needed that address the multiple needs of the resource user and promote sustainable demand. Making informed decisions as to where to focus efforts in this broad spectrum of options is crucial to avoid wasted effort and resources, and maximise the chances of success. The analyses presented in this thesis provide valuable tools and research for realising this goal, both in the Kumasi catchment area and other commercial bushmeat systems.

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Appendix A – Supplementary material for Chapter 2

A 1: Schedule of protected species under Ghana Wildlife Conservation Regulations, 1971

SCHEDULE 1

The hunting, capturing or destroying of any species listed in this schedule is absolutely prohibited at all time.

Series A – Mammal	Scientific Name
Primata	
Chimpanzee	Pan troglodytes
Black and White colobus	Colobus polykomos
Olive colobus	Colobus verus
Red colobus	Colobus badius
Diana monkey	Cercopithecus diana
Bosman's potto	Perodicticus potto
Bush baby sp.	Galago senegalensis
Bush baby sp.	Galagoides demidovi
Philidota	
Giant pangolin	Main gigantean
Long tailed pangolin	Manis tetradactyla
Tree pangolin	Manis tricuspis
Tubulidentata:	
Aardvark	Crycteropus afer
Sirenia:	
Manatee	Trichechus senegalensis
Carnivora:	
Lion	Panthera leo
Leopard	Panthera pardus
Cheetah	Acinonyx jubatus
Honey Badger	Mellivora capensis
Clawless otter	Anonyx capensis
Golden cat	Profelis aurata
Lynx	Felis caracal
Serval	Felis serval
African civet	Felis civetta
Two spotted palm civet	Nandinia binotata
Forest genet	Genetta maculata
Wild cat	Felis libyca
Side striped jackal	Canis adutus
Proboscidea:	
Elephant	Loxodonta africana
Rodentia:	
Palm squirrels	Expixerus ebii
Artiodactyla:	
Hippopotamus	Hippopotamus amphibious
Pygmy hippopotamus	Cheropsis libriensis
Senegal hartebeest	Damaliscus lunatus
Sitatunga	Tragelephas spekei
Eland	Taurotragus derbianus
Water chevrontain	Hyyamoshcus aquaticus
Bongo	Boocercus eucrycerus
Roan antelope	Hippotragus equinus
Giant forest hog	Hylochoerus meinertxhgeni

Reed buck	Redunca redunca
Red-fronted gazelle	Gazella rufifrons
Yellow-backed duiker	Cephallophus silvicultor

Series B – Reptile	Scientific Name
Crocodile	
Nile crocodile	Crocodilus niloticus
Long snouted crocodile	Crocodiles cataphratus
Broad fronted crocodile	Osteolaemus tetraspis
Lacertilia:	
Nile monitor	Veranus niloticus
Chelonia: ***all marine turtle***	
Hawksbill turtle	Eretmochelys imbricate
Green or Edible turtle	Chelonia mydas
Leathery turtle	Dermochelys coriacea

Series C – Birds	Scientific Name
All birds of prey *including*:	
Falcons, kites, hawks	Falconidae
Eagles, buzzards, kestrels	Various
Owls	Tytonidae and Strigidae
Egrets:	
Great white egret	Casmarodius albus
Little egret	Egretta garzetta
Cattle egret	Bubulcus ibis
Sagittariidae:	
Secretary bird	Sagittarius serpentarius
***Ciconiidea* (*storks*):**	
Marabou	Leptoptilos crumeniferus
Jabiru or saddle-bill	Ephippiorynchus Senegalensis
Sacred ibis	Threskiornis aethiopicus
Hadada	Hagedashia hagedash
Spotted brested ibis	Lampribis rara
Goliath heron	Typhon goliath
***Balearicidea* (*cranes*):**	
Crowned crane	Balearica pavonina
***hasianidae* (*Game birds*):**	
White breasted Guinea fowl	Agelastes meleagrides
icathartidae:	
Bare headed rock fowl	Picathartes gymnocephalus
terninea:	
All terns	

SCHEDULE 2

The hunting, capturing or destroying of any species listed in the schedule is absolutely prohibited between 1st August and 1st December in any year. The hunting, capturing or destroying of any young or adult accompanied by its young of any species listed in this schedule is absolutely prohibited at all times.

