Economic instruments for supplying agrobiodiversity conservation

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Declaration

I, Warwick Wainwright, declare that:

a) This thesis was composed by myself
b) The work contained herein is my own, except where clearly stated
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Abstract

Agrobiodiversity is declining across global farm production systems. These declines transcend both farm animal genetic resources (FAnGR) and plant genetic resources (PGR) – the focus of this PhD. Both can sustain greater adaptability and resilience in commercial production through so called ‘option value’. In addition, PGR and FAnGR embody cultural and heritage attributes that are often absent in global agriculture, but remain valued by society. Conservation is therefore important and economic incentives represent a potential supply-side mechanism to improve the status of rare breeds, cultivars and crop wild relatives. Yet, the exploration of incentive instruments for their conservation remains underexplored but may improve economic efficiency and conservation outcomes. Using different survey instruments and modelling approaches (including choice modelling, linear programming and multi criteria decision analysis) I investigate how rationalising incentive support, through more targeted interventions, could result in pro-conservation outcomes.

The findings suggest optimising subsidy support relies on three key factors. First, conservation contracts offered to farmers for conservation should reflect local farm business preferences and circumstances. This includes addressing barriers-to-entry in conservation programmes and the design of contractual schemes, that when improved will likely increase participation in conservation contracts. Second, identifying least cost suppliers of conservation services may enable more diversity to be conserved at comparable cost. Third, optimising what species, varieties and breeds are supported may improve conservation outcomes through more rational investments in diversity. Policy responses to address declining agrobiodiversity should consider the use of tender instruments (i.e. reverse auctions) to identify least cost suppliers for conservation services. Optimisation modelling and decision analysis techniques can be used to measure trade-offs inherent in different conservation goals, including social equity and diversity. Ultimately there is a need to balance the supply of use and non-use values of diversity that span the total economic value framework. While the drive for sustainable intensification of production may improve productivity, we need to be clear how breed and cultivar diversity can be encompassed into future policy priorities that reflect the need for greater food security plus cultural and heritage value attributes. The implications of deploying new and potentially disruptive technologies (i.e. gene editing) in the context of farm diversity are discussed.

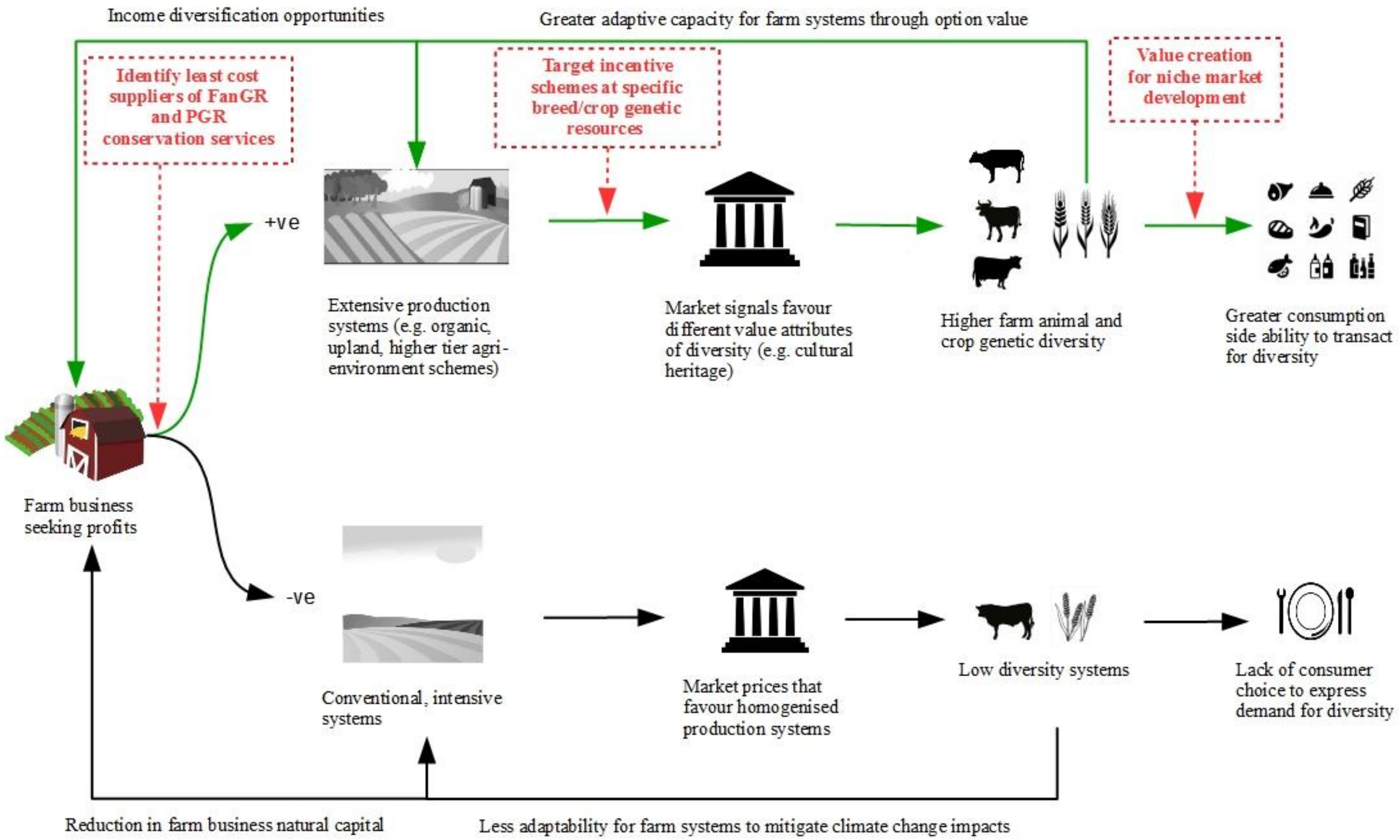
Lay summary

Farm systems globally are becoming more uniform and more reliant on a small sub-set of livestock breeds and crop varieties for food production. This is because the economics of production favours the most productive varieties and breeds in the pursuit of profit. This narrowing of the genetic base is having an adverse effect on production sustainability and food security, most notably a loss of adaptive capacity challenges that include land degradation and climate change. In addition, many genetic resources are synonymous with different regions and cultures and are valued for reasons beyond food production. While there is a recognisable need to conserve so-called farm animal genetic resources (FAnGR) and plant genetic resources (PGR) in agriculture there have been few studies exploring how conservation approaches could be improved. This work addresses this gap, though the application of different modelling approaches that aim to explore how conservation agencies (usually government departments and non-governmental organisations) can ultimately improve the cost effectiveness of conservation programs. Results of this thesis suggest three key factors that may improve conservation outcomes.

First, conservation contracts that pay farmers subsides for conserving genetic diversity must reflect the local circumstances in which farmers operate. Farmer preferences and farm businesses are variable. This is particularly true when contrasting developed and developing countries, but also different regional contexts. Ensuring contractual schemes match farm business circumstances and preferences will likely increase participation in conservation programmes. Second, novel approaches to identify least cost suppliers of conservation services can be used by conservation agencies to reduce cost. These competitive tenders allow farmers to bid to supply conservation services relative to a pre-defined contract (similar to tendering for construction contracts). Employing such approaches ensures suppliers that deliver the greatest benefits relative to the cost can be selected as conservation service providers. Third, developing indicators to better monitor the status of rare breeds can lead to improved decision making concerning where investments in genetic resources should be prioritised and the different activities that should be funded.

Ultimately, while there is a need to improve the sustainability of global food production there is also a need to consider non-productive factors in agriculture. These include adaptability, resilience, cultural and heritage values that reflect the fabric of rural landscapes. Supplying these different value attributes makes sound economic sense.

Graphical abstract



Graphical depiction of the thesis key findings according to alternative farm production pathways. Note: the red dotted arrows indicate interventions that can be used to improve current conservation approaches; the green arrows show positive interactions while the black arrows are negative.

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List of abbreviations

AES	Agri-environment scheme
AI	Artificial insemination
ASC	Alternative specific constant
BIF	Breed improvement fund
BLP	Binary linear programming
CAP	Common Agricultural Policy
CBD	Convention on Biological Diversity
CE	Choice experiment
CL	Contract length
COS	Subsidy
CSA	Climate smart agriculture
CT	Competition tender
CWR	Crop wild relatives
DEFRA	Department for Environment, Food and Rural Affairs
DNA	Deoxyribonucleic acid
FAnGR	Farm Animal Genetic Resources
FAO	Food and Agricultural Organisation
FGD	Focus group discussion
FMD	Foot and Mouth Disease
GAP	Global Plan of Action
GIS	Geographical information system
GMA	Game management area
IPBES	The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
HNV	High Nature Value
IPCC	Intergovernmental Panel on Climate Change
LP	Linear programming
MCDA	Multi-criteria decision analysis
MNL	Multinomial logit model
NBAR	Native breed at risk
Ne	Effective population size
NGO	Non-governmental organisation

N0	Non-contract option
RBST	Rare Breeds Survival Trust
RDP	Rural Development Programme
RP	Revealed preference methods
RPL	Random parameters logit
PA	Protected area
PACS	Payments for agrobiodiveristy conservation services
PC	Principal component
PCA	Principal component analysis
PDO	Product designation of origin
PES	Payments for ecosystem services
PGR	Plant genetic resources
SADC	South African Development Community
SI	Sustainable agricultural intensification
SP	Stated preference methods
SOS	Structure of scheme
SS	Scheme support
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total economic value
TSG	Traditional specialities guaranteed
WTA	Willingness to accept
WTP	Willingness to pay
ZARI	Zambia Agriculture Research Institute

Chapter one

Introduction

1.1 Agricultural production challenges

Global agricultural production is at a crossroads. On the one side, the need to produce more food more cheaply is homogenising production systems with dramatic consequences for biodiversity, ecosystems and biomes. On the other, population growth, changing consumption patterns, rising incomes and globalisation are changing what and where food is consumed. Meanwhile, global production of meat is projected to more than double from 258 million tonnes in 2006 to 455 million tonnes in 2050, whilst milk production is expected to grow from 664 to 1,077 million tonnes (Alexandratos and Bruinsma, 2012). The Food and Agriculture Organization (FAO) has estimated annual global production of crops will need to increase by 60% from 2006 levels by 2050 to keep pace with rising demand (FAO, 2016).

Potential yield gains for crops and livestock are hindered by widespread land degradation, land scarcity, and climate change, which threaten where and how much food we can produce (D'Odorico et al., 2014; Tai et al., 2014; Alexander et al., 2015; Webb et al., 2017). A review conducted for the Intergovernmental Panel on Climate Change (IPCC) suggests climate change will adversely effect crop yields post 2030 (Porter et al., 2014), and these impacts will vary regionally in response to precipitation variation and temperature change (De Pinto et al., 2016). For livestock, climate change related impacts will likely decrease meat and milk production primarily due to changing quality of forage (Chapman et al., 2012), pest/disease prevalence (Nardone et al., 2010; Bett et al., 2017) and water availability (Thornton et al., 2009; Havlík et al., 2015). Webb et al. (2017) and Bommarco et al. (2018) suggest retaining biodiversity and ecosystem services in agriculture are paramount to meeting these food security challenges.

Meanwhile, farm systems worldwide are being homogenised in pursuit of productivity goals that are at the expense of local diversity and farm-systems resilience (Tscharntke et al., 2012; IPES-Food, 2016). Reduction in diversity increases vulnerability to climatic and other stresses, raises risks for individual farmers, and undermines the adaptability of agriculture to meet future drivers of change (Thrupp, 2000).

1.2 Agrobiodiversity is undersupplied

Agrobiodiversity (see Figure 1.1) can be broadly defined as all domesticated biodiversity (i.e. crops and livestock) within agricultural systems, plus non-domesticated biodiversity that interplay in various ways with the health and functioning of agricultural systems (Pascual et al., 2011). The former is declining primarily in response to farm intensification, which has eroded natural capital in many agroecosystems (Chaplin-Kramer et al., 2015; Tsiafouli et al., 2015).

Global agriculture is increasingly reliant on a limited subgroup of plant and animal diversity. Only 15 animal species account for 90% of livestock production (Villanueva et al., 2004). Just 12 plant species worldwide provide more than 70% of all human calorific intake from arable crops (Frison et al., 2012). Within these species, a declining number of breeds and varieties are responsible for the majority of production (FAO, 2015a; Gruber, 2017). Yet, the ability to grow crops and graze pastures in challenging environments, particularly those most affected by climate change, will require adaptive genetic resources. Rojas-Downing et al. (2017) suggests crop and animal diversification are the most promising adaption measures for climate change and this suggests a role for farm animal genetic resources (FAnGR) and plant genetic resources (PGR) for agriculture.

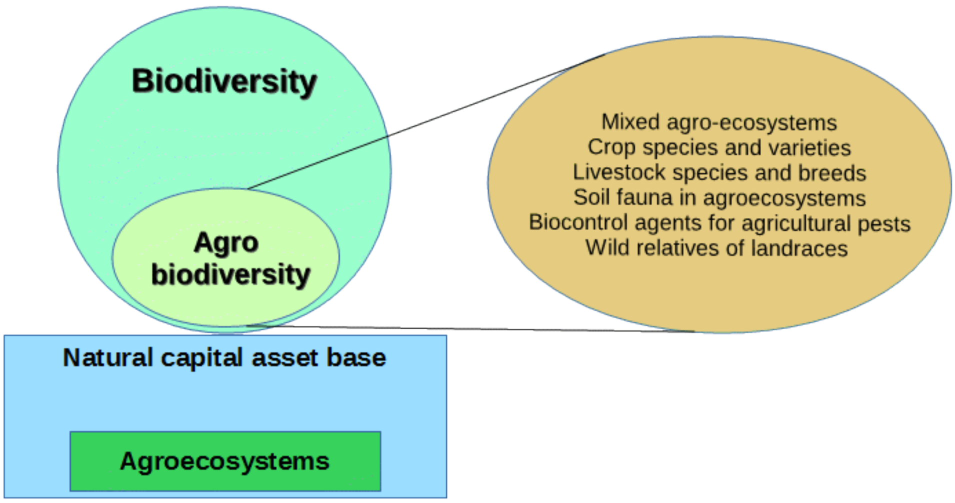

Figure 1.1: Biodiversity and agrobiodiversity are underpinned by sustaining natural capital and agroecosystems. The various elements that comprise agrobiodiveristy are outlined. Adapted from FAO (2004).

FAnGR can be defined as the avian and mammalian species used for food production, while PGR comprises cultivars and their wild relatives (FAO, 2015b). Both facets of diversity are undersupplied and this can be appreciated with reference to the economic conceptual framework that suggests diversity is a public good whose value is not captured by markets. As such this element can lack an explicit value for providers (Pearce and Moran, 1994). Diversity is therefore not considered in the cost of food production and this leads to undersupply as farmers ‘disinvest’ in pursuit of profit (Pascual and Perrings, 2007; Sustainable Food Trust, 2017). The resulting market failure has homogenised production landscapes worldwide and corrective measures are necessary to supply more diversity through policies that govern food production and biological resource use (IPES-Food, 2016).

The need to conserve genetic resources for agriculture has been formally recognized by the Convention on Biological Diversity (CBD) Aichi Biodiversity Targets (CBD, 2013) and various international declarations[1]. Recent work by The Economics of Ecosystems and Biodiversity for Agriculture and Food (TEEBAgriFood) has stressed the importance of valuing natural capital in agroecosystems, and the need to invest in agrobiodiversity for future food security (TEEB, 2018). This is further stressed by The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2018), which suggests such investments make sound economic sense, i.e. the benefits generally outweigh the costs.

But while much work has explored the costs and benefits of preserving biodiversity, much less has focused on the supply and demand side aspects of agrobiodiversity. Work by Bioversity International (2018) has begun to offer insights by exploring the use of payments for agrobiodiversity conservation services (PACS) for the delivery of agrobiodiveristy from private land via incentives (e.g. Narloch et al., 2011, 2013; Pascual et al., 2011; Krishna et al., 2013). The thesis develops this agenda further by focusing on a key literature gap: how to improve the design of agrobiodiveristy incentive schemes for better conservation outcomes.

[1] The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) was effective from 2004 while the Global Plan of Action (GPA) for FAnGR was adopted in 2007.

1.3 Economic incentives to supply more diversity

Economic incentives can address market failures through a range of policy tools including regulation, taxation, certification, and subsides. Incentives work by influencing the behaviours of actors and firms through the alteration of market signals, and have become an increasingly popular way to address a range of environmental problems, including biodiversity loss (Tietenberg and Lewis, 2016). Market-based incentives are preferred because they offer more flexibility than 'command and control' policies that typically require firms to adhere to minimum standards or regulations (de Vries and Hanley, 2016). These tend to be more costly ways of insuring compliance with environmental objectives (OECD, 2018).

The advantages of market-based approaches extend to voluntary incentive schemes, such as payments for ecosystem services (PES), where landowners are rewarded for supplying ecosystem services on private lands (Farley and Costanza, 2010). While incentive instruments for biodiversity are proving more popular worldwide, funding limitations are a major constraint (McCarthy et al., 2012; Waldron et al., 2013). Moreover, buyers of conservation services (usually governments) often face uncertainty and lack of information on how the costs of supplying diversity are distributed across landowners. The conservation benefits can also vary across sites (and genetic resources). This poses challenges to the design of incentive mechanisms in being both effective and efficient at sustaining agrobiodiveristy improvements by targeting lowest cost providers. It is therefore of interest to explore how the design of incentive schemes can be made more (cost) effective.

Globally, incentive schemes specifically targeting PGR conservation are uncommon as most conservation occurs either *ex situ* or in protected areas and reserves rather than on-farm (FAO, 2010; Frese et al., 2014). Where such schemes are implemented, they generally work by providing landowners with a fixed payment (per ha) for providing conservation services (Pascual et al., 2011). Similarly, schemes for FAnGR provide fixed payments (usually per animal) to landowners for conserving rare breeds (Kompan et al., 2014). The key problem with such uniform payment schemes is adverse selection – i.e. payment levels might not actually relate to the actual costs of participation for scheme entrants, resulting in over-compensation due to information asymmetries (de Vries and Hanley, 2016). Additionally, fixed price schemes are seldom differentiated based on different value attributes of diversity or extinction risk and few target specific suppliers (agents) of conservation services. The challenge of revealing suppliers true opportunity cost, preferences for conservation contracts and overall costs/benefits from conservation investments has given rise to a range of empirical approaches that can be used to better inform policy. This thesis considers three approaches to improve conservation policy design.