Series A – Mammal	Scientific Name
Primata:	
White colored mangabey	Cerocebus torquatus
Mona monkey	Cercopithecusmona
Spot nosed monkey	Cercopithecus petaurista
Green monkey	Cercopithecus aethiops

Patas monkey	Erythrocebus patas
***Carnivora**:*	
Bush genet	Genetta tigrina
Gambian mongoose	Mungos gambianus
Cusimanse	Mungos obscurus
Dwarf mongoose	Herpestes sanguinus
Marsh mongoose	Atilax paludinosus
White tailed mongoose	Ichenumia albicaudas
Egyptian mongoose	Herpestes inchneumon
Spotted hyena	Crocuta crocuta
Hunting dog	Lycaon Pietus
***Lagomorpha**:*	
Togo hare	Lepus capensis
***Rodentia**:*	
Crested porcupine	Hystrix sp.
Brush tailed porcupine	Artherurus africanus
Pel's flying squirrel	Animalurus peli
Flying squirrel	Animalurus spp.
Pygymy flying squirrel	Idiurus spp.
***Hyracoidea**:*	
Tree bear	Dendrohyrax arboreus
Rock hyrax	Procavia capensis
***Artiodactyla**:*	
Warthog	Phacochoerus aethipicus
Red River hog (bush dog)	Potamochoerus porcus
Bush buck	Tragelaphus scriptus
Buffalo	Syncerus caffer
Western hartebeest	Alcelaphus bucelaphus
Waterbuck	Kobus defassa
Kob	Kobus kob
Oribi	Ourebia ourebi
Royal antelope	Neotragus pgmaeus
Black duiker	Cephaslophus niger
Bay duiker	Cephalophus dorsalis
Red flanked duiker	Cephalophus rufitatus
Red duiker	Cephalophus natalensis
Maxwell's duiker	Cephalophus maxwelli
Gray duiker	Sylvicapra grimmia

Series B – Reptiles	Scientific Name
***Ophidia**:*	
African python	Python sabae
Royal python	Python regia
***Chelonia**:*	
Bell's hinged tortoise	Kinixys belliana
Common hinged tortoise	Kinixys sp.
Gabon terrapin	Pelusios sp.
Marsh terrapin	Polemedusa subrufa
Soft shelled turtle	Trionyx triunguis
***Larcetilla**:*	
Bosc's Monitor	Vearanus exanthematicus

Series C – Birds	Scientific Name
***Psittacidae**:*	
All parrots	
***Columbidae**:*	
All doves and pigeos	
***Musophagidae**:*	
All touracos and plantain eaters	

Ploceidae:	
All weavers, waxbills, man-nikins, bishop bird, fire finches, cordonsbleus, whydahs and canaries	

SCHEDULE 3

The hunting, capturing or destroying of any species listed in this schedule is absolutely prohibited between 1st August and 1st December in any year.

Primata:	
Baboon	Papio anubis
Erinaceidae:	
Hedgehogs	Atelerix, Atelerix & Paraechinus sp.
Rodentia:	
Tree squirrels	Helioscriurus, Funisciurus & Protoxerus Sp.
Ground squirrels	Xerus sp.
Giant rat (pouched rat)	Cricetomys gambianus

Series B – Birds	**Scientific Name**
Phasianidae:	
All francolins (bush fowl)	Fancolinus sp.
Stone partridge	Ptilopacus petrosus
Quails	Coturnix sp.
All Guinea fowls	Numida meleagris & Guttera sp.
Otididae:	
All bustards	Ardeotis arabs, Neotis denhami & Eupodotis melanogaster
Anatidae:	
Hartlaubs's duck	Pteronetta hartlaubii
White faced duck	Dendrocygna viduata
Fulvous duck	Dendrocygna bicolor
Pygmy goose	Nettapus auritus
Knob billed goose	Sarkidiornis melanotos
Egyptian goose	Alopochen aegytiacus
Spur winged goose	Plectropeterus gambensis

SERIES C – OTHER ANIMALS

All other species, other than grasscutter (Thryonomys swinderianus), not specified in the First, Second and this Schedule

Appendix B – Supplementary material for Chapter 3

Appendix B1 – Householiold Surveys

B 1: Household survey instrument

I	**Household Survey**				
	Household Number: Location:	Date: Time:			
Basic Demographics					
1	Number of People in Household (last month)	Adult F	Adult Male	Children (<16)	
2a. b c	Head of Household (Each household member) Ethnicity How many year in village	Male/ Female	Age:	Educational level:	
3	Religion	Christian	Muslim	Other	
4 a b c d e f g	Assets (household) Area of Land owned House type (concrete, wood) Number of animals Number of vehicles mobile phone TV Generator Notes	 Hectares concrete number number cars number number Yes	 wood Bycicles No	 Motorbikes	
5	Estimate total annual household income				
6	How comfortable do you consider yourself?	Struggling	coping	confortable	Well-off
Livelihood screening					
7 a	What are the livelihood activities carried out by household members How often do they do them?	Tick boxes table 1 1. Every day 5. never	 2. Weekly	 3. monthly	 4. rarely

8	Rank livelihood activities as household income source	Table 1			
9	Haw long has the household been involve in the main livelihood for:	1. less than 5	2. less then 10	3. more	
10 b	Membership of an association Name of the Association	Yes	No		
11	Are you a member of any community group				
FARMER (main livelihood)					
1 **2**	What crops are grown on the land? What months are the harvest seasons for each crop?	list			
3	Do you farm primarily for food or income?				
4	Household income per year from farming?				
5	Rank crops in order of income generator				
6 a	If Cocoa: Do you save the money earnt during the cocoa harvest? How many months?				
7	Rank crops in order of regularly eaten for food in the household:				
8 a b c d e	Of crops grown: What proportion of crops are sold to Kumasi What proportion sold to the local market Proportion sold to other households Proportion consumed Other Crop Pests				
9 a	In the last 12 months have your crops been raided? To what extend have they been raided	Yes Percentage:	No		
	Is crop damage a greater concern at a particular time of year? When?				
10 b	Do you hunt on your farm How?	Yes Traps	No guns		
11	What species do you hunt				
12	Why do you hunt	Food	Pest	income	Other
13	How many animals did you catch in the last month				
14	If they sell, what proportion of the catch do they sell?				