Choice modelling has been a common approach to elicit landowner preferences for the design of conservation schemes and to measure willingness to accept (WTA) monetary rewards for contracts, thereby revealing cost heterogeneity (e.g. Ruto and Garrod, 2009; Greiner, 2015). Such approaches have been used to identify factors that may impact participation in schemes (e.g. contract length) and ultimately the cost of implementing schemes under specific contractual terms (Hanley et al., 2012). Alternatively, conservation auctions are an incentive based mechanism that can potentially deal with the issues of adverse selection, information asymmetry and poor cost effectiveness by promoting price competition amongst landowners opting to supply conservation services (Windle and Rolfe, 2008; Whitten, 2017). Such approaches can be combined with optimisation modelling to maximise a certain objective function relative to various constraints, and have been shown to outperform fixed priced schemes (Rolfe et al., 2017). Lastly, decision support tools, such as multi criteria decision analysis (MCDA), have emerged to combine technical information and stakeholder preferences to appraise costs/benefits of different project alternatives (Adem Esmail and Geneletti, 2018). Despite an urgent need to rationalise investments for more effective conservation outcomes the development of simple decision making frameworks to guide investments in agrobiodiveristy has been lacking (Bruford et al., 2015; Verrier et al., 2015).

1.4 Aims and objectives

The contribution of this thesis lies in the application of different modelling approaches (outlined below) to explore how incentive instruments could be improved or implemented to support PGR and FAnGR conservation. Developing rationalised incentive instruments for FAnGR conservation is a stated research and policy challenge outlined by Cardellino and Boyazoglu (2009), while the need for on-farm conservation of PGR through PES type schemes has been noted by Wale et al. (2011). This work therefore improves our understanding of the likely costs of maintaining farm system diversity and the role of supply side instruments and incentives to affect (good) conservation outcomes in developed and developing countries. The specific aims are too:

- Explore the measurement of “diversity” as a public good, with a focus on genetic metrics that denote difference
- Determine the use and non-use values of FAnGR and to evaluate how such values are supplied across different institutions, including the market
- Outline key proximate threats to FAnGR, and to consider how these threats can be addressed by different supply side mechanisms
- Explore the factors driving farmer choice of breeds and motivations for participating in conservation schemes
- Measure farmer WTA contracts for conserving rare breeds in small-scale farm systems through different contract options using a choice experiment (CE)
- Explore cost heterogeneity for supplying PGR conservation services using a competitive tender mechanism
- Use linear programming (LP) to assess how different site selection goals impact the cost of establishing an incentive scheme for PGR
- Develop a decision analysis framework using MCDA to prioritise investments in rare breeds according to different value attributes of diversity

The objective of the thesis is to explore the current supply of animal and, to a lesser extent plant diversity, with a view to developing our understanding of the potential cost of supplying more diversity through incentive instruments. The former will broadly consider how contractual forms might be improved under existing agri environmental schemes (AES) or stand-alone schemes (e.g. PES), and how investments in such schemes can be rationalised for better conservation outcomes. The thesis is comprised of four studies, each presented as individual multidisciplinary chapters.

Chapter 2 provides a review of public good characteristics associated with rare breeds and is complimented by discourse concerning how institutions mediate rare breed conservation. Multiple proximate threats to diversity and issues pertaining to the use of incentive support schemes are discussed. Chapter 3 employs choice modelling to determine farmer preferences for rare breed conservation contracts in Romania. Uptake in conservation programmes is modelled based on various payment scenarios related to farmer WTA conservation subsides.

Barriers-to-entry that may preclude farmers from enrolling in incentive schemes are discussed, particularly in the context of small-scale producers where conservation arguably has a pivotal role to play. Chapter 4 describes a competitive tender (CT) survey applied in Zambia to identify least cost conservation service providers for crop wild relative (CWR) conservation. An LP model is used to demonstrate how selection of conservation sites and service providers can be optimised, subject to multiple diversity and social equity constraints. The appropriateness of selection under certain selection goals is discussed alongside resource needs and costs for national scale CWR conservation programmes. Chapter 5 provides an application of MCDA to determine how livestock breeds (in the UK) could be prioritised to maximise returns on investments in diversity. Ethical arguments around prioritisation are provided alongside consideration of potential trade-offs between different conservation goals. Finally, Chapter 6 offers conclusions and recommendations from the thesis, plus suggestions for further work.

The data from the three empirical chapters of the PhD can be accessed form a repository on Github (see https://github.com/wainwrigh).

Chapter two

Valuing rare livestock breeds and farm animal genetic diversity: preferences, institutions and prospects

Abstract

This chapter considers the state of rare livestock breeds and farm animal genetic resources (FAnGR) in the context of global biodiversity conservation and agricultural development trajectories that may favour forms of intensification and breed homogenisation. We focus on European Union (EU) and particularly United Kingdom (UK) FAnGR conservation where the percentage of breeds classified as 'at risk' is above the global average and rising. The chapter considers the demand-side value concepts that apply to breed attributes and considers how institutions mediate or respond to wider societal preferences for conservation. We consider that rare breeds span the tensions between conservation of cultural capital and the need to maintain productivity options in pursuit of sustainable agricultural intensification (SI). Economic issues such as forms of market failure appear to exacerbate breed status and diversity. We suggest policy options and highlight important considerations concerning the use of policy instruments to balance conservation for use (production), cultural and option values.

2.1 Introduction

Climate change, associated resource scarcities, population growth and shifting dietary preferences are reshaping global agriculture with increasing calls for sustainable intensification (SI) of production (Nellemann et al., 2009; Godfray et al., 2010). SI generally refers to resource use efficiency in production plus the management of demand or consumption for some products (Garnett et al., 2013). Both approaches are typically but not exclusively focussed on the reduction of environmental externalities arising from agriculture. Within this discourse the management of other public goods is less clearly articulated, particularly notions of cultural capital and diversity of farm systems that provide national or local public good properties. Arguably, these attributes are most closely linked to public support for more sustainable production and we need to be clear how they feature in future priorities concerning SI.

In the UK and Europe, broader discussion concerning intensification has been most conspicuous regarding technological change, economies of scale, and the need to farm for profit. The advent of so-called mega dairies is, for many, symbolic of the anxieties of rural and urban populations actively or passively engaged in the debate about future farming systems. As a form of production efficiency, intensification in housed or confined feeding systems is often negatively ingrained in public perceptions that associate large scale housing systems with lower welfare conditions than externally grazed animals (Scholten, 2014). They are also seen as part of a supply chain re-configuration tilting the economics of production against small farms (Anderson and Harper, 2003).

Less clearly articulated or measured is the perceived accelerating homogenisation in systems, with the intensive dairy production debate representing a deeper psychological diminishment related to the perceived irreversible loss of both biological and cultural heritage and production options (Daugstad et al., 2006). In truth, breed homogenisation (the reliance on few breeds for animal production) is a result of centuries of deliberate breeding for trait specialisation, accelerated by globalisation and the rise of multinational breeding companies supported by reproductive technologies such as artificial insemination (AI) (Hoffmann, 2010). In this context, the institutions and incentives for breed and diversity preservation become crucial to counterbalance a tendency to breed for productivity and economic benefit at the expense of cultural heritage and diversity (Drucker, 2010). The latter is important because it allows breeders to incorporate new traits into future breeding lines, thereby ensuring greater resilience in livestock systems against continuous technological and environmental change. Meanwhile, the heritage dimensions of rare breeds often relate to rural identities through so-called sense of place; that is the geographic characteristics of specific regions and landscapes. Yet, surprisingly little is documented concerning public preferences for breed preservation and this complicates the interpretation of institutional successes or failures regarding conservation agendas and public demand for breed-related public goods.

Livestock breeding agency is often spatially explicit and is most pronounced in developed countries where investments in breeding technologies are generally higher. Breed diversity is therefore unevenly distributed (FAO, 2007a) and while developed countries may harbour fewer but more advanced (commercial) breeding lines, developing countries may possess a greater proportion of the world's breeds that are well adapted to indigenous extensive production systems. Yet, the importation of improved 'exotic' breeds poses a serious threat to indigenous breeds in developing countries (Rege and Gibson, 2003) and is homogenising global breed genetic diversity. Thus, actions in both developed and developing countries are necessary to reduce further declines in diversity.

The UK is particularly important for farm animal genetic resources (FAnGR) conservation given it has approximately 700 breeds, or 9% of global livestock breeds, across the major farm species (cattle, sheep, goats, pigs, horses ponies and poultry). Some133 of these are native (excluding poultry) of which 106, or 80%, are classified as a native breed at risk (NBAR) by the Department for Environment, Food and Rural Affairs (Defra, 2016) The Rare Breeds Survival Trust (RBST, 2017) suggests 17 of these breeds can be considered as 'critical' or 'endangered' populations on their 'watchlist'. Urgent action is therefore required to prevent the loss of these breeds with some discrimination in terms of the relevant values that they encode.

This chapter reviews the roles and responsibilities of institutions and how they are supplying the public good dimensions of rare breeds. We consider institutional contributions to global and national efforts for rare animal breed conservation and the preservation of FAnGR more generally. Many of the observations can equally apply to PGR but the focus on animals reflects lower levels of international effort on livestock genetic resources conservation and more specific issues in terms of resource conservation by collective voluntary effort *in situ*. While providing international context, the chapter focusses on factors in the UK, considering the roles played by voluntary and market-led initiatives. We conceptualise the public good cultural and biological elements embodied in rare breeds and convey the tensions between market failures and institutions (some of which face challenges outside of their control) that may be conserving for different reasons. This discourse helps to understand current competing objectives that may be pulling the economics of conservation in opposing directions.

Section two of this review considers relevant metrics of diversity and rarity and more objective genetic measures of difference. We also define the values associated with diversity and rarity concepts, including public good values and the need for producers to capture these largely non-market values as a return to conservation efforts. Section three considers institutional responses including market-based incentives to transact for public good values. Section four considers how these responses can be used to address identifiable proximate threats to rare breed conservation, including SI. Section five provides conclusions.

2.2 Characterising rarity, diversity and FAnGR

Much commonly observed farm or agri-diversity is a result of long-standing human stewardship and is an adjunct to a sub-set of broader naturally occurring biological diversity (Evans and Yarwood, 2000). This stewardship and agency is evident in both producer breeding decisions and demand-side preferences for use and non-use of species. As with wild species, farmed or domesticated animals can be classified using the common diversity nomenclature of species and genes, as well as their functional role in specific agro ecosystems. Rare breeds embody additional morphological, physiological and territorial attributes that can define their cultural status, but that do not necessarily match more objective genetic metrics denoting biological difference (Gandini and Villa, 2003). There is therefore a potential tension between a focus on FAnGR for productivity and other socially desirable breed attributes.

Criteria used to define a breed are usually based on population structure, genetic and phenotypic attributes that are objectively and subjectively measured, whilst acknowledging the social organisations and institutional frameworks that support cultivation. Table 2.1 outlines national and international breed definitions.

Table 2.1: Breed definitions by multilateral, ministerial and non-governmental organisation

Organisation and reference	**Definition of a breed**
Food and Agricultural Organisation (FAO, 1999)	A sub specific group of domestic livestock with definable and identifiable external characteristics that enable it to be separated by visual appraisal from other similarly defined groups within the same species or a group for which geographical and/or cultural separation from phenotypically similar groups has led to acceptance of its separate identity.
Department for Environment, Food and Rural Affairs (Defra, 2013)	An interbreeding population of husbanded or formerly husbanded domesticated animals of consistent genotype and phenotype with a recognised history and administrative framework.
Rare Breeds Survival Trust (RBST, 2014)	A group of animals that has been selected by humans to possess a set of inherited characteristics that distinguishes it from other animals within the same species.

Breeds may be at risk because they suffer from low actual or effective population sizes, have low genetic variability, are geographically isolated, or face challenges adapting to a particular environment (Carson et al., 2009; Simm et al., 2004; Villanueva et al., 2004). The FAO defines livestock breed risk as dependent on male and female population sizes. Further differentiation between species with high and low reproductive capacity, population trends and pedigree, i.e. the recorded ancestry of an animal, is also used (FAO, 2015a).

The EU defines risk assessment thresholds for the purposes of providing conservation incentive payments to farmers. Calculations are based on the number of breeding females summed across all EU countries with separate thresholds for each species (Alderson, 2009). Thresholds are conservative but, as argued by Gandini et al., (2004), preventing loss of a population is easier than restoration. Other breed watch list criteria add heritage dimensions. For example, in addition to the number of breeding females, the RBST requires continuous existence of the breed for 75 years and at least two criteria from a list including: a) accepted herd book registrations for six generations; b) <20% genetic contribution from other breeds; c) parent breeds used in the formation of the breed are no longer available. DEFRA (2012) classify a NBAR as satisfying similar criteria. Hence, even crude endangerment metrics are accommodating both option/insurance value and recognising historical pedigree.

2.2.1 Measuring diversity

Genetic diversity, both within and between breeds, represents an objective metric to guide conservation decisions. Low numerical populations within a breed can result in a range of negative implications including inbreeding depression (reduced fitness of a given population due to matings of related individuals); population bottlenecks (sharp reductions in population size that reduce variation in the gene pool), and genetic drift (fixation of alleles[2]). Matings of related animals, inevitable in closed populations but occurring at different rates, leads to an increase in the frequency of animals that carry two identical copies of the alleles present at a given locus (the position on the chromosome where the gene occurs). These animals are termed homozygotes. The higher the degree of homozygosity, the lower the genetic diversity in a population and vice versa (Falconer and Mackay, 1996). Maximisation of diversity generally relies on ensuring matings between more distantly related individuals to maintain variation within the population (Hartl et al., 1997).

Numerical estimates of breeding population size employed as proximate indicators of population diversity can be a poor determinant of within-breed genetic variation, particularly because not all animals of breeding age contribute to the next generation (Koenig and Simianer, 2006; Weigel, 2001). This has given rise to a number of metrics to determine more accurately the genetic diversity and structure of breeding populations.

Within breed diversity can be measured most accurately by molecular approaches, but a commonly used alternative statistical indicator is effective population size, *Ne*. *Ne* is defined as the number of reproducing individuals, bred in an idealized population (ideal refers to a hypothetical population with a constant population size, equal sex ratio, and no immigration, emigration, mutation, or selection) that leads to the same decrease of genetic diversity as the population being studied (Harmon and Braude, 2010). *Ne* is a globally accepted measure of within-breed genetic diversity and can be measured crudely through numerical population data of males and females (Wright, 1931), but more accurately through

[2] An 'allele' is an alternative form of a gene that can be found at the same place on a chromosome that encodes for a specific trait but in various forms - e.g. coat colour (Falconer and Mackay, 1996).

the use of ancestral pedigree records that detail specific matings between individuals and their lineage (Cervantes et al., 2011).

Between breed diversity is often measured by phylogenetic methods that describe the evolution of a species or breed, being based on the assumption that more closely related breeds will embody similar characteristics. Studies generally use molecular data to infer genetic breed divergence (Nei, 1972, 1987). This approach has been proposed for decision making in biodiversity conservation where decisions are framed as maximising difference for minimum cost (Weitzman, 1993), and the need to identify unique breeds for conservation priority setting (Bruford et al., 2004). However, different methodologies to calculate genetic distance lead to fundamentally different recommendations for breed prioritisation (Baumung et al., 2004). The complexity of accounting for the phylogenetic component of diversity in farm animal breeds and the need to maintain desired levels of variation within those breeds may produce conflicting management strategies (Bruford et al., 2003). Thus, development of diversity indicators seeking to maximise diversity conservation using within and between breed diversity might not always be desirable or possible.

Recent progress in genetics means animals can be characterised at greater speed and detail with decreasing cost. As such, genetic diversity in farm animals is becoming recognized as a highly significant resource (Bowles, 2015). Advances in DNA (deoxyribonucleic acid) sequencing technologies, coupled with availability of single nucleotide polymorphisms (SNP) chips[3] for most farm animal species, means molecular approaches are increasingly used for breed improvement including work addressing global sheep and cattle diversity (Decker et al., 2014; Hayes, 2009; Kijas et al., 2009; Wengel et al., 2015). However, many applications of new molecular technologies focus on enhancing productive traits in commercially leading breeds (Bowles, 2015). This has resulted in a divergence between current state-of-the-art tools to characterise genetic resources and application to many non-commercial, or rare, breeds (Bruford et al., 2015).

In parallel, a number of other socially valuable traits (e.g. methane emissions intensity or fatty acids profile in milk and meat) are yet to be intensively selected for, but this may change in the future following work to address climate change, nutrition and health

[3] A DNA sequence variation occurring when a single nucleotide in the genome differs between members of a species or paired chromosomes in an individual (ISoGG, 2017)

(Hayes et al., 2013). Application of new technologies, including genomic selection[4], whole-genome sequencing[5] and gene editing[6] will also be critical in addressing these challenges (Hayes et al., 2013; Newman and Ausubel, 2016; Boichard et al., 2015). Such technologies may permit rapid identification of beneficial traits at decreasing cost. At the same time, the resurrection of extinct species or their close genetic proxies is becoming a technical possibility (Bennett et al., 2017) but this raises further questions concerning human attitudes towards species and their social value.

2.2.2 Defining value

Breeding and conservation decisions reveal different facets of private and social value that can be complementary or mutually exclusive. In the context of agricultural reform and potential system transformations, clarity on these values may help to define incentives and alternative institutional roles on both the supply (producer) and demand (public and consumers) sides. In broad terms rare breeds can be defined using the total economic value (TEV) taxonomy (Table 2.2) where 'economic' refers to the variety of societal preferences typically expressed in relation to status of the resource (Roosen et al., 2005). Breed attributes are most clearly demanded for their contribution to market products that provide a proximate incentive for producers, breeders and to a lesser extent, consumers, to support conservation. In practical terms this suggests an emphasis on adaptive or productive traits embodied within certain breeds for commercial use primarily through the maintenance of FAnGR collections for potential future use and option value (Hoffmann, 2010). These attributes are largely private and excludable in production and consumption but this focus can crowd-out some other public good attributes where demand is harder to identify and measure.

Significant non-market value categories are indirect, optional and existence values (Pearce and Moran, 1994) which act as strong incentives for supplying both rarity and genetic difference (Tamminen, 2015). These values are often more complex to estimate (Christie et al., 2006). Indirect value derives from the functional role of an animal in a specific system. Thus, some breeds may be valued for the way they contribute to farm resilience or because they are relatively efficient or less polluting and resource-intensive per

[4] Augmenting prediction of the genetic merit of animals from markers covering the genome.
[5] The process of determining the complete DNA sequence of an organism's genome.
[6] A type of genetic engineering allowing the insertion, deletion or replacement of DNA at a specific site in the genome of an organism or cell.

unit product. Thus, their value relates to the environmental objective they serve relative to another breed.

Table 2.2: use and non-use values associated with FAnGR

Type of value	**Description**
Direct use	- Food or fibre; tourism; breeding programmes
Indirect use	- Risk aversion (farm income); climate change adaption; landscape management
Option values	- A portfolio for future breeding programmes hedging against risk
Existence values	- Value from knowing rare breeds exist irrespective of any other uses
Bequest values	- Value from the knowledge that future generations might benefit from breed diversity in the future
Cultural values	- Cultural heritage preference that arguably cross-cuts use and non-use motives
Intrinsic values	- The value of a breed irrespective of human agency and preferences

Option value suggests maintaining the largest portfolio of assets or resources, in this case genetic diversity, as insurance for potential agri-food sector adaptation to environmental change or changing consumer preferences. This might encompass private and public good eventualities although the public good dimensions may be undersupplied by markets. The categories of cultural and bequest value suggest intergenerational preferences maintained by keepers of rare breeds whose value often overlap commercial systems (Yarwood and Evans, 1999). These values are commonly embedded in geographical denominations that are also signifiers of specific production systems, for example ‘terroir’ in France (Bérard and Marchenay, 1996, 2006) and ‘streuobst’ in Germany (Herzog, 1998). Existence and intrinsic values are more complex. The former derives from knowing a resource exists irrespective of other use (UK NEA, 2011). This is sometimes conflated with intrinsic value, which by definition is outside the domain of utilitarian value systems (Davidson, 2013).

Private and public value incentives overlap, with many producers supplying breeds and genetic material motivated by non-market value to safeguard traditional breeds, often with support but sometimes voluntarily (Gibson et al., 2006). Supplier and consumer preferences can also overlap in that consumers can reveal preferences for rare breeds out-with marketable products, as well as for the market products they provide. While preferences may overlap, the current status of many breeds reveals an extent of both market and institutional failure that need to be addressed more systematically in the face of new threats posed by global environmental change and the ways we respond.

2.3 Institutions and instruments

Institutional and policy responses can be judged on how they address information and market failures that undermine producer and consumer incentives. Private and public sector actors have a complementary role in correcting market failure, improving information and regulating supply; in some cases creating new markets and incentive mechanisms that can transact between public preferences and a conservation effort.

2.3.1 Multilateral organisations

Supranational bodies and multilateral organisations (e.g. United Nations) work to set common conservation standards across nations. Above centres of formal and informal conservation and breeding effort, global conservation initiatives are implemented via international agreements. Most prominent is the Convention on Biological Diversity (CBD), a global institutional arrangement defining conservation obligations. The important institutional objective is the need for improved information on global species conservation, including values and benefits, and the challenges of national sovereignty and unmet needs (or costs). The CBD objectives have been reinforced by the Aichi Biodiversity targets (2011-2020), which highlight the need to strengthen conservation of rare farm animal breeds.

The CBD overlaps the FAO's role as a global platform for information provision on best practice for food security. The FAO working groups address the provision of global public goods and the failures inherent in markets to supply them without interventions. Its Commission on Genetic Resources for Food and Agriculture identifies global conservation priorities for PGR and FAnGR and seeks governmental commitment to combat diversity loss (Hoffmann and Scherf, 2010).

2.3.2 Markets

Global agreements and institutions seek to moderate or enhance the role of markets, which are a fundamental driver of conservation behaviours. As institutions that broker the exchange of value, markets typically fail to allow the transaction of public good values thereby depriving producers of a return on conservation effort. On the demand side, consumers can only use market transactions to a limited extent to signal preferences, mainly for labelled products that clearly convey some information on diversity and rarity status. Consumers cannot demand what producers and other supply chain agents do not supply. Thus, while successful in some small-scale initiatives, formal markets are limited in their influence.

A second form of market failure lies in the nature of imperfect competition that allows the prevalence of market power at key points of supply chains. This can encourage homogenisation in production, deliberately or inadvertently driving diversity from systems as a cost-saving measure through greater optimisation. Such failure is increasingly prevalent as agri-food systems become more concentrated across fewer input suppliers, processors and retailers (Burch and Lawrence, 2005). These distinct failures require different solutions. In the first case, non-market valuation of costs and benefits is a prerequisite for market development. In the second, government intervention may be necessary to regulate supply chains or to offer incentives for the maintenance of diversity in production methods and the way products are labelled.

2.3.3 Non market valuation

Revelation of non-market values and their internalisation in decision making has been a focus of economic research seeking to correct market failure in the supply of public goods (Macmillan et al., 2002; White et al., 2001). The costs and benefits of each breed will vary depending on biophysical and social context, which can be appreciated when set in an ecosystem services framework (Figure 2.1).

This framework allows management options to be directly and indirectly linked to ecosystem service flows and societal values. The latter can then be quantified using revealed preference (RP) or stated preference (SP) methods (Bateman et al., 2011). The former uses existing market data and transactions to infer value. Thus, as well as buying products from rare breeds, an individual may travel some distance to visit a rare breed or be willing to pay to enter a farm park housing rare breeds. SP uses non-market data to reveal both use and non-use values associated with a wide range of goods and services. This usually involves surveys constructing hypothetical markets to elicit respondent preferences or willingness to pay (WTP) directly.

Several papers have acknowledged the largely non-market element of cultural value associated with rare breeds (Gandini and Villa, 2003; Martin-Collado et al., 2014; Roosen et al., 2005; Zander et al., 2013) and high WTP for conservation services (Zander and Drucker, 2008; Ahtiainen and Pouta, 2011; Martin-Collado et al., 2014), revealing the need for *in-situ* conservation strategies to supply such values. These values often relate to anthropocentric attributes such as charisma, rarity and heritage goods like sense of place, history and tradition (Christie et al., 2006; Tempelman and Cardellino, 2007). Inevitably, due to bounded rationality, preferences tend to favour breeds with richer histories (e.g. Aberdeen Angus cattle), distinctive phenotypic appearances (e.g. Highland cattle), and strong sense of place (e.g. Herdwick Sheep). Such preferences can crowd-out lesser-appreciated breeds emphasising the importance of institutions that improve information and wider appreciation.

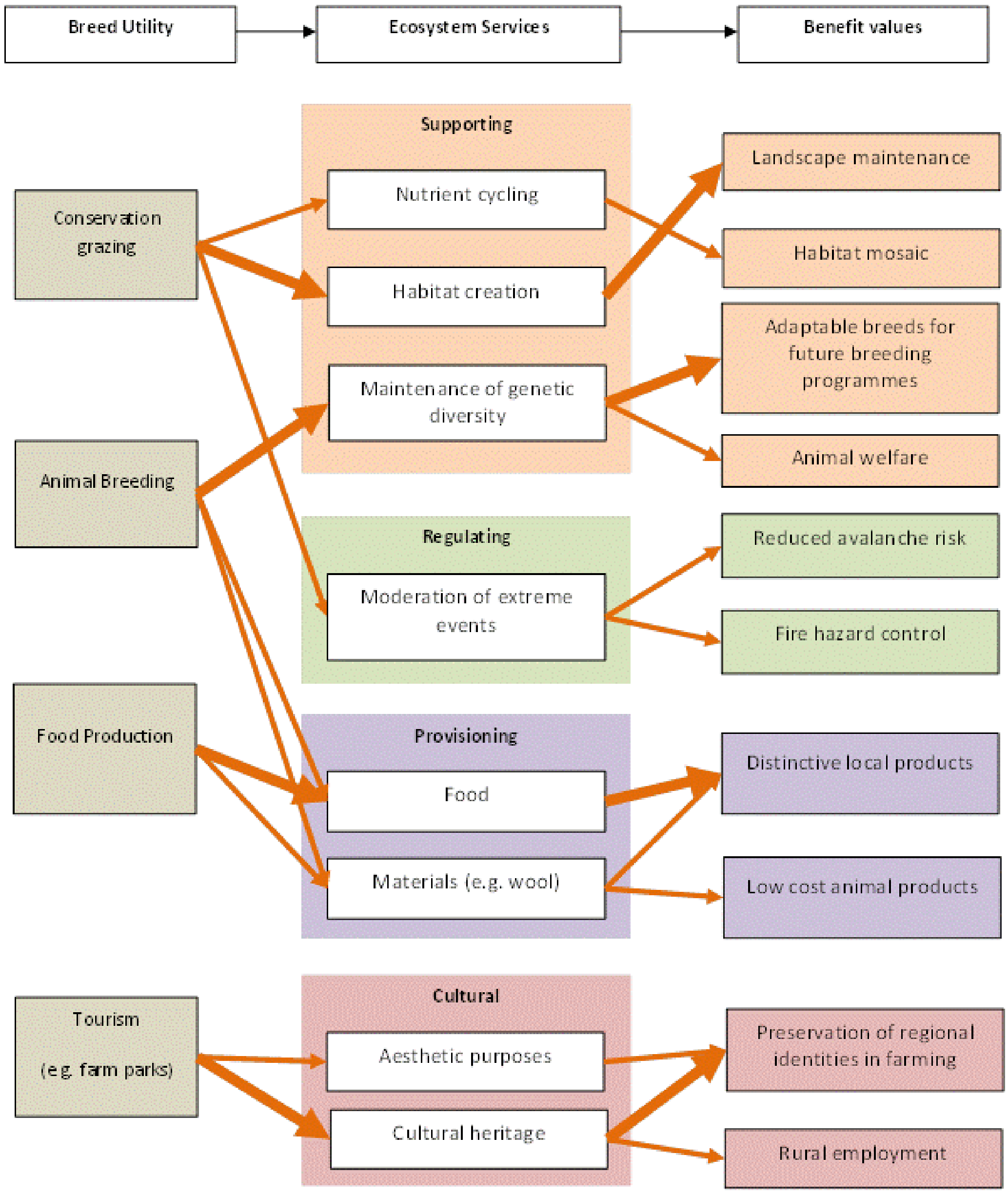

Figure 2.1: Ecosystem services associated with conservation of FAnGR, dependant on the breed. Arrow width indicates the strength of linkages between each process.

2.3.4 Market creation and supply-side incentives

Correcting market failure is the objective of incentive structures that reward producers from public and private sources. Government can intervene as a surrogate for consumer demand using mechanisms under pre-existing farm support schemes such as the EU Common Agricultural Policy (CAP), or through public and private surrogate markets including PES or PACS schemes.

Interest in PES has increased in the last decade in recognition of potential efficiencies related to private-to-private transactions for the supply of environmental benefits. Novel conservation mechanisms for rare breeds have been widely discussed (e.g. Carson et al., 2009; Ligda and Zjalic, 2011; Simianer et al., 2003; Simon, 1999) and the concept of PACS is mooted to incentivise the supply of domesticated plant and animal diversity. PACS is advantageous because it can be combined with protocol for the rational prioritisation of cultivars and breeds (e.g. Cañón et al., 2001; Fadlaoui et al., 2005; Martín-Collado et al., 2013; Reist-Marti et al., 2003; Zander et al., 2009). In addition, PACS can be used in conjunction with a safe minimum standards approach (Drucker, 2006) and competitive tenders (CT)[7] that permit the identification of least cost conservation service providers (Narloch et al., 2013, 2011; Pascual et al., 2011). While CTs have been piloted in PGR (Narloch et al., 2013) and biodiversity conservation (Blackmore and Doole, 2013) their use in rare breed conservation remains under-explored.

2.3.5 Public subsidy schemes and regulation

Information failures mean market-based approaches are slow to emerge, and support is usually provided through public subsidy schemes or interventions supporting diversity and fostering market development. In Europe, public support for FAnGR works through three main policy vehicles: the CAP, including subsidy schemes and specific agricultural regulations (e.g. The EU Animal Health Law), biodiversity legislation (e.g. The EU Biodiversity Strategy to 2020) and eco-labelling and certification of origin schemes (e.g. Product Designation of Origin (PDO)). The latter help to make breeds economically self-sustaining and have been promoted for minority breeds that produce desirable products. PDO schemes offer important valorisation opportunities for traditional breed keepers (Zjalic et al., 2012) allowing consumers to express demand for specific breed-related attributes. Such mechanisms only offer a limited demand-side correction of market failure, tending to favour breeds with greater market potential.

EU subsidy payments can be initiated through Rural Development Programme (RDP), the CAP or under the discretion of national policies (Hall, 2013). Relevant conservation policies often have multiple objectives, for example conservation grazing that

[7] An auction process where environmental services are more efficiently procured from landholders using either public or private funds (Windle and Rolfe, 2008).

meets wider landscape goals (Yarwood and Evans, 2003) and financial support given to farmers rearing 'local breeds in danger of abandonment' (Ligda and Zjalic, 2011). Analysis of European subsidy programmes by Kompan et al (2014) indicates inconsistent conservation approaches across Europe. While many countries reported increasing numerical population sizes of breeds, there is little indication any objective measures of diversity are used to optimise conservation.

2.3.6 National bodies – the case of the UK

In the UK a range of policy measures influence rare breed conservation with additional oversight form the FAnGR Committee, which acts as an independent non-departmental advisory body to the UK government (Small, 2013). Several UK conservation initiatives operate through agri-environmental schemes (AES) linked to the delivery of habitat management (Van Diepen et al., 2007).

Natural England, a non-departmental public body responsible for management of England's natural environment, used conservation grazing supplements (worth £70 / ha) to support NBAR (Natural England, 2012). These have been widely adopted, and from 2005 to 2015 there were 1,468 agreements covering ~59,244 ha (Natural England, 2015). These supplements have recently been increased to £94 / ha for the period 2015 to 2020. Evidence suggests supplements have benefited sheep and cattle breeds most while equine and pig breeds are in severe decline, suggesting a need for differentiated conservation incentives (Defra, 2016).

2.3.7 Domestic and international non-governmental organisations (NGO's)

NGO's deliver support for FAnGR conservation through breeding activities, training of farmers, promotion of local products and public awareness (SAVE Foundation, 2004). Their activities complement governmental conservation efforts and around 18 out of 35 European countries reportedly have specialised NGO's for conservation (Kompan et al., 2014). They also provide a powerful social network for breeders, policy makers, genetic resource managers and academics (Hall, 2013). NGO's are arguably more focussed supplying the public good characteristics of conservation (i.e. cultural and existence value) as opposed to genes or traits of commercial interest.

In the UK, the RBST serves as an important communication platform between stakeholders, strengthening collective actions to reduce decline in rare breeds (Gamborg and Sandøe, 2005). They have worked to promote rare breed food products alongside introducing conservation grazing initiatives for NBAR with the National Trust, a charitable conservation organisation with statutory powers (Van Diepen et al., 2007). RBST activities also support *ex-situ* conservation, managing the UK's largest heritage genebank for native breeds.

Breed societies act as essential information centres through the operation of pedigree registers that are fundamental to the maintenance of genetic variation within breeds. However, maintaining accurate pedigree records in appropriate data formats largely depends on the technical ability of staff (Hall, 2013). Despite being cultural strongholds, the involvement of new actors in breed societies can lead to institutional changes that inevitably augment tensions between different stakeholders with diverging interests (Labatut, 2013). The level to which change is tolerated and encouraged within a breeding group could reduce or increase the desirability of a breed (Lauvie et al., 2014). This reveals attitudes towards breed evolution that may be desirable from a commercial perspective, but less so from a cultural viewpoint. In extreme cases, these tensions have led to the divergence of breed societies into separate institutions representing now distinct breeds (e.g. Aberdeen Angus and Aberdeen Angus Original).

2.3.8 Private sector breeding and retailing

As noted, imperfect competition represents a distinct form of market failure of relevance to the maintenance of diversity. Breeding efforts in the private sector, including breeding companies and commercial breeders, typically follow a pyramid structure with an elite or nucleus herd at the top, followed by one or more middle tiers of pure bred (or cross bred) multipliers which feed into a final commercial flock or herd (Simm, 1998). This has resulted in a highly consolidated breeding sector for poultry (DEFRA, 2006a), pigs (Laval et al., 2000) and dairy (Mc Parland et al., 2007) leading to substantial rates of genetic gain in many breeds but a reduction of genetic diversity (Taberlet et al., 2008).

In contrast, the beef and sheep sectors encompass a more fragmented breeding system as all tiers of the breeding pyramid are usually operated by individual breeders (Simm, 1998) resulting in higher levels of breed diversity (Todd et al., 2011). This diversity is partly a consequence of breeding history but also the nature of beef and sheep systems, which require a range of genotypes to optimise production in characteristically extensive systems (Morgan-Davies et al., 2014).

Supply chain processors and retailers further impact diversity through demand for animal products of consistent quality, appearance and size, in response to both consumer preferences and supply chain optimisation. This has tended to favour the highest yielding breeds that offer better economic performance (Notter, 1999). Several supermarkets now sell traditional breed specialised product lines (e.g. Hereford beef) responding to consumer demand for improved meat quality. For example, Morrisons (a large UK retailer) supports conservation through price premiums of 30p/kg for Shorthorn beef and 10p/kg for traditional breed beef cuts, and latest figures from the British Cattle Movement Service have shown an 18% rise in registrations of Beef Shorthorn calves (Morrisons, 2015).

While the former suggests a clear dichotomy between private and third sector conservation goals that is expressed through interventions that target different elements of the TEV spectrum, there are perhaps some overlapping wants and needs that concern the creation of markets for rare and traditional breed produce. Forging third and private sector partnerships may therefore aid in stimulating niche market development whilst retaining the fundamental requisites of conservation.