Appendix B2 – Hunter Surveys

Table B2: Hunter survey instrument

B	Hunting				
	Individual Number: Location:	Date: Time:			
DEMOGRAPHICS					
1	Sex				
2	Age				
3	Highest Educational level				
4	Ethnicity				
5	How many year in village				
6	What are the livelihood activities carried out?				
7	Do you own any farm land?	Yes	No		
8	Rank livelihood activities as income source				
9	How long have you been a hunter	1. less than 5	2. less then 10	3. More	
10	How comfortable do you consider yourself?	struggling	coping	comfortable	well-off
HUNTING					
11	Do you hunt all year round?	Yes	No		
a	If not what months do you hunt				
	why?				
b	What months do you not hunt				
	why?				
12	When do you hunt	Day	Night		
13	How many hours do you hunt on average?				
14	What equipment / hunting strategy do you use?	Guns	Trap (forest)	Trap (field)	dogs
15	Rank most commonly used strategy	Guns	Trap (forest)	Trap (field)	dogs
16	Number of owned hunting equipments	Guns	Trap (forest)	Trap (field)	dogs

17	What do you spoend most money on?	bullets	Guns	Traps	transport
18	What are the reasons for pursuing hunting? (rank)	Income	Food	Crop Pests	Other
19	What are the peak months for hunting?				
	why?				
20	What are the low months for hunting?				
	why?				
	Heavy Hunting period				
21	Number of hunting days/week for this period	Table 3			
22	Number of caught animals/ week for this period	Table 3			
23	Where do you hunt during this period	Farm	Fallow land	Secondary forest	Primary Forest
24	Which species do you catch most?	Table 4			
25	Which species do you earn most money from?	Table 4			
26	How far do you travel to hunt in this this period?		km		
27	Mode of Transport	Walking	Car	Bike	other
28	Rank own game that is:				
a	Sold locally				
b	Sold to Kumasi / Large town market				
d	Consumed by the household				
	Low hunting period				
29	Number of hunting days/week for this period	Table 3			
30	Number of caught animals/ week for this period	Table 3			
31	Where do you hunt during this period	Farm	Fallow land	Secondary forest	Primary Forest
32	Which species do you catch most?	Table 4			
33	Which species do you earn most money from?	Table 4			
34	How far do you travel to hunt in this this period?		km		
35	Mode of Transport	Walking	Car	Bike	other
36	Rank own game that is:				
a	Sold locally				

b c	Sold to Kumasi / Large town market Consumed by the household
TRADITION AND GENERAL	
37 **38** **39** **40**	Do you use hunting to support your family during times of hardship? Any species that are no longer hunted? Do you percieve rising fuel prices as a disincentive to hunting? (maybe ask inrelation to transport and city markets? During the rainy season is it more difficult to hunt? Are fires a problem in the dry season?
SPECIFICS	
41 a	When did you last go hunting? What did you catch How far did you travel Where did you go
Hunter consumption/trade	
42 **43** **44** **45**	Do you ever buy bushmeat, or only eat what you catch? What species is your favourite to eat? What species do you eat most often? Would you want your son to be a hunter? why?

Appendix B3 – Urban Consumer Survey

Table B3: Urban consumer survey instrument

B	**Consumer**			
	Individual Number: Location:	Date: Time:		
DEMOGRAPHICS				
1	Sex			
2	Age			
3	Tribe			
4	What is your main source of income			
THE QUESTIONS				
5	What type of meat (inc fish) do you eat most of? (Rank)	Bushmeat (which)	Livestock (which)	Fish
6	Of all meat (inc fish) what is your favourite? (Rank)	Bushmeat (which)	Livestock (which)	Fish
7	How often do you eat fish?	Daily	Weekly	Monthly
8	How often do you eat bushmeat?	Daily	Weekly	Monthly
9	Where do you buy your bushmeat	Market	Chopbar	Other
10	If fish was cheap at the market, I would buy more fish and less bushmeat			
11	If the price of bushmeat increased, I would still buy bushmeat.			