2.3.9 National and international *ex-situ* storage

Ex-situ collections complement *in-situ* approaches and represent a potentially lower cost effort to develop stores of diversity offering insurance against future uncertainty. Gene banks target protected commercial material for breeding lines and public collections are curated more to protect non-market attributes of genetic diversity. *Ex-situ* programmes for farm animals are less common than *in-situ* approaches (FAO, 2015a) which may represent the technological constraints associated with *ex-situ* storage of genetic material from some species (FAO, 2012). Gene banks are advantageous as they offer protection from disease epidemics, but a major limitation is the inability of genetic material to adapt and evolve over time (Defra, 2006b). Ultimately, *ex-situ* strategies alone do not solve the conservation challenge but do make an important contribution to insuring a back-up for *in-situ* efforts.

Many genebanks are operated at the national, rather than international, scale (Boettcher and Akin, 2010) and collection sizes vary in terms of scope and coverage (Paiva et al., 2014). Most develop collections based on rare, native and endangered breeds and are currently more active in storage than distribution(Hiemstra, 2015). This means characterisation and utilisation of genetic material remains low in contrast to *in-situ* approaches.

Developing regional or species level core collections of material is an idea supported by the FAO (FAO, 2012) and could make an important contribution to the optimisation of gene-banking by avoiding costly redundancy in collections. While some overlap is important from an insurance perspective (i.e. if one collection fails), reducing inefficiencies through greater integration will allow more samples of ‘unique’ material to be stored and characterised. New research initiatives are addressing these issues by identifying rational approaches for the collection and integration of genetic material (Hiemstra, 2015).

2.4 Discussion

The fate of rare breeds depends increasingly on the effectiveness of institutions to correct the fundamental issue of market failures that undervalue or prevent the expression of public preferences for rare breeds. This fundamental failure accentuates proximate threats to diversity loss including homogenisation of agri-systems, and overarching threats related to climate change and emerging disease risks. Proximate threats and their responses are often politically driven by societal preferences concerning the management of sovereign resources. In the UK, Brexit will impact how NBAR are managed and supported via changing policy frameworks and incentives that govern conservation. First, we address SI and two overarching threats.

2.4.1 Sustainable Intensification (SI)

The fate of FAnGR and rare breeds is inevitably intertwined with agricultural systems in which they have co-evolved, sometimes in completely unsuitable environments (Yarwood and Evans, 1998). In the UK and Europe this has inevitably been linked to incentives and disincentives inherent in the CAP and more recently the rhetoric of SI. The latter is a contested concept (Loos et al., 2014; Rockström et al., 2016) but generally refers to resource use efficiency in production combined with modified consumption. The SI imperative is a policy and industry response to the ‘perfect storm’ rhetoric, which includes population growth, changing consumption preferences and resource scarcities that are exacerbated by climate change.

Much of the discomfort felt about SI is that it could distract from factors other than efficiency gains (Godfray and Garnett, 2014). In this context, the SI literature is unclear on the role of cultural and heritage value attributes in farming systems and breeds. Such values receive little mention in SI other than signalling their proximate correlation with breeds that tend to perform well in marginal environments (Morgan-Davies et al., 2014). These areas are the focus of production under some climate scenarios (Pascual et al., 2011). Conway (2012) has suggested SI might be decomposed into a series of sub-objectives including genetic intensification of plant and animal breeding. Balancing these activities with investments in diversity, as a form of breeding option, is gaining importance as the difference between intensively and extensively managed breeds becomes more pronounced.

SI advocates the use of advanced genetic technologies, such as genomic selection and gene editing to promote greater production efficiencies. Both are disruptive technologies and it is unclear how they will impact breed diversity and conservation going forward (Bruford et al., 2015). While it is likely consumer demand will influence how this technology is deployed, SI as a paradigm needs to be clear how we consider public and private values in advanced livestock breeding.

2.4.2 Climate change

The consequences of climate change are likely to feature increased risk to geographically restricted or vulnerable rare breed populations more prone to disturbances (Hoffmann, 2010). Intensive and housed livestock systems have more potential for adaptation through the adoption of technological innovation but with greater reliance on external inputs to meet production goals (Berckmans, 2014). For grass fed systems, where the rate of technological adoption is considered to be lower, more risk is perceived (Anderson, 2004).

In areas most at risk to climate change (i.e. sub-Saharan Africa) severe environmental changes are anticipated (Pachauri et al., 2014) and these will impact agro-ecological production characteristics including changes to farm animal breed suitability and distribution (FAO, 2017a). The risks are therefore potential yield reductions arising from a lack of adaptive capacity due to genetic uniformity in breeding stock. It is therefore imperative to consider conservation options that are most appropriate to ensure adaptive capacity.

While *ex situ* conservation has been suggested as a mitigation measure, there is an indication that despite being sheltered from disease epidemics, collections may be increasingly vulnerable given the inability of genetic material to adapt and evolve over time. Such collections are simply not comprehensive enough to provide adequate safeguards and require updating periodically. In contrast, *in-situ* approaches have the major advantage that genetic material can continuously adapt and evolve and is promoted by Thrall et al., (2011) as ‘evolutionary agriculture’. Adaptations, such as disease and heat resistance, drought tolerance and ability to cope with poor quality feed, are valuable characteristics of a breed which, when stored *ex-situ*, are unlikely to be characterised with the same ease as *in-situ* approaches (Hoffmann, 2010).

In recognising the threats arising from climate change, opportunities may emerge to develop and promote livestock systems with greater environmental, economic and social resilience to risk (Howden et al., 2007). Adaptation requires diversified farming systems and local adaptation planning, which are facets of climate smart agriculture (CSA). CSA involves three elements: increasing agricultural productivity to support food security; improved adaptive capacity at multiple levels and reducing greenhouse gas (GHG) emissions and increasing carbon sinks (Campbell et al., 2014). Improving adaptive capacity is largely centred on fostering ecosystem services in agri-systems that enhance resilience. Here, systems and breed diversity make an important contribution through the adoption of locally adapted breeds and husbandry practices (Kantanen et al., 2015). Such responses may simultaneously contribute to GHG mitigation since locally adapted breeds often have higher feed conversion ratios on marginal grazing land, thus resulting in lower emissions intensities per animal in such environments (FAO, 2015b). Adoption of CSA principles may also contribute to mitigation measures aimed at reducing risk from disease threats.

2.4.3 Disease events

Climate change is emerging as a key driver of fungal and bacterial pathogens and a range of pest species such as ticks, mosquitos and parasites (Kantanen et al., 2014). Pest and disease events are predicted to change as well as increase in geographical range, which may have further implications for breed suitability in some areas (Kantanen et al., 2014). Large-scale industrial production systems may create more enabling environments for disease transmission between animals over large distances, further exacerbating these threats (Otte et al., 2007).

Rare or minority breeds in limited geographical ranges are more vulnerable to disease events, and the 2001 UK Foot and Mouth Disease (FMD) epidemic highlighted that rare breeds had no particular status in terms of controlled movement or culling policies. In response to the outbreak safeguards to protect rare breeds in the event of disease epidemic (e.g. Article 15 of Regulation 2003/85/EC) have been incorporated into the new EU Animal Health Law (European Comission, 2016). A key argument for preserving rare breeds through such laws is the potential benefit of sustaining a diverse number of breeds that could mitigate against future pest, parasitic and disease outbreaks via resistance, immunity or tolerance attributes (FAO, 2007a). Important examples of resistance or tolerance already documented include trypanosomosis, the stomach worm *Haemonchus contortus*, liver flukes, ticks and various tick-borne diseases including anaplasmosis (FAO, 2015b).

Thus, despite the threats arising from climate change, there are also opportunities for greater utilisation of breed and genetic diveristy as an adaptive response (Hoffmann, 2010). Cross-breeding to introduce beneficial genes into higher yielding breeds from individuals with better disease resistance could increase the future value of some rare breeds (Thornton, 2010).

2.4.4 Brexit

The UK's formal withdrawal from the EU is currently under negotiation and considerable uncertainty surrounds the potential consequences for CAP-related schemes that have supported the supply of agricultural public goods. Furthermore the UK's agricultural sector will likely be subject to increased global competition from less regulated, global markets, or more subsidised markets of the EU (Berkum et al., 2016). This could impact breed conservation if grazing subsides for NBAR are reduced or removed. At the same time, EU product designations applied to UK products, such as traditional specialities guaranteed (TSG) could be affected if no substitute schemes are forthcoming. Equally unclear is how UK FAnGR regulations will be impacted and those relating to NBAR concern 'exemption from culling' regulations under the new EU Animal Health Law. Though many such EU regulations are adopted voluntarily by national legislation, Brexit implies these regulations may be at risk.

Brexit also offers potential opportunities to shape a new policy concerning the allocation of support through a new Agricultural Bill that uses public funds for public goods (Defra, 2018). Helm (2016) suggests that a more efficient future Agricultural Bill may decentralise the payment mechanism for the provision of public goods. The suggestion is to allocate funding to agencies and conservation bodies with a better understanding of the supply agents (i.e. land owners and managers). Funding could then be better directed to the most efficient suppliers via forms of restricted conservation tender, open to target conservation bodies, landowners or groups of farmers to bid for the lowest cost supply of specific environmental goods. In such a PACS-like scheme, specialised breed groups (such as RBST) may be in a privileged position to supply agri diversity through rare breeds.

2.5 Conclusion

Rare breed conservation has traditionally been motivated by voluntarism and stewardship motives unrelated to values commonly transacted by markets, which typically fail to enable transaction for all attributes of rare breeds, including diversity and heritage values. But research suggests there is a public desire to see future farms that do not solely employ intensive systems but supply additional public goods (Weatherell et al., 2003; Adam, 2004).

The public policy challenge is therefore to balance public demand with the regulation of external pressures that reduce the variability of maintaining cultural capitals. These include moves toward more globalised and homogenised supply chains and the SI imperative. The latter is in danger of prioritising efficiency above all other considerations including the need to retain option value. This is of particular importance when considering proximate threats such as climate change and disease risk but also disruptive technologies, such as genetic engineering. The former may be harnessed to the benefit of conservation through greater utilisation of diversity (via gene editing) by procuring traits of market and non-market value from across the breed spectrum. But this prospect may only be realised if the policy landscape provides adequate scope and guidance on the sustainable use of FAnGR; underpinned by an increasingly sophisticated arsenal of biotechnologies.

The fundamental failure of markets to reward conservation effort requires institutional responses to palliate market failures that include the homogenisation of breeds and production systems. Different private and public institutional responses to correct for failure target different elements of public good value. On the supply side, the use of PACS approaches represent a potential opportunity to improve the efficiency of procurement of public goods (Narloch et al., 2011a). However, the use of such extrinsically motivated instruments is problematic in potentially crowding out intrinsic behaviours motivated by stewardship, actually resulting in lower levels of conservation effort (Frey and Jegen, 2001; Lawler, 1998). It is therefore important that responses to address market failure compliment voluntary collective effort whilst providing public and private institutions with some control over conservation agendas (i.e. which breeds to conserve and in what quantity). The design of any new Agricultural Bill represents an opportunity to make these trade-offs explicit.

Chapter three

Contracts for supplying Farm Animal Genetic Resources (FAnGR) conservation services in Romania

Abstract

This chapter describes a choice experiment (CE) administered to explore farmer preferences for conservation agreements to conserve rare breeds among a sample of 174 respondents in Transylvania (Romania). The study site was chosen due to the prevalence of small-scale and extensive farm systems threatened by a changing policy environment that is increasing the scale and intensity of production units. Agreement attributes included length of conservation contract (5 or 10 years); scheme structure (community or individual managed conservation programme), and scheme support (application assistance or farm advisory support). A monetary attribute that reflects compensation for scheme participation allows the assessment of farmers' willingness to accept (WTA) for different contracts. Results suggest 89% of respondents would be willing to farm with rare breeds; cattle and sheep being the most popular livestock option; 40% of farmers were reportedly farming with endangered breeds. However, only 8% were likely to qualify for funding support under current requirements. WTA estimates reveal minimum annual compensation values of €167 and € 7 per year respectively, for bovine and ovine farmers to consider enrolling in a contract. These values are comparable to Romanian Rural Development Programme (RDP) support offered to farmers keeping rare breeds of € 200 and € 10 per year for bovine and ovine farmers respectively. Our estimates of scheme uptake, calculated with coefficient values derived from the CE, suggest rare breed conservation contracts are considered attractive by Romanian farmers. Analysis suggests meeting farmer preferences for non-monetary contractual factors will increase participation.

3.1 Introduction

FAnGR diversity underpins resilient agricultural systems and need to be part of any SI strategy to meet rising demand for livestock products (Eisler et al., 2014). However, concentration on elite breeding lines has reduced genetic variation in many commercial breeds whilst marginalising traditional breeds whose value is often poorly understood (Ahtiainen and Pouta, 2011; FAO, 2015a).

SI strategies should include investments to maintain genetic variation across a range of breeds (including rare breeds) to ensure adaptive capacity in livestock systems. This is particularly important when considering profound demographic and environmental changes facing the agri-food sector including population growth, land scarcity and climate change (FAO, 2017b). Equally important, but less often articulated in decision making, are the cultural and heritage attributes embodied in rare breeds (Gandini and Villa, 2003b; Zander et al., 2013). Markets often fail to reflect these values, which can be substantial but difficult to measure. Breed genetic diversity is therefore undersupplied by markets and there is a need to explore policy interventions to counter market failure.

While contractual schemes for rare breed conservation are present in Europe, many are often poorly targeted (Kompan et al., 2014; Bojkovski et al., 2015). Targeting incentives towards small-holder and extensive farm systems may improve scheme efficiency and uptake, given their lower opportunity cost of conservation (Naidoo et al., 2006). This chapter explores rare breed conservation contracts in Transylvania (Romania), where the average farm size is only 3.4 ha and the economic efficiency per farm (as measured by standard monetary output of agri-products per holding) is significantly lower than the EU average (Popescu et al., 2016).

Traditional farm systems in Transylvania are under pressure from development of more intensive farm systems that are changing the scale and nature of practices (Sutcliffe et al., 2013, 2015). A focus on improved efficiency is at the expense of the supply of public goods, including breed diversity. Some 42% of livestock breeds in Romania are classified as 'at-risk'[8] (Draganescu, 2003). This figure may be an underestimate since population estimates for many Romanian breeds are unknown (FAO, 2018). There is therefore a need to develop

[8] Corresponding to the United Nations Food and Agricultural Organisation (FAO) definition of an 'at-risk' breed.

targeted policy responses that aid conservation by balancing an intensification agenda with incentives for the supply of other non-market goods and services.

Farm scale drivers of diversity loss are often assumed to relate solely to the lower productivity of traditional livestock breeds (Cicia et al., 2003). While income forgone is a key factor to establish the cost of incentive-based schemes, other factors also motivate farm business decisions, and may be particularly relevant in a semi-subsistence farming context. Such non-financial motives may include tradition, community relations, professional pride and independence (Gasson, 1973; Ilbery, 1983; Burton et al., 2008). It is therefore necessary to identify how such attributes might influence the design of conservation programmes and farmer willingness to supply diversity. Other potential technical and institutional barriers-to-entry (i.e. requirements for breed genealogical records) also warrant exploration in this context.

We used a CE survey to elicit farmer preferences for supplying (rare breed) conservation under alternative contracts forms. CEs are a SP technique where individual preferences for attributes of a good or service are elicited using surveys that mimic hypothetical scenarios – in this case conservation contracts (Louviere et al., 2000). The chapter adds to the literature on farmers' willingness to participate in incentive-based schemes (Ducos et al., 2009; Ruto and Garrod, 2009; Broch and Vedel, 2010; Espinosa-Goded et al., 2010; Greiner, 2015; Lienhoop and Brouwer, 2015) but focuses on the neglected issue of the cost of conserving FAnGR in small-holder and extensive farm systems.

The chapter is structured as follows. Section 2 presents background to the CE design and case study site. Section 3 reports the analysis of choice data. Section 4 provides discussion of the design of rare breed conservation programmes, and Section 5 provides conclusions.

3.2 Methods

3.2.1 Case study: Romania

As an EU member state, Romania's agricultural policy is structured and supported in an agreed RDP (2014-2020), which includes a support measure (M10.2, art 28) for rearing endangered livestock breeds under EU Regulation 1305/2013 (MARD, 2014). Uptake for this RDP option is anticipated to be low due to farmer difficulties in meeting EU standards to qualify for subsidy payments (Page, 2015, *personal communication*). Data on uptake rates are not yet available, but previous work has found that 70% of Romanian farmers experienced difficulties meeting EU environmental standards for payments under the CAP (Fischer et al., 2012). It is therefore important to explore whether such barriers persist for farmers in small-scale and extensive systems, as this could reduce participation. Equally important is to measure whether voluntary AES measures, specifically M10.2, match farmer preferences and expectations for scheme design and rewards.

Much of the study site (Figure 3.1) is situated in the foothills of the Carpathian Mountains and features an undulating topography with low nutritional pastures (Mikulcak et al., 2013). Part of the area (Tarnava Mare) is classified as high nature value (HNV) farmland. Traditional agricultural practices are common in this area, as is the presence of many small scale and semi-subsistence farms (Page et al., 2011). Mechanised systems are the mainstay for medium to large farms, though are much less common. The site is characterised by high levels of rural poverty, with average household incomes below the national average (Gherghinescu, 2008).

We surveyed livestock keepers across 5 counties (Sibiu, Brasov, Mures, Cluj and Alba). The sampling frame was based on local farmer information held by village mayors, with further random sampling of farms. The survey was administered from June to August (2015).

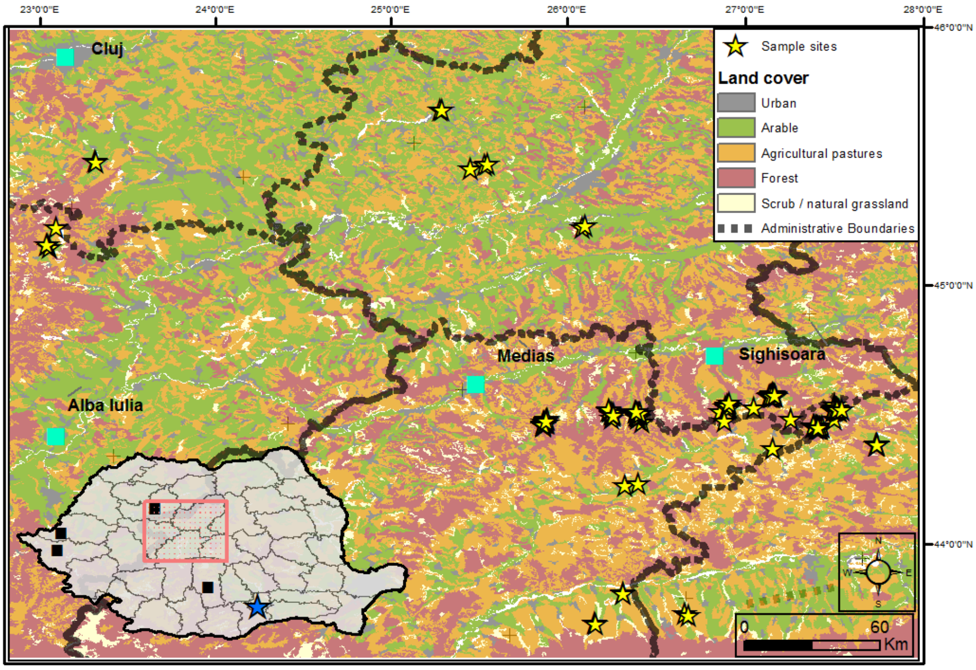

Figure 3.1: Land cover map of the survey area with inset map of Romania. Sampling locations are shown by yellow stars.

3.2.2 Questionnaire design and administration

The survey consisted of four sections (provided in Appendix 1). The first asked about the farm business including livestock species and breeds, farm size, and traits farmers deem most important when considering choice of breed. In the second, respondents were asked if they receive AES payments and whether they were aware of financial support for rare breeds and ever considered applying for this support. The third part of the questionnaire included the CE. Two CE versions were created - one for ovines and one for bovines. Farmers answered either one or both depending on whether they were keeping ovines, bovines, or both. After the CE tasks were completed, respondents were asked to state their motivations for their choices in the CE, and this information was used to identify genuine choices from protest bids; the latter subsequently being removed from the analysis. Respondents were also asked about their preference concerning scheme remittance (i.e. individual or community payment). The fourth section collected socio-economic information including respondent age, gender, educational attainment and household income.

3.2.3 Choice experiment design

In CEs, respondents are asked to repeatedly choose from a number of options that differ in their attributes or characteristics following an experimental design. The CE elicited individual preferences using hypothetical contract choice sets requiring farmers to upkeep rare breeds from a list of breeds proposed by the Romanian Government for support under the 2014-2020 RDP measure (see Appendix 2 for list of eligible breeds). Farmers were advised that the breeding of animals must be pedigree to qualify for further subsides on offspring (i.e. non-random mating). Each choice task consisted of two alternative contracts and a ‘none’ option to embody the voluntary nature of the conservation scheme. Attributes and their levels used to describe the conservation contract were determined in a multi-stage process involving literature review, expert consultations and pilot testing.

Each contract option consisted of four attributes (Table 3.1). The first three attributes described contract length (CL); scheme support (SS); and structure of scheme (SOS). Choice of attributes drew on empirical work suggesting their importance in AES scheme design (Ruto and Garrod, 2009; Christensen et al., 2011; Greiner, 2015). A final monetary attribute (COS) represented an annual payment to farmers (per animal) and took four different levels. The monetary attribute in local currency (Lei per year) was based on a percentage (10%, 30%, 60% and 100%) of the proposed monetary reward outlined in the RDP; the premise being that some farmers may be WTA a lower reward, depending on contract design. The choice tasks were differentiated based on the livestock species. For bovine (cattle, horses and buffalo) and ovine farmers (sheep and goats) the choice tasks were similar except for the value of the monetary attribute, which reflected the relative support normally given to different species under current RDP conditions.

Table 3.1: Attributes and attribute levels used in the CE including relevant coding and a prioir expectations.

Contract attributes	**No. of levels**	**Coding**	**Attribute levels**	**Expected sign**
Contract length (CL)	2	Effects	- 5 years + 10 years	-
Scheme support (SS)	2	Effects	- Basic assistance to complete the scheme application form + Additional advisory support throughout the scheme (e.g. additional training for animal	+

			breeding)	
Structure of scheme (SOS)	2	Effects	- Individually managed conservation scheme + Community managed conservation scheme	-
Subsidy (COS)	4	Discrete Discrete	- Bovines = 90; 270; 530; 890 Lei / year - Ovines = 5; 15; 25; 45 Lei / year	+

Choice set design was optimised according to prior information on the distribution of random parameters to improve statistical efficiency - i.e. reduction in sample size needed to achieve statistical significance (Crabbe and Vandebroek, 2011). Prior information concerning the parameter coefficients was estimated from results of the pilot data that was collected *in situ* to ensure the attributes were relevant to participants. A D-efficient experimental design optimised for the random parameter logit (RPL) model was formulated using NGene (Metrics, 2012). The final CE comprised 16 choice sets which were blocked into 4 blocks of four choice tasks each in a bid to reduce the cognitive burden for respondents (Hensher, 2006). Figure 2 shows a typical choice task presented to respondents.

	Option A	**Option B**	**No contract**
Contract Length	5 years	10 years	--
Scheme support	Basic application assistance only	Additional advisory support (e.g. extra training)	--
Structure of conservation scheme	Community managed conservation programme	Individually managed conservation programme	--
Subsidy (per animal / per year)	Lei 90	Lei 270	Lei 0

I prefer:	Option A	Option B	Nothing
	❑	❑	❑

Figure 3.2: A typical choice task shown to respondents

3.2.4 Econometric specification of choice models

Respondent choices in a CE can be modelled with reference to Lancaster's theory of value (Lancaster, 1966) and Random Utility Theory (McFadden, 1973; Luce, 2005). For a general description see (Holmes et al., 2017). The standard choice mode is the multinomial logit

(MNL) model (McFadden, 1973) which assumes the random component of the utility of the alternatives is independent and identically distributed (*i.i.d*.). A key limitation of the MNL is that preferences for attributes of different alternatives are assumed to be homogenous across individuals. The RPL model for choice data analysis is more advanced and takes into account heterogeneity of the parameter values among respondents and relaxes key assumptions that constrain the use of conditional logit models, namely independence of irrelevant alternatives - *iia* (Hensher et al., 2005). Under a RPL specification, the utility a respondent *i* derives from an alternative *j* in each choice situation *t* is given by:

$$\boldsymbol{U_{ijt} = \beta_i X_{ijt} + \epsilon_{ijt}} \tag{3.1}$$

Where U_{ijt} is a utility maximising individual, X_{ijt} is a vector of observed attributes associated with each contract option (i.e. contract length, scheme support, structure of scheme and price) plus the socio-economic characteristics of respondents, and ε_{ijt} is the random component of the utility that is assumed to have an *iid* value distribution. Conditional on the individual specific parameters β_i and error components ε_i the probability that individual *i* chooses alternative *j* in a particular choice task *n* is represented as:

$$\boldsymbol{Pr(j|X_{it}, \beta_{it}, \varepsilon_{it}) = \frac{exp(\beta_i X_{ijt} + \varepsilon_i)}{\sum_k^J exp(\beta_i X_{ikt} + \varepsilon_i)}} \tag{3.2}$$

Choices for bovine and ovine farmers were modelled separately to explore preference heterogeneity between both groups. The unconditional choice probability is the expected value of the logit probability over all possible values of β weighted by the density of β. The marginal probability of choice can be derived from integrating the distribution functions for the random parameters β. The probability of choosing alternative *j* over *N* observed choices is:

$$\boldsymbol{Pr(j|X_{it}) = \int \left(\prod_{n=1}^{N} \left[\frac{exp(\beta_i X_{ij} + \varepsilon_i)}{\sum_k^J exp(\beta_i X_{ik} + \varepsilon_i)} \right] \right) f(\beta|\theta) d\beta} \tag{3.3}$$

Where $f(\beta|\theta)$ is the density function for β with a mean *b* and covariance *W*. This equation does not have a closed form and so we rely on simulation methods (for details see Train (2009)). Draws of values of β are drawn from $f\ (\beta_i|\theta)$ for r=1,…, R. The probabilities are approximated by drawing the values from the density function and averaged to estimate the simulated probability. Random parameters were estimated using 1000 Halton draws which take into account the heterogeneity of parameter values sampled from the distribution of respondent’s choice (Mariel et al., 2013; Greiner, 2015). A normal distribution is assigned to the all random parameters (accept subsidy) to allow respondents to have either positive or negative marginal utility for the contract attributes (Christie et al., 2015). A triangular distribution was assigned to the subsidy attribute to ensure the parameter does not change sign over its range.

In a CE, the standard approach to calculate respondent WTA is to is to compute $\frac{\beta_{attribute}}{\beta_{cost}}$. Given the contract attributes were effects coded WTA estimates were calculated from the ratio $\frac{2*\beta_k}{\beta_c}$ where *k* is the attribute coefficient and *c* is the cost coefficient as outlined by Bech and Gyrd-Hansen (2005). Confidence intervals were estimated using the Delta method. Individual specific parameters (Table 2) for individual *i* were dummy coded and interacted with random parameters to determine policy relevant factors influencing contract preferences. Contract probabilities of enrolment were calculated under alternative payment scenarios to determine how probability of uptake varied according to contract attributes and payment rates, following a similar method to Adams et al, (2014). Based on the CE, the probability of an individual *i* choosing a contract alternative *j* is given by:

$$\boldsymbol{Pr(j|x_i, z_i)} = \frac{\mathbf{exp}(\boldsymbol{z_{ij}\gamma + x_i\beta_j})}{\sum_{\boldsymbol{k}}^{\boldsymbol{j}} \mathbf{exp}\,(\boldsymbol{z_{ik}\gamma + x_i\beta_k})} \tag{3.4}$$

whereby alternative specific variables (i.e. contract options) for individual *i* and alternative *j* are given by z_{ij} whilst coefficients are denoted by γ. Case specific variables for individual *i* are given by x_i whilst coefficients are denoted by β. We estimated the probability of participation for case specific contracts under two scenarios– ‘optimal’ and ‘non-optimal’ contracts. ‘Optimal’ refers to contract attributes (excluding subsidy) that meet the preferences of agents while ‘non-optimal’ contracts do not. This was relative to a non-enrolment option. The empirical model was estimated using the econometric software NLOGIT 5.0.

3.3 Results

3.3.1 Respondent characteristics

A total 174 respondents were surveyed - 116 were bovine farmers and 81 were ovine farmers (note 45 respondents kept both ovines and bovines). The means and standard deviation of multiple individual specific variables is outlined in Table 3.2. There were later used as interaction terms in the choice model to determine significant covariates that help to explain respondent choice. The mean age of participants was from 40-49 years, with highest education levels of either secondary school or college. Fewer female respondents featured in our sample as more males are employed in agriculture (European Commission, 2012).

Average monthly household income was reported to be in the range of €181 to €362; lower than the national average but anticipated at the sample site (Page et al., 2011). The primary income for most farmers was EU subsides, while sale of milk and meat products were generally secondary and tertiary sources, respectively. Some 40% of farmers claimed to be farming with a rare breed from a list of 'at risk' breeds, while 32% were enrolled in AES measures. Only 21% of respondents were aware of RDP support for rare breeds whilst only 8% actually met the EU's criteria to qualify for payments.

Table 3.2: Summary of individual specific variables (with means) and relevant interpretation

Variable	**Interpretation**	**Mean**	**Std. Dev**	**National mean**
Gender	1, if male, 0 otherwise	0.83	0.91	49% male[a]
Age	Categorical (1=<20, 2=20-29, 3=30-39, 4=40-49, 5=50-59, 6=60-69, 7=over 70 years)	4.23	1.44	55.7% (25-64 years)[a]
EDU	Categorical (1=secondary, 2=college, 3=degree & professional)	1.58	0.61	85.6% (secondary or college)[a]
Income	Categorical (1=<€45, 2=€45-€90, 3=€91-€181, 4=€181-€362, 5=€362-€678, 6=>€679)	3.8	1.45	€ 566[b]
Size	Categorical (1=1-2 ha, 2=3-6 ha, 3=7-20 ha, 4=>20 ha)	2.59	1.05	3.6 ha[c]
FRB	1, if farming with rare breeds, 0 otherwise	0.4	0.49	-
CON	1, if farmer would consider farming with rare breed in the future, 0 otherwise	0.89	0.32	-
AES	1, if farmer is currently enrolled in an agri-environment scheme (AES), 0 otherwise	0.32	0.47	-
RDP	1, if farmer aware of RDP support for rare breeds, 0 otherwise	0.21	0.41	-
BEN	Categorical (1=if farmer prefers 100% individual cash benefits from a conservation programme, 2=50% cash benefit, 50% community in-kind benefit, 3=100% community in-kind benefit)	1.39	0.71	-
REG	1, if farmer is registering livestock in a genealogic register, 0 otherwise	0.08	0.27	-
Yield	1, if farmer is keeping cross breeds for yield improvement, 0 otherwise	0.47	0.5	-

References: [a](National Institute of Statistics, 2013) [b](National Institute of Statistics, 2015) [c](Popescu et al., 2016)

3.3.2 Farm characteristics

To determine how intensification may threaten traditional farming systems and breed diversity, respondents were asked to detail how their farming practices have changed over the preceding 10 years (Figure 3.3). Increases to dairy cattle herd size were reported by 52% of respondents. Of the 20% of our sample that reported manual hay cutting, 74% reported this to be either stable or increasing; a clear response to EU incentives that reward small-holders for the activity. Mechanical hay cutting was reported to be increasing (67% of respondents) and some 54% of farmers also stated their sheep herd size was increasing.

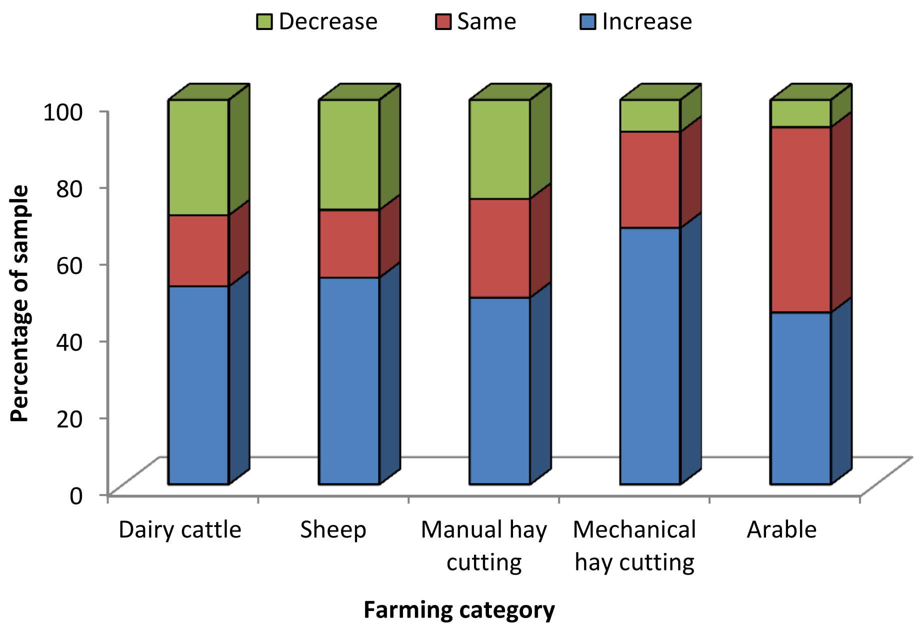

Figure 3.3: Reported change in farming practices over the last 10 years from respondents.

To investigate whether willingness to participate in a (rare breed) conservation programme was linked to preferences for farm animal species, respondents were asked both livestock species kept and their interest in joining a conservation scheme. Pigs were the most frequently kept farm animal followed by cattle and sheep (Table 3.3). The highest number of breeds reported was for pigs, while buffalo had the least. The prevalence of breed diversity varied across species. For instance, the main breed kept for each farm species ranged from 83% (Romanian Buffalo) to 37% (Large White pig). Across the sample, 89% of farmers registered interest in joining a rare breed conservation programme, of which cattle (52%) and sheep (39%) were the most popular species. Least popular species were goats (11%); horses (13%) and buffalo (14%). Of interest is the low preference for conserving rare horse breeds given their popularity in the Romanian farming context. This may suggest rare horse breeds do not match farmer preferences for horse breed characteristics and hence are undersupplied.

Table 3.3: Summary of farm animal and breed characteristics across our sample.

Species	**Incidence of farm animal in sample (%)**	**Total no. breeds reported**	**Most popular breed (% abundance)***	**Farmers stating interest in farming with rare breed (%)**
Sheep	61	8	Tsurcana (47%)	39
Goats	24	4	Unknown (56%)	11
Pigs	84	13	Large White (37%)	-
Buffalo	10	3	Romanian Buffalo (83%)	14
Cattle	73	9	Baltata Romanesca (61%)	52
Horses	51	8	Unknown mix (51%)	13

* Percentage abundance was calculated as the number of farm animals in our sample that correspond to a specific breed

Livestock-keepers in different countries prefer different breed attributes (Simm, 1998). Respondents were asked to rank livestock attributes by importance for breed selection. In Figure 3.4 radar charts indicate different preferences between rare breed and commercial breed keepers for some attributes. Yield was the most important attribute for both. Adaptability was ranked 2nd for farmers keeping rare breeds, while disease and parasitic resistance was ranked 3rd. For commercial breed keepers, yield was also ranked 2nd and adaptability 3rd. This suggests productive traits are considered most important by both farmer groups, but they differ in perceived importance of non-productive traits. This supports work suggesting rare breed adaptability characteristics play an important role within the livestock sector not matched by commercial breeds (Leroy et al., 2018).