Appendix B4 – Bushmeat Trader Survey

Table B4: Trader survey instrument

D	**CHOP BAR OWNER**				
	Individual Number: Location:	Date: Time:			
DEMOGRAPHICS					
1	Sex				
2	Age				
3	Highest Educational level				
4	Ethnicity				
5	How many year in village				
6	What are the livelihood activities carried out?	Farming	Fishing		
7	Do you own any farm land?	Yes	No		
8	Rank livelihood activities as income source				
9	How long have you been a trader	1. less than 5	less then 10	3. More	
10	How comfortable do you consider yourself?	struggling	coping	comfortable	well-off
CHOPPING					
	General				
10	What is your daily income from trading?				
11	Do you sell other types of meat				
12	What do you sell most of (all meat)				
13	What do you make most of your money from (all meat)				
14	Where do you source your meat? (non-bushmeat)				
	Bushmeat				
15	Do you sell bushmeat all year round	Yes	No		
a	if no what months do you trade bushmeat				
16	What is the most valuable species				
17	What is the cheapest species				
18	What are the peak months for trading bushmeat				

	why?					
19	What are the low months?					
	why?					
	Peak Season					
20	How often do you sell bushmeat?	daily	weekly	monthly	rarely	Never
21	What do you sell most of in this period? (Rank..??)					
22	What do you make most money from during this period?					
23	Where you buy your bushmeat from (Rank)					
a	a) Farmers b) Hunters c) Traders d) Other					
24	Who do you sell your meat to (Rank)					
a	Large Town Markets (which ones)					
b	Local Market					
c	Households					
d	Own consumption					
25	What species are more available	Table 6				
26	What species provides the most income?					
	Low Trading months					
27	How often do you sell bushmeat?	daily	weekly	monthly	rarely	Never
28	What do you sell most of in this period? (Rank..??)					
29	What do you make most money from during this period?					
30	Where you buy your bushmeat from (Rank)					
a	F a) Farmers b) Hunters c) Traders d) Other					
31	Who do you sell your meat to (Rank)					
a	Large Town Markets (which ones)					
b	Local Market					
c	Households					
d	Own consumption					
32	What species are more available	Table 6				
33	What species provides the most income?					
SPECIFICS						
34	In the last week how many animals were traded?					

b	From whom goods predominantly bought			
c	To who predominantly sold			
35	What species were traded?	Table 6		
PAST CHNAGES				
36	Has the amoount of bushmeat sold in the village changed	Increased	Decreased	Stayed same
37	Has the composition of species changed?	Y	N	
38	What species are no longer present?	Table 6		
39	Has the price of bushmeat changed? Why?	Increased	Decreased	Stayed same

Appendix C – Supplementary material for Chapter 4

Appendix C1 – Atwemonom market survey June 2011

C 1: One week survey of the Kumasi market, June 2011

Species	Total Number	Total Weight	Price per kilo 2011 price
Grasscutter	260	1226.4	8.71
Giant Rat	40	58.7	5.70
Ground Squirrel	30	54.3	3.84
Bushbuck	25	1139	4.13
Maxwell Duiker	21	175.5	6.26
B.T Porcupine	18	80.3	8.09
Royal Antelope	11	35.2	6.67
Black Duiker	3	77	4.67

Appendix C2 – Instrumental variable validation.

Table C2: OLS regression of instruments on price and quantity. Standard errors are given in parentheses. Significance codes * 5%, **1% and ***0.1%. p-values for model categories (supply, demand and market controls) are calculated using separate F-tests.

	All Species		Rodents		Ungulate		Grasscutter	
Variable	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity
				Supply Shifters				
I	3.13E-04	-7.72E-05	2.38E-04	7.00E-04	2.48E-04	-5.24E-04	2.12E-04	9.42E-04
	(2.32E-04)	*(4.74E-04)*	*(1.84E-04)*	*(6.64E-04)*	*(2.15E-04)*	(5.68E-04)	*(1.91E-04)*	*(6.89E-04)*
L	7.37E-07**	-1.85E-06**	7.94E-07***	-1.20E-06	6.26E-07*	-2.17E-06**	8.81E-07***	-1.31E-06
	(2.82E-07)	*(5.75E-07)*	*(2.23E-07)*	*(8.06E-07)*	*(2.61E-07)*	(6.90E-07)	*(2.35E-07)*	*(8.45E-07)*
M	0.052	0.16	-0.16*	0.18	0.063	0.16	-0.16*	0.13
	(0.073)	*(0.15)*	*(0.064)*	*(0.21)*	*(0.067)*	(0.18)	*(0.068)*	*(0.22)*
R	-1.95E-04	-1.17E-03**	-3.25E-05	-1.19E-03*	-1.86E-04	-1.06E-03*	-3.69E-05	-1.28E-03*
	(1.78E-04)	*(3.64E-04)*	*(1.41E-04)*	*(5.10E-04)*	*(1.65E-04)*	(4.37E-04)	*(1.47E-04)*	*(5.30E-04)*
p-value	*[0.0012]*	*[<0.001]*	*[<0.001]*	*[<0.001]*	*[0.0026]*	*[0.0074]*	*[<0.001]*	*[<0.001]*
				Demand Shifters				
W	0.0081***	0.017***	0.0071***	0.029***	0.0064***	0.0075**	0.0073**	0.031***
	(0.0011)	*(0.0021)*	*(8.28E-04)*	*(0.003)*	*(9.68E-04)*	*(0.0026)*	*(8.67E-04)*	*(0.0031)*
F	0.082*	-0.093	0.053	-0.12	0.093*	-0.095	0.04	-0.12
	(0.041)	*(0.085)*	*(0.033)*	*(0.19)*	*(0.038)*	*(0.10)*	*(0.035)*	*(0.13)*
p-value	*[<0.001]*	*[<0.001]*	*[<0.001]*	*[<0.001]*	*[<0.001]*	*[<0.001]*	*[<0.001]*	*[<0.001]*
				Market Controls				
C	0.039	1.45	-0.34	-2.80*	0.51	3.59***	-0.24	-3.51**
	(0.44)	*(0.89)*	*(0.35)*	*(1.25)*	*(0.40)*	*(1.07)*	*(0.36)*	*(1.29)*
A	-3.89E-07***	1.57E-07(*)	-2.53E-07***	-1.54E-07	-3.69E-07***	3.50E-07**	-2.60E-07***	-1.70E-07
	(4.48E-08)	*(9.15E-08)*	*(3.55E-08)*	*(1.28E-07)*	*(4.15E-08)*	*(1.10E-07)*	*(3.69E-08)*	*(1.33E-07)*
Intercept	7.45***	-0.096	8.00***	-3.34***	7.66***	1.10	8.09***	-4.20***
	(0.28)	*(0.58)*	*(0.22)*	*(0.81)*	*(0.26)*	*(0.69)*	*(0.24)*	*(0.86)*
p-value	*[0.002]*	*[<0.001]*	*[0.91]*	*[<0.001]*	*[<0.001]*	*[<0.001]*	*[0.84]*	*[<0.001]*
p-value	*[<0.001]*	*[<0.001]*	*[<0.001]*	*[<0.001]*	*[<0.001]*	*[<0.001]*	*[<0.001]*	*[<0.001]*
$\bar{R}^2$	*0.48*	*0.47*	*0.50*	*0.53*	*0.48*	*0.24*	*0.49*	*0.57*
Number of Observations	*169*	*169*	*161*	*161*	*161*	*161*	*156*	*156*

Appendix C3 - Correlation matrix of model variables.

Table C3 – Correlation matrix of model variables relating to the econometric model

	I	L	M	R	W	F	C	A	P^a	P^r	P^u	P^g
I	1.00	0.62	0.21	0.06	0.51	0.16	-0.14	0.78	-0.08	0.09	-0.18	0.08
L	0.62	1.00	0.06	-0.14	0.53	0.32	0.02	0.56	0.20	0.36	0.13	0.35
M	0.21	0.06	1.00	0.56	0.02	-0.02	-0.15	-0.02	0.04	-0.06	0.02	-0.05
R	0.06	-0.14	0.56	1.00	0.02	0.02	-0.17	-0.01	-0.04	-0.03	-0.05	-0.04
W	0.51	0.53	0.02	0.02	1.00	0.49	-0.11	0.67	0.32	0.50	0.19	0.49
F	0.16	0.32	-0.02	0.02	0.50	1.00	0.03	0.19	0.38	0.45	0.34	0.43
C	-0.14	0.02	-0.15	-0.17	-0.11	0.03	1.00	-0.16	0.06	0.00	0.15	0.02
A	0.51	0.56	-0.02	-0.01	0.54	0.19	-0.16	1.00	-0.22	0.02	-0.34	0.01
P^a	-0.08	0.20	0.04	-0.04	0.32	0.38	0.06	-0.22	1.00	0.83	0.97	0.82
P^r	0.09	0.36	-0.06	-0.03	0.50	0.45	0.00	0.02	0.83	1.00	0.75	0.99
P^u	-0.18	0.13	0.02	-0.05	0.19	0.34	0.15	-0.34	0.97	0.75	1.00	0.75
P^g	0.08	0.35	-0.05	-0.04	0.49	0.43	0.02	0.01	0.82	0.99	0.75	1.00

Symbol	Description
I	Income (agriculture)
L	Labour (agriculture)
M	Maize season (pest proxy)
R	Rainfall
W	Wealth
F	Fish price
C	CPI
A	Ashanti Population
P^a	Bushmeat price (all)
P^r	Bushmeat price (rodent)
P^u	Bushmeat price (ungulate)
P^g	Bushmeat price (grasscutter)

Appendix C4 –Durbin Watson autocorrelation tests

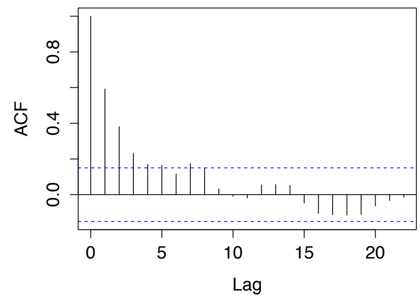
Appendix C4: Results of the Durbin Watson test for autocorrelation. Test statistic takes a value between 0 and 4, where 2 implies no autocorrelation, vales < 2 positive autocorrelation and values > 2 negative autocorrelation. Lower and bound figure is presented from the Durbin Watson Significance tables, where n = 180 and k (the number of regressors) = 8 (supply model) and 5 (demand model). Values below the lower are statistically significant. The upper bound is not presented as no test statistic lay in this region (i.e. all autocorrelation was positive).