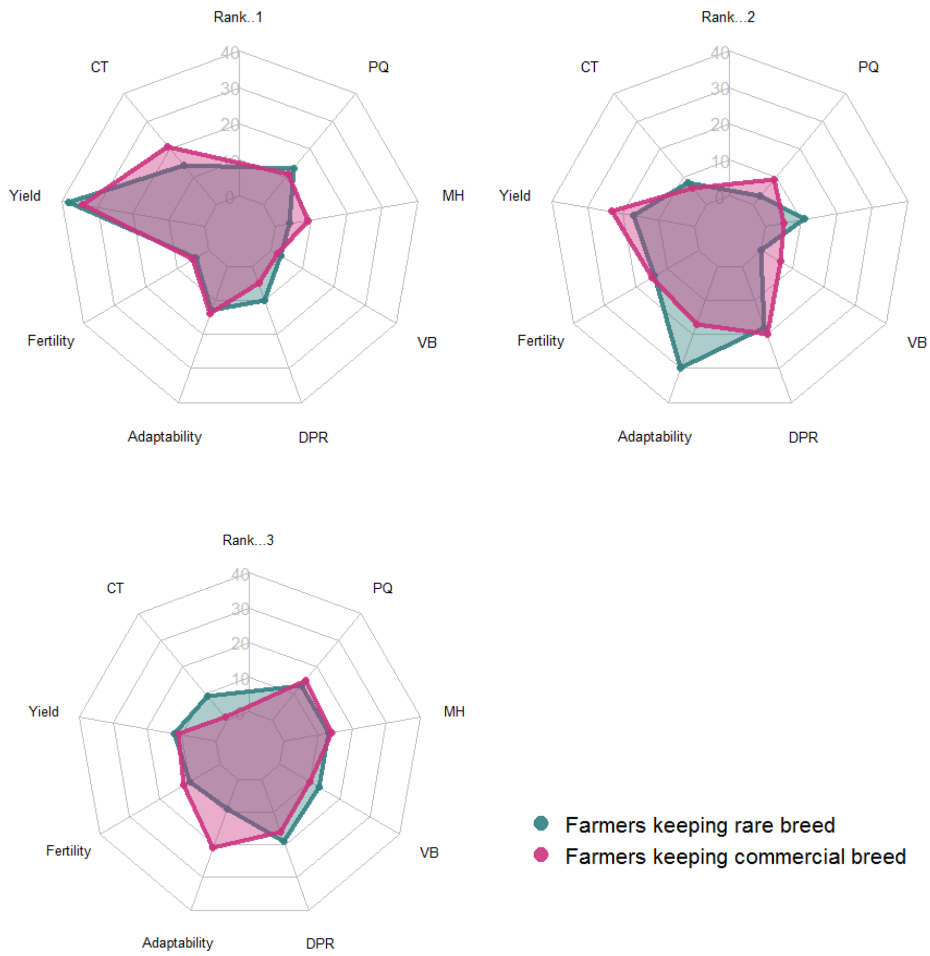

Figure 3.4: Radar charts showing ranked importance of livestock attributes according to farmer preference. The charts reveal the percentage of farmers who chose each attribute in 1st 2nd and 3rd rank. Note, CT = cultural tradition; DPR = disease and parasitic resistance; VB = veterinary bills; MH = management and handling; PQ = product quality.

3.3.3 Choice Models

The choice models explore the hypothetical contract choices made by respondents that are dependent on information concerning contract attributes and respondent/farm characteristics. The models seek to explain farmers' choices of contract options depending on the values that the attributes take in each contract option. This provides information on the relative importance of each attribute for selecting a contract option and the overall compensation needed by farmers to enrol, which may be heterogeneous across farmers. The model investigates if some of this heterogeneity is systematically associated with farm or farmer characteristics.

Initial results from the MNL are provided in Appendix 3 to offer an overview of the basic model estimation. Results from the more sophisticated RPL model for bovine and ovine farmers are reported separately in Table 3.4. Both models delivered a good statistical fit (i.e. the model is a good estimator of respondent choice) as indicated by McFadden pseudo R^2 values[9] of 0.33 (bovines) and 0.38 (ovines).

Table 3.4: RPL model output for estimated marginal utilities for both ovine and bovine models for the CE attributes including interaction terms

Attribute	**Bovines**		**Ovines**	
	Coefficient	SE	Coefficient	SE
Random parameters				
[CL] Contract Length	-0.829***	0.175	-0.984***	0.213
[SS] Scheme Support	0.147	0.230	0.618	0.259
[SOS] Structure of Scheme	-0.554**	0.221	1.499***	0.466
[COS] Subsidy	0.022***	0.003	0.594***	0.108
[N0] Nothing option	1.90***	0.516	2.301***	0.492
Standard deviations of random parameters				
[CL] Contract Length	0.501	0.311	0.652**	0.291
[SS] Scheme Support	1.022***	0.261	0.297	0.495
[SOS] Structure of Scheme	1.689***	0.324	1.223***	0.279
[COS] Subsidy	0.006	0.012	0.018	0.282
[N0] Nothing option	1.675***	0.358	1.112***	0.378
Covariates (socio-economic variables)				
COS:AES	-0.981***	0.374		
COS:BEN	0.016***	0.006		
N0:AES	1.681***	0.509		
SOS:BEN			-2.506***	0.565
COS:AES			-0.110*	0.062
COS:BEN			-0.188**	0.077
Model summary				
No of observations	464		324	
Log likelihood	-344.089		-222.246	
Chi squared	331.345		267.409	
Prob > Chi square	0.000		0.000	
McFadden Pseudo R^2	0.325		0.376	

Note: ***; ** indicates significance at 1% and 5% respectively. SE=standard error

[9] Note the McFadden pseudo R^2 can be interpreted very much like a regression R^2 value but the goodness of fit will always be much lower in CE modelling (typically between 0.2 to 0.4).

The N0 is positive and significant in both models meaning most farmers have preferences for the status quo option which follows economic theory (Greiner, 2015). This is perhaps because there are some variables, not included in the model, which induce farmers to prefer to not join the offered contract alternatives. The COS attribute is positive in both models meaning higher conservation payments increased likelihood of enrolment. CL (bovines and ovines) is significant and negative meaning respondents prefer a shorter contract. SS was not significant for both bovine and ovine farmers. SOS was negative and significant for bovine farmers meaning they prefer individually managed conservation schemes. For ovine farmers structure of scheme is positive and significant, suggesting they prefer community managed conservation programmes.

Significant standard deviations of the normally distributed coefficients indicate there is heterogeneity in farmers' preferences for some attributes. The standard deviations were significant for all attributes accept contract length and subsidy (bovines only) and scheme support and subsidy (ovines only). This heterogeneity can complicate interpretation of the parameter estimates.

Additionally, we also tested for significant relationships between respondent preferences for different contract attributes and various individual specific covariates. The significant covariate interactions for both models are listed in Table 3.4. For both models, a negative, significant relationship was obtained by interacting farmers currently enrolled in AES schemes with COS suggesting farmers enrolled in AES measures require less subsidy support. Conversely, farmers not enrolled in AES schemes demanded higher subsidy payments. The N0 interacted with AES was positive and significant suggesting farmers currently enrolled in AES schemes were more likely to select the non-contract option. Education level did not influence likelihood of enrolling into a contract and farmer age did not affect preferences for contract length (both non-significant).

For bovine farmers, interacting respondents wishing to receive community benefits from the scheme (BEN) with COS was significant and positive, indicating farmers looking to receive community based (in-kind) rewards require a higher equivalent subsidy reward. For ovine farmers, interacting BEN with SOS is negative and significant meaning farmers preferring individual benefit schemes also prefer individually managed conservation programmes (i.e. consistency in our results). Interacting BEN with COS was also negative and significant suggesting ovine farmers preferring individual payment schemes are WTA lower subsidy premiums.

3.3.4 Willingness to accept estimates

For WTA estimates (Table 3.5) the positive value for the N0 of €167 $^{year-1}$ and €7 $^{year-1}$ for bovine and ovine farmers, respectively, can be interpreted as the starting value needed for farmer participation in the contractual scheme relative to the baseline contract (Christensen et al., 2011); where baseline refers to a shorter contract length, scheme application support only and an individually managed conservation breeding programme. Changing from a 5 to 10 year contract would cost around €72.8 $^{year-1}$ and €3.3 $^{year-1}$ for bovines and ovines respectively. To move from an individual to a community managed conservation scheme would cost an additional €48.6 $^{year-1}$ for bovine farmers while conversely for ovine farmers it would cost an additional €5 $^{year-1}$ to enrol them in an individual scheme.

Table 3.5: WTA results (€ $^{year-1}$) derived from the RPL model for both ovine and bovine farmers

Attribute	Bovines		Ovines	
	Coefficient	95% confidence interval	Coefficient	95% confidence interval
[CL] Contract Length	-72.8***	-33.1 to -144.7	-3.3***	-1.4 to -7.3
[SS] Scheme Support	12.9	40.7 to -37.6	-0.2	1.4 to -2.3
[SOS] Structure of Scheme	-48.6**	-8.3 to -121.8	5.0***	6.0 to 3.1
[COS] Subsidy	-	-	-	-
[N0] Nothing option	166.9***	198.3 to 109.8	7.0***	67.6 to 5.9

Note, ***; ** indicates significance at 1% and 5% respectively

3.3.5 Estimating contract participation

Contract participation was estimated according to different payment and contract scenarios to determine how projected uptake by farmers varied according to contract attributes. Coefficient means from the RPL model were used for calculating probabilities under two alternative scenarios; optimal and non-optimal contracts, where optimal refers to contract attributes that meet farmer preferences elicited in the CE while ‘non-optimal’ contracts do not. For instance, for bovines this would be a 5 year contract that is individually managed. The subsidy premium took consistent values across both scenarios, ranging from

10% to 100% of remuneration offered in the RDP scheme option. This allowed exploration of how scheme uptake might vary with different contract options to gauge the importance of monetary and non-monetary attributes in farmer decision making.

As expected, non-optimal contracts were estimated to receive lower participation relative to optimal contracts (Figure 3.5). Participation estimates ranged from 4% (€20 $^{\text{year-1}}$) to 70% (€200 $^{\text{year-1}}$) for bovines and 2% (€1 $^{\text{year-1}}$) to 78% (€10 $^{\text{year-1}}$) for ovine farmers under the non-optimal scenario. Conversely, in the optimal scenario participation estimates ranged from 38% (€20 $^{\text{year-1}}$) to 97% (€200 $^{\text{year-1}}$) for bovines and 71% (€1 $^{\text{year-1}}$) to 99% (€10 $^{\text{year-1}}$) for ovine farmers. Recalling that subsidy premiums are comparable across both contract scenarios, our estimates show the difference in participation between the two scenarios ranges from 27% to 58% for bovine farmers and 22% to 84% for ovine farmers.

We find a non-linear relationship between participation and financial reward, suggesting a one unit change in subsidy does not necessarily equate to a mirrored change in participation (i.e. there are other factors exogenous to our model influencing farmers willingness to participate). Respondents presented with optimal contract designs were much more likely to enrol in a conservation programme even at lower premiums. Ovine farmers were less likely to enrol in a contract that did not match their preferences for non-monetary attributes at lower subsidy premiums (though this was not the case with higher premiums).

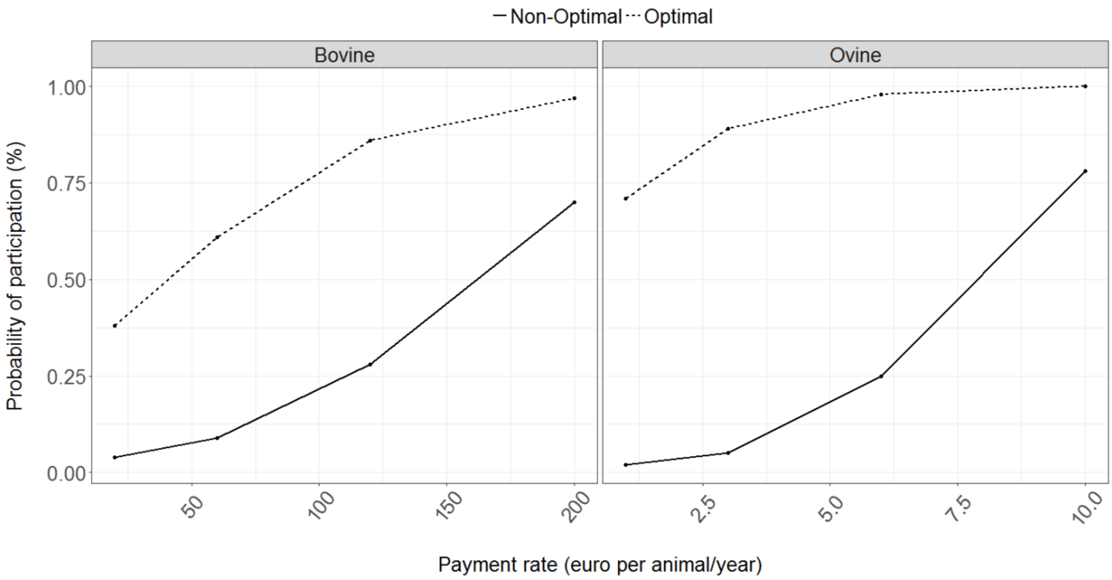

Figure 3.5: Probability of contract participation according to ‘non-optimal’ and ‘optimal’ contract scenarios for different subsidy premiums (bovine and ovine farmers). ‘Optimal’ refers to contract attributes that meet the preferences of agents.

3.4 Discussion

3.4.1 Contract preferences

Results suggest farmers demonstrate a clear willingness to participate in conservation programmes for rare breeds. Participation may be reduced by up to 84% if farmer preferences for non-financial attributes are not taken into consideration. Within the model, the N0 may capture the dis-utility of enrolling in a voluntary subsidy scheme that is not linked to contract attributes, but potentially other factors not included in our model (e.g. family tradition or mistrust in authorities). It may also reflect a general reluctance to join a voluntary incentive scheme (Christensen et al., 2011). However, heterogeneity across farmers in our sample (as shown by significant standard deviation of non-random parameters) complicates interpretation of the N0.

Farmers revealed a tendency to value flexibility in contracts as demonstrated through a preference for shorter contract durations, a common finding in similar studies (Christensen et al., 2011; Tesfaye and Brouwer, 2012; Santos et al., 2015). While bovine farmers preferred individually managed conservation programmes ovine farmers preferred community managed schemes. This seems logical in post-communist Romania, which has seen a shift from collective to individual ownership rights across agriculture (Tudor and Alexandri, 2015). On the other hand an enduring communal herd grazing regime among sheep farmers may explain the alternative preference. The significance of the standard deviation for this attribute further complicates interpretation. Although scheme support for a conservation programme was not considered important by both farmer groups similar attributes were significant in other studies (Ruto and Garrod, 2009). For instance, work by Christensen et al. (2011) has shown farmers are able to place a monetary value on being released from certain administrative burdens and that the use of farm advisors for schemes might make farmers willing to accept a lower payment for enrolling in a scheme. In developing countries like Romania, where rural populations are generally less educated than the wider population (FAO, 2001) application support for schemes may in-fact be paramount to securing farmer participation.

A number of covariates help explain heterogeneity in both models. We did not find that farmers keeping rare breeds were WTA less for supplying conservation services, perhaps suggesting other non-monetary motives were driving their decisions regarding the contract options. Both farmer groups enrolled in AES schemes were WTA less compensation for supplying conservation services, thus providing a means for conservation agencies to target least cost service providers. However, farmers enrolled in AES schemes were also more likely not to select a contract option, suggesting overlap with existing contractual schemes may deter farmers from participating. In addition, farmers already enrolled on AES programmes are more likely to harbour pro-environmental attitudes (Heyman and Ariely, 2004) that may improve compliance with contractual schemes.

In both models community (in-kind) based support is associated with higher cost than those preferring cash based payments; implying the use of in-kind rewards will increase overall scheme cost. However, in-kind payments have been shown to be more effective than cash payments in stimulating conservation effort (Gorton et al., 2009) and may provide longer term infrastructure benefits to communities supplying public goods. In addition, Narloch et al. (2017) argue collective payments to community groups may effectively 'crowd-in' compliance, thus reducing monitoring costs and improving conservation outcomes. The additional costs of community schemes must therefore be weighed against (potentially) improved social and farm animal diversity outcomes.

3.4.2 Contract participation

Contract participation estimates reveal a trade-off between non-monetary attributes and financial incentives. For instance, if RDP subsidies paid € 120/ animal $^{\text{year-1}}$ and € 6/ animal $^{\text{year-1}}$ for bovine and ovine farmers in an 'optimal' contract scenario then uptake rates could be as high as 86% and 98%, respectively. This contrasts with enrolment of just 28% and 25% for identical price premiums but with 'non-optimal' contracts for bovine and ovine farmers, respectively. The higher uptake rates associated with ovine farmers in optimal contracts may reflect that performance differences between rare and commercial breeds are larger for bovines than ovines, though this supposition requires further evidence.

These participation estimates are still well above actual participation rates of 15% for an AES scheme in Northern Italy (Defrancesco et al., 2008). Empirical work by Wossink and van Wenum, (2003) suggests participation of up to 60% might be achieved in a hypothetical Dutch field margin programme, suggesting the scheme proposed here is indeed considered attractive by farmers. However, while strategies were employed to prevent hypothetical bias (e.g. cheap talk statement) it nonetheless must be considered that the high participation rates found in our work may be exaggerated by such bias (i.e. the hypothetical nature of a CE may induce respondents to overstate their desire to enrol in a contract option). That said, farmers in our sample were generally poorer than the national average which may be an underlying factor driving an increased desire to participate.

Contrary to expectations, farm size, education level and age did not have a significant effect on participation. These findings confirm conflicting results found in the literature concerning the influence of education (Dupraz et al., 2002; Defrancesco et al., 2008; Greiner, 2015), age (Wossink and van Wenum, 2003) and farm size (Christensen et al., 2011; Adams et al., 2014) on participation in contractual conservation schemes. The hypothesis that farmers keeping rare breeds would be more likely to participate in a conservation scheme was not supported. This may be because a high number of farmers were keen to participate in the scheme, irrespective of whether they were currently farming with a rare breed. Although few studies have directly assessed farmer willingness to participate in rare breed conservation programmes, work by Pattison et al. (2007) suggests that farmers keeping rare breed pigs in Mexico were willing to participate in a community conservation breeding programme even without financial incentives.