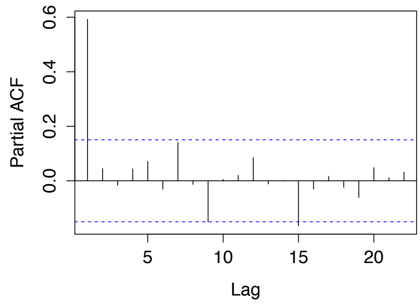
Model	**DW test statistic Supply function (Lower bound 1.637)**	**DW test statistic Demand function (Lower bound 1.665)**
All species	0.53	0.84
Ungulates	0.60	0.82
Rodents	0.75	1.10
Grasscutters	1.02	1.33

Appendix C5 – Autocorrelation and Partial Autocorrelation functions

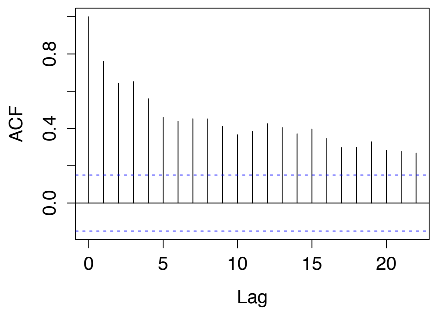
C5.1 All Species

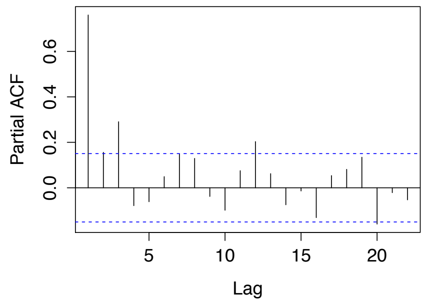
Demand function





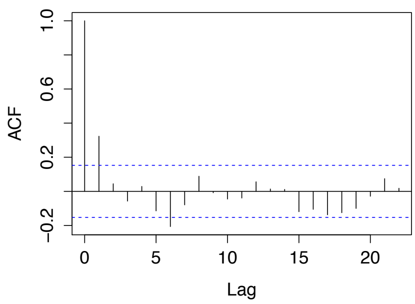
Supply function

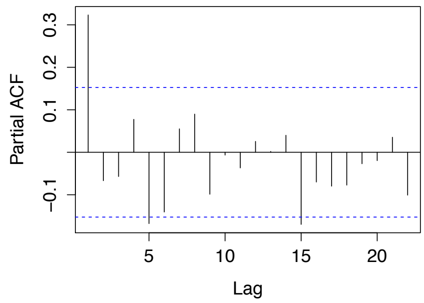




C5.2 Grasscutter

Demand function





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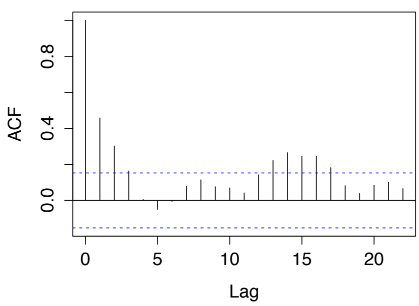
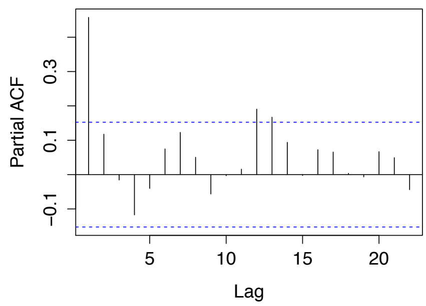
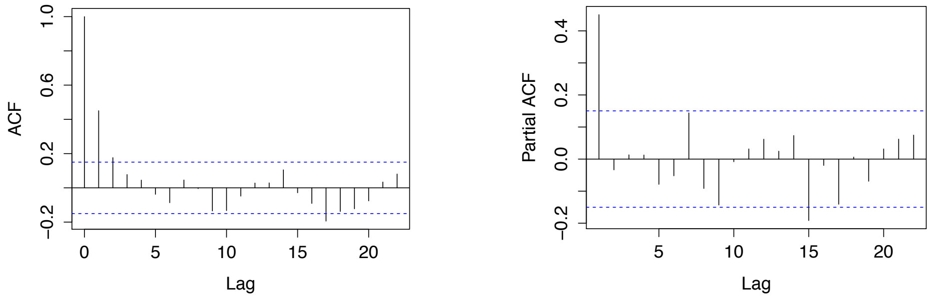