3.4.3 Barriers to uptake

Some have been critical of RDP approaches to rural policy (Shortall, 2008; Milcu et al., 2014). This study suggests there are clear barriers to entry for smallholder farmers wishing to participate in some RDP options. This is apparent where RDP eligibility requires a minimum parcel size of 0.3 ha to be entered into agreements and a cumulative field size of 1 ha or more (Mikulcak et al., 2013). The average farm size in our sample was 3-6 ha and discussion by Page et al. (2011) stresses this is a major obstacle for small-scale farmers in Eastern Europe wishing to enrol land into incentive schemes (Gorton et al., 2009). Herd or flock-book registration of livestock is a requirement to qualify for RDP support for rearing local livestock breeds in danger of extinction (MARD, 2014) yet only 8% of farmers in our sample reported having animals registered in this way revealing a major barrier-to-uptake. Implementing alternative mechanisms, or proxies, to identify the genetic merit of farm animals has been identified as an important consideration by Pattison et al. (2007) and novel approaches developed by Bhatia et al. (2010) may serve as a way to surpass such barriers through phenotypic identification of breeds.

EU rural development policy needs be more clearly communicated. In our sample, only 21% of farmers were aware of RDP funding support for farmers rearing endangered breeds. Surveys by Mikulcak et al. (2013) suggest funding measures are often poorly communicated to small-scale farmers and local mayors in Transylvania, emphasising the importance of using local communication channels. In Transylvania, Fundatia ADEPT (a local conservation NGO) are meeting this need by helping small scale farmers through workshops on the CAP and RDP measures; developing milk collection points in local villages and facilitating cooperative bids for farm applications to AES options where, individually, farmers would be ineligible to apply (Fundatia ADEPT, 2014). These factors have culminated in better support for small-scale farm incomes in Transylvania while maintaining the high levels of public goods that arise from these production systems.

3.5 Conclusion

Farm intensification is a trend across Romania and Central and Eastern Europe (Henle et al., 2008; Popescu et al., 2016) threatening breed diversity. Sustaining this diversity makes an important contribution to the delivery of SI objectives given the high option value that arises from breed diversity, through greater adaptive capacity (Hoffmann et al., 2014). This adaptability, in addition to breed cultural heritage, is considered important by farmers in Transylvania, particularly those keeping rare breeds.

This analysis supports the findings of other work (e.g. Greiner, 2015; Permadi et al., 2018) that suggest contract length and the structure of schemes, in addition to monetary rewards, are important determinants of participation rates in conservation programmes. But we also acknowledge that the monetary values farmers place on accepting specific contractual schemes are case specific (Christensen et al., 2011). As a consequence, the robustness of these results needs to be addressed in further work exploring cost-effectiveness of FAnGR conservation programmes in similar contexts. Moreover, this work has not explored how farmer WTA a contract might vary depending on breed options as part of the scheme. Indeed, work by Zander and Drucker, (2008) suggests farmer do possess heterogeneous preferences for breed attributes and breeds themselves. Exploring the importance of alternative breed and attribute combinations in contracts appears warranted and may further affect farmer willingness to participate in schemes and their WTA a conservation contract.

We found that the average bovine farmer (in Transylvania) needs to be paid €122 per annum per animal extra in order to enrol in a 10 year community managed conservation contract. For ovines, an additional price incentive of €8.3 would be required for farmers to enrol in a 10 year individually managed conservation contract. A key question is whether the conservation and genetic diversity benefit of a longer contract that either includes a collectively or individually managed conservation breeding scheme will exceed the additional costs.

Chapter four

Estimating *in situ* conservation costs of Zambian Crop Wild Relatives under alternative conservation goals

Abstract

Crop wild relatives (CWR) are a globally threatened group of plants that may harbour genes that could be used in commercial crops varieties with important implications for improved food security. Current CWR conservation strategies are inadequate and there is a need to improve conservation efforts, particularly *in situ*. To understand the costs of *in situ* conservation efforts this chapter uses a payment for agrobiodiversity conservation services (PACS) approach to estimate *in situ* costs of conserving CWR in Zambia, where 30 CWR have been prioritised for conservation (of which nine are present in our sample). The method works by seeking competitive tender applications from farmers willing to accept compensation for conservation effort. Using data from 26 communities we determined the cost of conserving CWR on-farm, specifically in field margins/borders. Selection of bid offers under four different conservation goals using a binary linear programming (BLP) model reveals the mean cost of conservation ranging from US$23–91/ha. Heterogeneity was evident in farmer bid offers, meaning discriminatory price mechanisms can potentially deliver cost savings over uniform payment rules. Supply costs increased where other criteria were added to the BLP model constraints including social equity and diversity goals. We demonstrate how wild relative diversity conserved might vary with changing conservation budgets and goals.

4.1 Introduction

Population growth and changing diets are expected to increase food demand above projected crop yield gains (Ray et al., 2013; Seto and Ramankutty, 2016). Climate change may reduce agricultural production by 2% each decade (Pachauri et al., 2014), yet demand for agricultural products is expected to increase by 50% between 2012 and 2050 (FAO, 2017b). Advances in genotyping technologies and plant breeding to meet yield improvement goals offers one approach to increase global production using fewer inputs (Tester and Langridge, 2010). Such advances have increased the potential for using exotic genetic material, thereby heightening the importance of conserving and using CWR to deliver yield improvements, whilst also enhancing adaptive traits in crops (Dhariwal and Laroche, 2017). In this context, CWR, that is, the wild plant species that are genetically closely related to cultivated crops (Maxted et al., 2006) are an increasingly important genetic resource (Zhang et al., 2017). They have for example provided cultivars with pest and disease resistance, heat and drought tolerance, tolerance of salinity and abiotic stresses, and enhanced nutritional quality (Hajjar and Hodgkin, 2007; Maxted and Kell, 2009; Dempewolf et al., 2014).

Wild relatives are estimated to contribute US$ 120 billion to increased crop productivity per annum (Price Waterhouse Coopers, 2013). Despite their importance, CWR have been depleted by agricultural intensification and habitat destruction and a range of other threats and are known to be a globally threatened group of plant species (Kell et al., 2011). Efforts to improve conservation of CWR are therefore warranted to reduce further loss of diversity(Castañeda-Álvarez et al., 2016).

CWR resources are sometimes found in disturbed anthropogenic habitats, e.g. around farms, which should be the focus of some conservation effort (see Jarvis et al., 2015). Moreover, there is limited information on the costs of *in situ* CWR conservation at multiple scales, including the farm level. This constrains our understanding of farmers' willingness to accept (WTA) conservation incentives and ultimately appreciation for heterogeneity in the per unit cost of selecting conservation service providers. This study seeks to demonstrate how the costs of conserving CWR *in situ* (through a measure that restricts farm activities in field margins) can be measured and analysed using a Zambian case study. Note, this is different to conservation of landraces, where cultivation is actively required. The chapter adds to the literature on the economics of *in situ* CWR conservation and to the growing body of work addressing development of payment for ecosystem services (PES) schemes in developing countries, particularly payment for agrobiodiversity conservation services (PACS) (Narloch et al., 2011a, 2011b, 2013; Krishna et al., 2013). It makes a further contribution by considering distributional aspects of PES (e.g. social equity).

The chapter is structured as follows. Section two provides background relating to CWR in Zambia, the use of incentives, conservation tenders and site selection models. Section three describes the research sites and outlines the methodological and modelling approach used. Section four provides an overview of the results and a discussion of these follows in section five, with the identification of further work necessary to improve future cost estimates. Section six presents conclusions.

4.2 Background

4.2.1 CWR conservation in Zambia

Zambia was the case study given its participation within a wider project in the South African Development Community (SADC) addressing *in situ* conservation and use of CWR (http://www.cropwildrelatives.org/sadc-cwr-project/). A previous exercise (see Ministry of Agriculture, 2016) identified 30 priority CWR species in Zambia for conservation to address food security. Using a sub-set of this priority list (see Appendix 5 for case study CWR species), we examine the cost of selecting farmer managed sites for conservation containing priority CWR. The nine CWR species were selected based on their verified presence in the sampling frame for the economic surveys. The need to conserve is driven by threats posed to CWR in sub-Saharan Africa primarily from climate change (Jarvis et al., 2008) and land use change, including intensification of farming practices and alien invasive species (Burgess et al., 2006).

4.2.2 Payment for ecosystem services and competitive tender auctions

PES has emerged as a key voluntary incentive mechanism to reduce biodiversity loss by paying landowners for actions that sustain or enhance ecosystems (Börner et al., 2017). The introduction of PES type schemes for agrobiodiversity conservation (otherwise termed PACS) has been limited but a growing body of work suggests this is becoming more widely applied, including in Bolivia, Peru, Ecuador, Guatemala and India (Narloch et al., 2011a, 2011b; Krishna et al., 2013; Midler et al., 2015; Drucker et al., 2017). This work provides an application of PACS that compensates farmers for conserving CWR in field borders. A hypothetical CT auction measured farmer WTA monetary rewards for conservation effort. CTs are a reverse auction mechanism, whereby agents submit a bid offer for a pre-defined conservation contract supplying, in this instance, CWR conservation services.

Relative to fixed price approaches CTs are incentive compatible in allowing participants to reveal their true opportunity costs (which include both market and non-market values and preferences). This allows identification of least-cost suppliers through the formulation of cost curves that reveal differences in agents' opportunity costs. CT mechanisms have been used to determine the costs of agrobiodiversity conservation (Bertke and Marggraf, 2005; Narloch et al., 2011a), though none have been applied to the case of CWR.

4.2.3 Binary linear programming (BLP)

This work combines CT cost elicitation with BLP modelling to optimise selection of farmer sites for CWR conservation under alternative conservation goals. BLP is a calculation process that finds the optimal solution to a problem with multiple attributes and constraints using a branch and bound algorithm (Messer, 2006). Many reserve selection problems are formulated as BLP problems because site selection decisions can be modelled with binary variables [0,1] which reflects the yes/no decision-making context associated with site selection (Beyer et al., 2016). Much previous work in reserve site selection has sought to solve the problem of maximising the expected number of species included in a reserve network subject to a restriction on network size or cost (Donaldson et al., 2017). BLP takes into account the benefits and costs of each site and evaluates all possible purchase combinations of sites, selecting sites that yield the highest possible aggregate conservation value (Williams et al., 2005). BLP thus facilitates determination of least-cost suppliers of conservation services under various objective functions (Haight and Snyder, 2009).

4.3 Methods

4.3.1 The study sites

The study regions were selected based on a review of records of populations for all 30 priority CWR species (held by the Zambia Agriculture Research Institute (ZARI)) (Ng'uni et al., 2016). After assessment of occurrence records we identified two study areas likely to contain the highest distribution of priority CWR species; Eastern Province and Northern Province (Figure 1). Historical records (obtained from herbarium collections varying in date) in these areas included wild relatives of melon and cucumber (*Cucumis* spp.), yams (*Dioscorea* spp.), millets (*Echinochloa* spp., *Eleusine* spp., *Pennisetum* spp.), sweet potato (*Ipomoea* spp.), rice (*Oryza* spp.), eggplant (*Solanum* spp.), sorghum (*Sorghum* spp.), and cowpea (*Vigna* spp.) (Ng'uni et al., 2017).

Eastern province (herein referred to as Ecoregion 1[10]) has a population of 1.3 million and a land area of 51,476 km^2 (Ministry of Local Government and Housing, 2017). The province houses Zambia's most fertile land and consequently the majority of the country's large-scale commercial farms (Chikowo, 2018). The province has higher human population and lower land availability than other areas in Zambia resulting in the application of more intensive farming practices that are impacting biodiversity (Eroarome, 2009). Northern province (herein referred to as Ecoregion 2) occupies a land area of 87,806 km^2 and with a population of 712,000 people is sparsely populated (Zamstats, 2010). The province sits on the Muchinga Escarpment and is characterised by large tracts of miombo woodland with predominantly small-scale agriculture. Land is relatively abundant and shifting cultivation (slash and burn) was widespread until recently (Grogan et al., 2013).

The areas selected for the CT exercise (within the study regions) were communities far from Game Management Areas[11] (herein referred to as 'non-GMA' sites) and communities adjacent to Game Management Areas (herein referred to as 'GMA' sites). People in GMAs are generally poorer and less educated than the national average, and these areas are associated with lower agricultural potential and fewer alternative livelihood opportunities (Manning, 2011). By contrast, non-GMA sites were considered better-off, with improved access to economic infrastructure. In both areas, agricultural production plays a crucial role in farmer livelihoods. An optimal conservation strategy may specify a combination of sites across both areas to ensure a diverse ecogeographic range of plant populations (e.g. those with restricted ranges and sub-populations) are captured for conservation (Rodrigues et al., 2004). Additionally, conservation in GMAs may enhance gene flow and dispersal from protected areas (PAs) whilst non-GMA sites may provide

[10] Ecoregions were subsequently used in the site selection model outlined further in Section 4.3.6.

[11] Game management areas are transitional zones that serve as protected areas (Pas) for the management of wildlife adjacent to national parks.

sanctuaries for species establishment outside formal designations. Both areas are therefore desirable for CWR conservation.

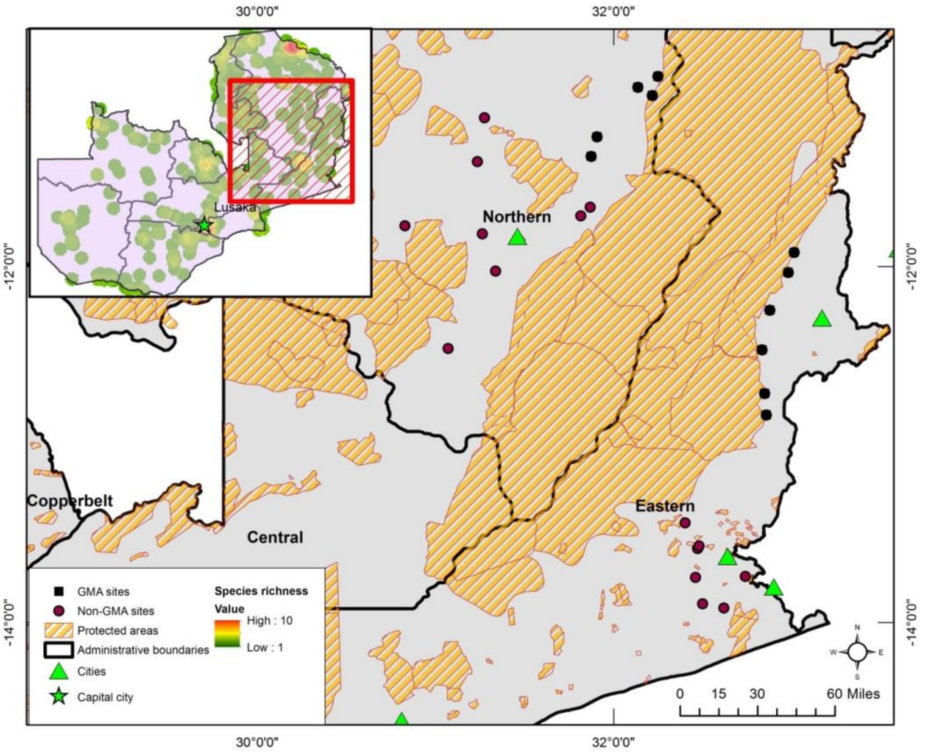

Figure 4.1: Map of sample sites detailing protected areas (PAs). Inset map shows the location of the sample area (red hatch) and species richness of 30 priority CWRs (red areas are CWR hotspots). Source CWR richness data (Ng'uni et al., 2016).

4.3.2 Focus group discussions

Focus group discussions (FGDs) were held in selected farming communities and participants were invited by agricultural extension officers that regularly engage with community groups. Five FGDs were conducted with 10–15 participants in each; encompassing a mix of genders, age groups, and wealth status. FGDs sought to understand the degree of recognition of CWR within communities, CWR status and conservation management and community farm management practices. Specific activities (and associated costs, as perceived by community members) that would need to be implemented in order to attain a desirable (as determined by a conservation programme) level of CWR conservation management were discussed.

4.3.3 Competitive tender design

Data from the FGDs and expert consultation informed the design of the area management option that would underpin the hypothetical tender. Expert consultation suggested that the tender should support CWR interventions through habitat-based conservation measures in field borders/margins – a habitat that has been shown to support CWR (Jarvis et al., 2015). The requirement was for conservation to be undertaken on individual farmer lands, as previous work has shown regular habitat disturbance regimes, through practices such as agriculture, are favourable for some CWR (Maxted et al., 2008; Padulosi et al., 2012).

The area management option prohibited application of herbicides within 3m of the field perimeter or on the field border, and the field border was to be left undisturbed for the duration of the scheme. These activities are most likely to benefit CWR that may inhabit field borders as weeds. In addition, bids were also accepted for conservation in crop fields and on communal land areas but are beyond the scope of analysis of the current chapter. The tender required farmers to detail the number of land plots and total area (in local land units) that they would be willing to enrol in the conservation programme, along with a monetary bid for providing the associated conservation service per annum. Additional information collected included gender, age and farm size (a proxy for wealth).

4.3.4 Competitive tender workshops

Farmers were invited to take part in the tenders by agricultural extension officers. Tender workshops were held at 26 different communities between April and May 2016, with a total attendance of 358 participants. This corresponded to 11 community GMA sites and 15 community non-GMA sites. The workshops used a format similar to the FGDs.

The first section of the workshop 'Existence and Management' prompted farmers to consider where CWR occur on their communal and farmed lands. Participants were asked to identify a set of CWR from photographs and describe where these occurred (if at all) on communal or farmed land. Respondents were then asked to consider how these might be managed and the implications of this management. The next section 'Conservation Management' asked farmers what activities might be required (on an annual basis) to maintain CWR on farmed lands, such as seed collecting, late burning of fields, selective weeding and training. The cost implications of these activities were discussed.

Next, a CT training exercise facilitated discussion and learning among the farmer groups regarding how a CT works in practice and what the rules and selection criteria of this particular tender were. For instance, the competitive nature of the tender was emphasised alongside other variables (not conveyed to participants) that would be considered in the selection process. All farmers were encouraged to participate in the exercise, including those not present at the workshops. An example of the CT bid offer form was then completed with participants, after which the actual bid offer forms were distributed and collected some days later to allow farmers time to deliberate. The bid offer form can be found in Appendix 4.