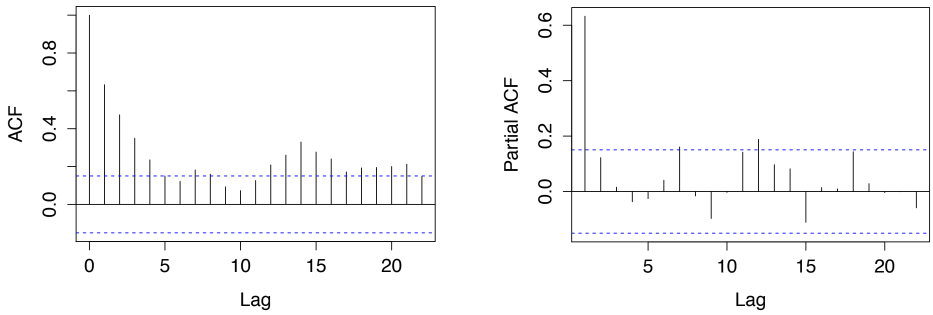


C5.3 Rodent

Demand function

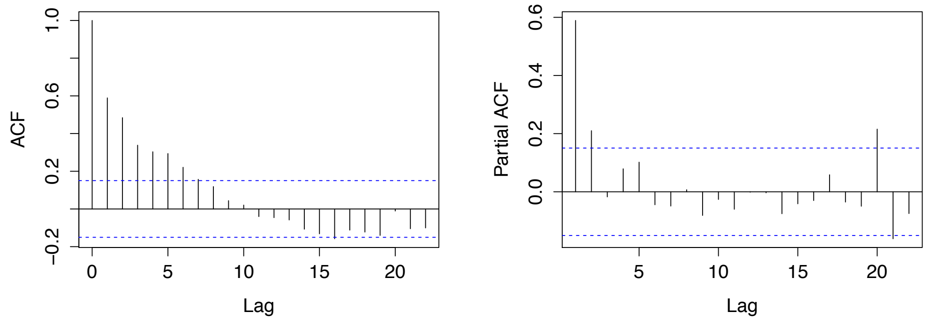


Supply function



C5.4 Ungulate

Demand function



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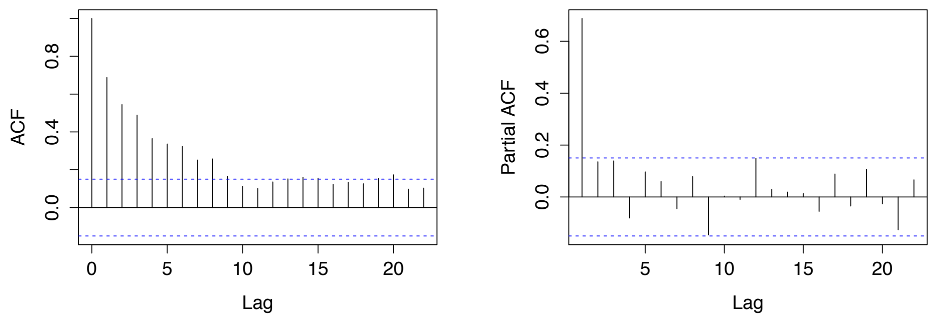

Appendix C6 – Supply and Demand model, 1983 bushfire

Table C6: Results of three-stage least square regression for the two subsamples, one prior to the 1982 bushfires, and two for the period following the fires. Time interval of the regression is month. The response variable is the log of the average number of animals recorded on the market per day in any given month. Standard errors are given in parentheses. Significance codes * 5%, **1% and ***0.1%.

Time period	1979 - 1982	1982 - 1986	1982 - 1989
		Supply Model	
Intercept	0.87 *(22.2)*	35.6 *(77.0)*	-11.3 *(16.8)*
ln(P)	1.87 *(3.31)*	-2.16 *(6.30)*	1.04 *(1.51)*
I	-0.0025 *(0.0036)*	-6.64E-06 *(0.0027)*	6.15E-04 *(0.0011)*
L	-4.96E-07 *(1.11E-06)*	4.67E-08 *(4.98E-06)*	-1.90E-06 *(1.07E-06)*
M	-0.68 *(0.66)*	0.12 *(1.73)*	-0.47* *(0.35)*
R	0.0018 *(0.0034)*	-1.48E-04 *(0.0041)*	-3.70E-04 *(6.93E-04)*
C	4.49 *(4.30)*	-0.58 *(1.84)*	-0.57 *(0.97)*
A	-5.13E-06* *(2.17E-06)*	-6.41E-06 *(9.63E-06)*	2.15E-06 *(1.34E-06)*
Number of observations	*24*	*22*	*56*
p-value	*<0.05*	*> 0.05 (n.s)*	*<0.05*
		Demand Model	
Intercept	-1.67 *(9.23)*	33.6 *(17.7)*	21.1 *(15.9)*
ln(P)	-1.25 *(0.89)*	-1.89 *(1.45)*	-2.15 *(1.55)*
W	0.045 *(0.020)*	-0.0019 *(0.012)*	0.019* *(0.0077)*
ln(F)	0.16 *(0.27)*	-0.011 *(0.23)*	0.019 *(0.17)*
C	1.92 *(1.08)*	-0.65 *(1.36)*	0.30 *(1.16)*
A	2.21E-06 *(3.18E-06)*	-6.46E-06 *(3.39E-06)*	-1.28E-06 *(1.51E-06)*
Number of observations	*24*	*22*	*56*
p-value	*<0.05*	*<0.05*	*<0.05*

Appendix D – Supplementary material for chapter 5.

Appendix D – Correlation matrix of model variables

D 1: Correlation matrix of model variables. Values are Pearson correlation coefficients.

	Disturbance	Distance	Hunting Density	Protected Area	Year
Disturbance	1	0.33	-0.38	0.47	-0.29
Distance		1	-0.79	0.42	-0.04
Hunting Density			1	-0.48	-0.00
Protected Area				1	-0.05

Appendix E – Supplementary material for Chapter 6

Appendix E1 – Threats to the bushmeat trade

E 1 Greatest threats to the bushmeat trade as reported by hunters, N = 90

Threat	Percentage of respondents
Bushfires	60
Deforestation and agricultural expansion	45
Overhunting	26

Appendix E2 – Scenario Analysis Questionnaire (Socio-economics, hunters and non-hunters)

E 2: Scenario analysis survey instruments

SOCIOECONOMIC INDICATORS	
Scenario Analysis – Socioeconomic profiles	
Socio Economic Indicators Primary livelihood Number of livelihoods in the household (i.e how many different work activities are carried out to earn money) Equipment owned (bicycle, moto, car) Generator Age Education Level Number of people in household Do you ever sell bushmeat anywhere other than Atwemonom / Anyimaye / Asumura?	
SCENARIO ANALYSES	
Hunter Scenarios	**Non- Hunter Scenarios**
Scenario 1	
Leading question:	
How long does it take you to travel to Kumasi?	
Q. If the time taken to travel to Kumasi was reduced by	Q. If the time taken to travel to Kumasi was reduced by
a) 25%	a) 25%
b) 50%	b) 50%
c) 75%	c) 75%
Would you	Would you
a) Stop hunting	a) Do nothing
b) Continue hunting as normal	a) Begin hunting

c) Hunt more or adapt	c) Change another aspect of your livelihood strategy
Hunter Scenarios	**Non- Hunter Scenarios**
Scenario 2	
Leading question:	
How far do you have to travel to reach to closest forest?	
Q. If the time taken to travel to the forest increased by	Not relevant
a) 25%	
b) 50%	
c) 75%	
Would you	
a) Stop hunitng	
b) Continue hunting as normal	
c) Hunt more or adapt	
Hunter Scenarios	**Non- Hunter Scenarios**
Scenario 3	
Leading question:	
How many animals do you catch a month?	
Q. If the number of animals you caught in a month fell by	Q. If the number of animals being caught in a month increased by
a) 25%	a) 25%
b) 50%	b) 50%
c) 75%	c) 75%
Would you	Would you
a) Stop hunitng	a) Do nothing
b) Continue hunting as normal	a) Begin hunting
c) Hunt more or adapt	c) Change another aspect of your livelihood strategy
Hunter Scenarios	**Non- Hunter Scenarios**
Scenario 4	
Leading question: None	

Q. If the price you received per carcass at market increased by	Q. If the price of bushmeat per carcass at market increased by
a) 25%	a) 25%
b) 50%	b) 50%
c) 75%	c) 75%
Would you	Would you
a) Stop hunitng	a) Do nothing
b) Continue hunting as normal	a) Begin hunting
c) Hunt more or adapt	c) Change another aspect of your livelihood strategy
Hunter Scenarios	**Non- Hunter Scenarios**
Scenarion 5	
Leading question: None	
Q. If the price you received per carcass at market decreased by	Not relevant
a) 25%	
b) 50%	
c) 75%	
Would you	
a) Stop hunitng	
b) Continue hunting as normal	
c) Change or adapt the way you hunt in some way	
Hunter Scenarios	**Non- Hunter Scenarios**
Scenario 6	
Leading question:	
What are the main crops you grow?	
Q. If agricultural productivity fell, and the number of bags you	Q. If agricultural productivity fell, and the number of bags you
produced decreased by	produced decreased by
a) 25%	a) 25%
b) 50%	b) 50%

c) 75%	c) 75%
Would you	Would you
a) Stop hunitng	a) Do nothing
b) Continue hunting as normal	a) Begin hunting
c) Hunt more or adapt	c) Change another aspect of your livelihood strategy