4.3.5 CWR surveys

Alongside the CT workshops, 26 simple line transect surveys (Buckland et al., 2007) were undertaken at randomly selected communities in both Eastern and Northern Province. The aim was to develop a better understanding of CWR abundance and diversity across different community and farmer sites. A 100 meter line walking transect was undertaken through different habitats at selected communities. The habitats consisted of field borders, croplands and communal bush land. A ZARI staff member walking the transects identified most of the CWR found. Any CWR not identified on-site were photographed and reviewed later. This survey data was subsequently used, in conjunction with occurrence data obtained from Dickson et al. (2016) in the site selection model.

4.3.6 Site selection model

The model focuses on optimizing decisions for CWR conservation site selection while minimising cost subject to area, diversity and social equity constraints. The model accounts for a basic requirement to conserve at least 50 ha of field borders in each ecoregion where CT data were acquired because areas of this size are capable of capturing safe minimum populations for a range of CWR diversity (Maxted et al., 2008b). Effectively, increasing the area constraint may result in an additional area cost with limited benefit for CWR diversity. The model was implemented in OpenSolver for MS Excel 2010 using a branch-and-bound procedure with the Simplex algorithm (Mason, 2012).

Initially, an untargeted area goal was developed to represent a simple method of site selection, based on procuring conservation sites at minimum cost, subject to the minimum area requirement per ecoregion. Three further conservation goals (different versions of the model) were then constructed: (i) a targeted area goal that uses a minimum CWR selection constraint[12] (ii) a social equity goal that ensures socially vulnerable groups are well represented and; (iii) a diversity goal that maximises the likelihood of capturing greater CWR diversity (Figure 4.2).

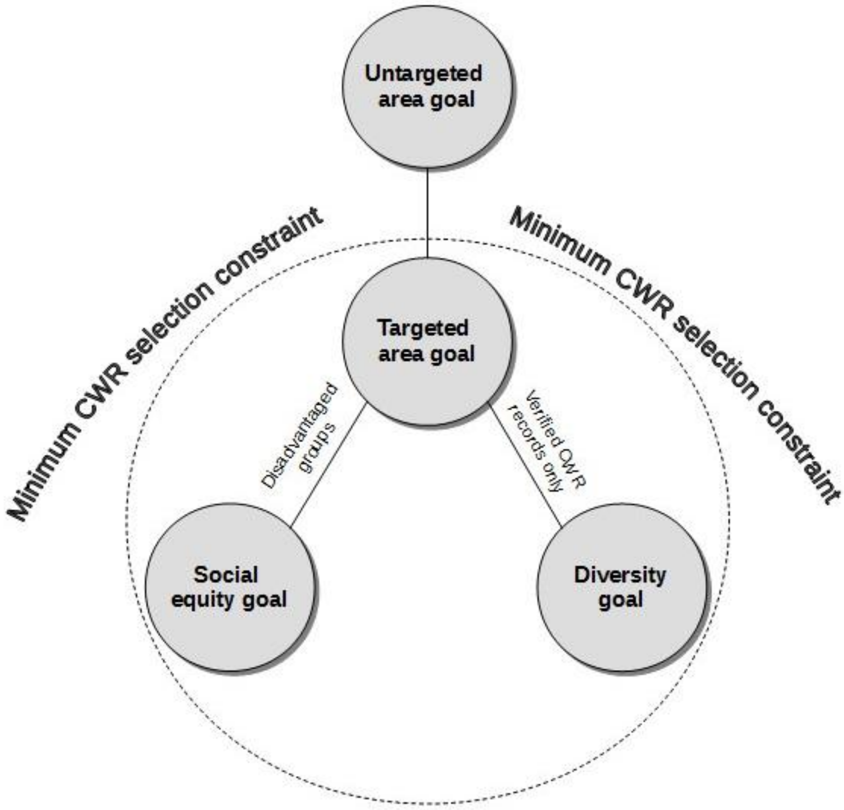

Figure 4.2: Schematic diagram of the different model goals

Bid offer data in the untargeted area conservation goal were selected using a discriminatory payment rule (Wünscher and Wunder, 2017). In discriminatory price auctions, bidders are paid their winning offer price while in a uniform payment rule all are paid the same. Discriminatory approaches can therefore improve cost effectiveness (Windle and Rolfe, 2008).

For the untargeted area goal, the objective function (4.1) was to minimise the cost of selecting farmer sites for conservation, subject to a constraint (4.2) concerning the minimum area (50 ha) to be procured for conservation services from each ecoregion.

[12] The minimum CWR selection constrain ensures that each CWR is conserved in at least three different community sites per ecoregion and 5 farmer sub-sites per community, wherever possible.

The model notation is:

$$\boldsymbol{Min\ Z} = \sum_{\boldsymbol{i} \in \boldsymbol{I}} \boldsymbol{c_i x_i} \tag{4.1}$$

Subject to

$$\sum_{i \in I} a_i e_i x_i \ \geq 50\ ha \tag{4.2}$$

$$\boldsymbol{x_i} \in \{\boldsymbol{0}, \boldsymbol{1}\} \qquad \textbf{for all i} \in \textbf{I} \tag{4.3}$$

Where a_i refers to the conservation area associated with site i, where i ϵ I = {1,2…,429}, e_i is a binary variable that indicates whether site i is located in either ecoregion 1 or 2. The ecoregions were categorised based on a data set obtained from WWF (2004) and original work by Olson et al., (2001). The binary decision variable X_i = {0,1} is used to determine selection of the parcels; 1 if the *ith* parcel is selected, 0 otherwise.

A set of additional constraints in the targeted goal (4.5) ensures that each priority CWR[13] is conserved in at least three different community sites per ecoregion and 5 farmer sub-sites per community, wherever possible[14]. Ideally, this genetic reserve design structure would be replicated across five distinct ecogeographic zones (Maxted et al., 2008b) although data were only available for two (Ecoregion 1 and 2). The additional constraints are summarised below:

$$\text{for all n} \in \text{N} \quad \sum_{i \in I} n_i\, e_i\, d_i\, x_i \ \geq 3\, d_i\, x_i + 5\, f_i\, x_i \tag{4.5}$$

$$\sum_{\boldsymbol{i} \in \boldsymbol{I}} \boldsymbol{m_i}\, \boldsymbol{x_i} \ \geq \boldsymbol{0.4} \sum \boldsymbol{x_i} \tag{4.6}$$

[13] A list of the priority CWR verified to be present at the sample sites and used in the modelling exercise is provided in Appendix 5.

[14] The proposed conservation design structure ensures CWR are conserved at different sub-plots per community (i.e. different farmers lands in each community) and per ecoregion, to capture different meta-populations and changes in local ecological conditions. Given limitations concerning the extent of our tender surveys, conservation to these requirements was not feasible for all CWR in the model.

$$\sum_{i \in I} p_i \, x_i \ \geq \mathbf{0.3} \sum x_i \tag{4.7}$$

$$\sum_{i \in I} v_i \, x_i = \ \sum x_i \tag{4.8}$$

$$\sum_{i \in I} q_i \, s_i \, y_i \, g_i \, x_i \geq \ \mathbf{0.5} \sum x_i \tag{4.9}$$

The diversity goal (equations 4.6, 4.7 and 4.8) employs the same constraints as the targeted area goal plus ensures CWR should be conserved in GMA sites at least 40% of the time. This is to facilitate active management of CWR in areas close to PAs. An additional constraint (4.7) specifies at least 30 % of sites selected contain plots that are ≥ 0.8 ha in size (based on an assumption that larger sites are better suited to maintaining species and population genetic diversity) (Lindenmayer and Burgman, 2005). All sites selected (4.8) should have verified CWR populations present[15].

The social equity goal (equation 4.9) employs the same constraints as the targeted area goal plus ensures that vulnerable groups, such as women, younger farmers and the poor have a minimum representation of 50% across the total selected conservation area. The social equity parameters specifically relate to the following:

- Number of female farmers, recognising the important role women play in the management of genetic resources (Escobar et al., 2017) as well as women's empowerment being considered a prerequisite for global food security (Quisumbing et al., 2014).
- Number of farmers aged ≤ 35 years of age. This contributes to the objective of motivating younger farmers to remain in farming – where the average age of farmers in Zambia is increasing (Brooks et al., 2013).
- Number of farms ≤ 2 hectares in size (a proxy for poorer farmers).
- Number of sites that are located in GMA areas, where the population may be up to 30% poorer than the national average (World Bank, 2007).

[15] Note, the presence of CWR at all farmer sites had not been directly verified by botanical surveys or species occurrence records held by ZARI. Thus, procuring conservation sites solely based on farmer identification of CWR provides less certainty of ensuing the presence of CWR, despite training received at the project workshops.

A description of the decision variables and parameters is provided in Table 4.1.

Table 4.1: Description of model parameters and associated notation used for different model goals

Notation	Parameter description
	Decision variable
x_i	[0,1] variable, 1 if site i is selected for conservation services from I index of all sites, 0 otherwise (unknown)
	Untargeted area model
a_i	area (ha) associated with site *i* from index *I* of potential sites for conservation services
c_i	the cost of selecting site *i* for conservation services
e_i	[0,1] parameter: 1 if site i is located in ecoregion 1, 0 otherwise
Z	objective function value (unknown)
	Targeted area goal
d_i	community corresponding to farmer *f* at site *i* from index D of all communities
f_i	farmer *f* corresponding to site *i* from index *F* of all farmers
n_i	[0,1] parameter: 1 if site i is associated with species *n* from index *N* of all species, 0 otherwise
	Social equity goal
g_i	[0,1] parameter: 1 if site i is located in a GMA area 1, 0 otherwise
q_i	[0,1] parameter: 1 if farmer *f* is female, 0 otherwise
s_i	[0,1] parameter: 1 if the size of farm i is ≥ 2 hectares, 0 otherwise
v_i	[0,1] parameter: 1 if farmer *f* is <35 years old, 0 otherwise
	Diversity goal
m_i	[0,1] parameter: 1 if site i is located in a GMA area 1, 0 otherwise
p_i	[0,1] parameter: 1 if plot *p* associated with site i is >0.8 ha in size, 0 otherwise
v_i	[0,1] parameter: 1 if site i contains verified priority CWR, 0 otherwise

4.4 Results

4.4.1 Summary statistics and bid offers

A total of 121 male and 79 female farmers submitted bid offers at non-GMA sites; whilst 170 male and 59 female farmers submitted offers at GMA sites across the 26 communities visited. Bid offers totalled $110,154 (USD) and encompassed 632 hectares. A significant difference between GMA and non-GMA sites was found for a range of variables, using a two sample t-test (Table 4.2). The GMA sites had smaller farms and their socio-economic status index score[4] was lower, suggesting this group of farmers are indeed generally poorer. Mean number of plots included in bid offers at GMA sites and the mean size of plots was higher than non-GMA sites, suggesting such farmers were willing to enrol significantly more land. Bid offers at GMA sites were significantly higher in total, as well as per ha and per plot. No significant differences were found for age of famers and the proportion of lands enrolled.

Table 4.2: Summary of descriptive statistics and t-tests for multiple parameters associated with farmer bid offers from GMA and non-GMA sites.

Variables	GMA		Non-GMA		*T*wo sample *t*-test	
	Mean	Std	Mean	Std	Obs	P value
Socio-economic status index[16]	4.4	1.0	4.9	0.8	427	***
Farm size (ha)	4.0	4.1	9.9	21.7	211	***
Age	42.4	12.0	43.2	12.5	422	ns
Plots bid	2.4	1.8	2.0	1.7	394	**
Average size of plot	1.0	1.2	0.3	0.3	216	***
Area bid (ha)	2.2	2.8	0.7	0.6	252	***
Proportion of land (%)	30.9	20.7	28.8	18.9	420	ns
Bid offer (USD)	396.7	560.1	96.5	73.3	237	***
Bid offer (USD per ha)	304.5	360.4	193.5	144.9	308	***
Bid offer (USD per plot)	213.0	205.3	64.2	56.1	223	***

Note: ‘Std’ = standard deviation, ‘Obs’ = observations. *** = P<0.01, ** = P<0.05, NS = not significant. Welch’s t-test was used where Fisher’s F-test indicated heteroscedasticity (unequal variance).

A correlation matrix reports the strength and direction of relationships between variables that may explain bid offer characteristics (Figure 4.3). Price/ha is negatively correlated with plots, area (ha) and proportion of land enrolled in the tender, suggesting as area, plots and the proportion of farmer lands enrolled in bid offers increases, so the price/ha of bid offers decreases. Bid offer is positively correlated with area and, to a lesser extent plots, suggesting higher bid offers are likely to contain more area and plots. Price is positively correlated with GMA, suggesting GMA areas resulted in higher bid offers. The proportion of land enrolled was negatively correlated (albeit weakly) with age, suggesting

[16] This refers to the FAO Richness Index (UN FAO, 2010) and represents the level of economic wellbeing associated with regions across Africa in 2010. This is measured from categories one (poorest areas) to six (wealthiest areas).

older farmers were willing to enrol proportionately less of their farms. Farm size was negatively correlated with GMA and ecoregion 1, as might be expected given that these areas house smaller farms. Finally, plots were positively correlated with area, suggesting as the number of plots included increases, so the area enrolled also increases.

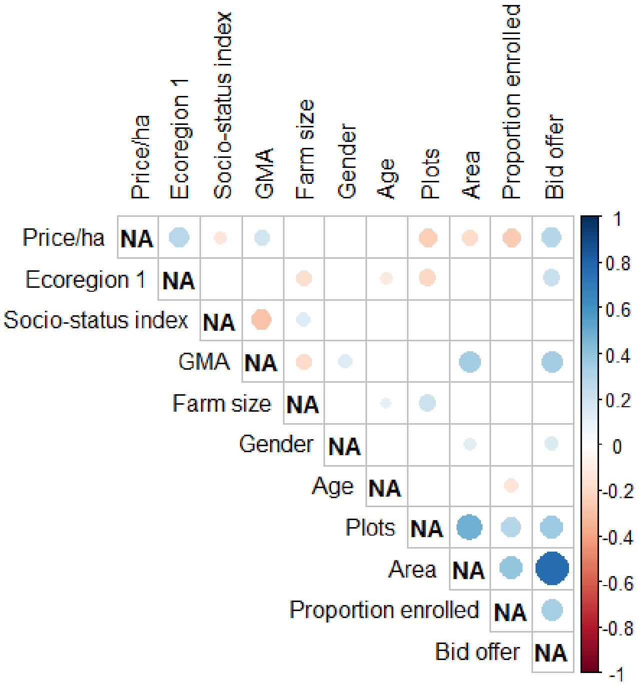

Figure 4.3: Correlation matrix demonstrating strength and direction of correlation for multiple explanatory variables for farmer bid offers. All populated variable cells were significant (P <0.05) in the analysis. Positive correlations are displayed in red, negative in blue. Colour intensity and the size of the circle are proportional to the correlation coefficients.

4.4.2 Site selection under multiple conservation goals

The construction of a supply curve allows the marginal cost for procuring an additional unit of conservation area to be estimated (Figure 4.4). The different model goals are shown through the varying supply curves, all of which are non-linear (i.e. price increments to procure more area vary along the curves). The untargeted area goal provided least-cost selection of conservation sites, followed by the targeted area and equity goals while the diversity goal was most expensive. The trade-offs between the different goals become more pronounced as selection of bid offers continues up the supply curve.

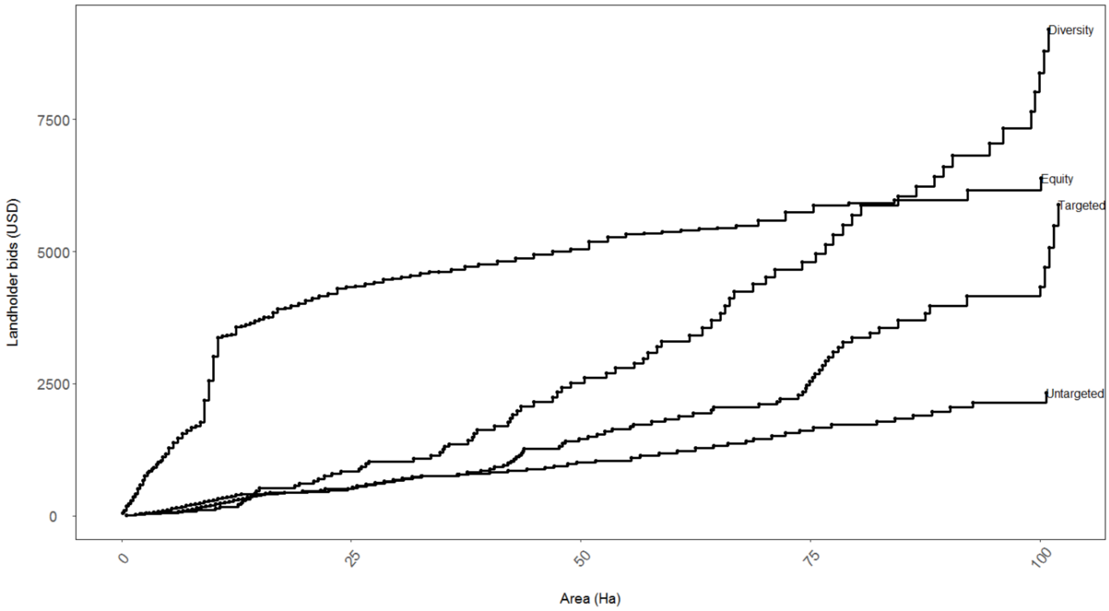

Figure 4.4: Supply curve of farmer bid offers (USD per annum) and area (ha) procured for conservation under the different conservation goals.

A range of diversity and social equity parameters varied depending on the goal employed (i.e. no. of younger farmers, no. larger plots, no. of female farmers, no. of GMA sites, no. of small farms and no. of communities). The untargeted area goal includes the highest proportion of larger plots of any goal, suggesting some farms with larger plots also sell cheapest (Figure 4.5). The targeted area goal selects more communities, verified CWR sites and female farmers relative to the untargeted goal. The diversity goal selected the highest proportion of sites with verified CWR records though not the highest number of larger plots. The social equity goal selected a higher proportion of younger farmers, female farmers, GMA sites and communities but with less emphasis on selecting sites with verified CWR.

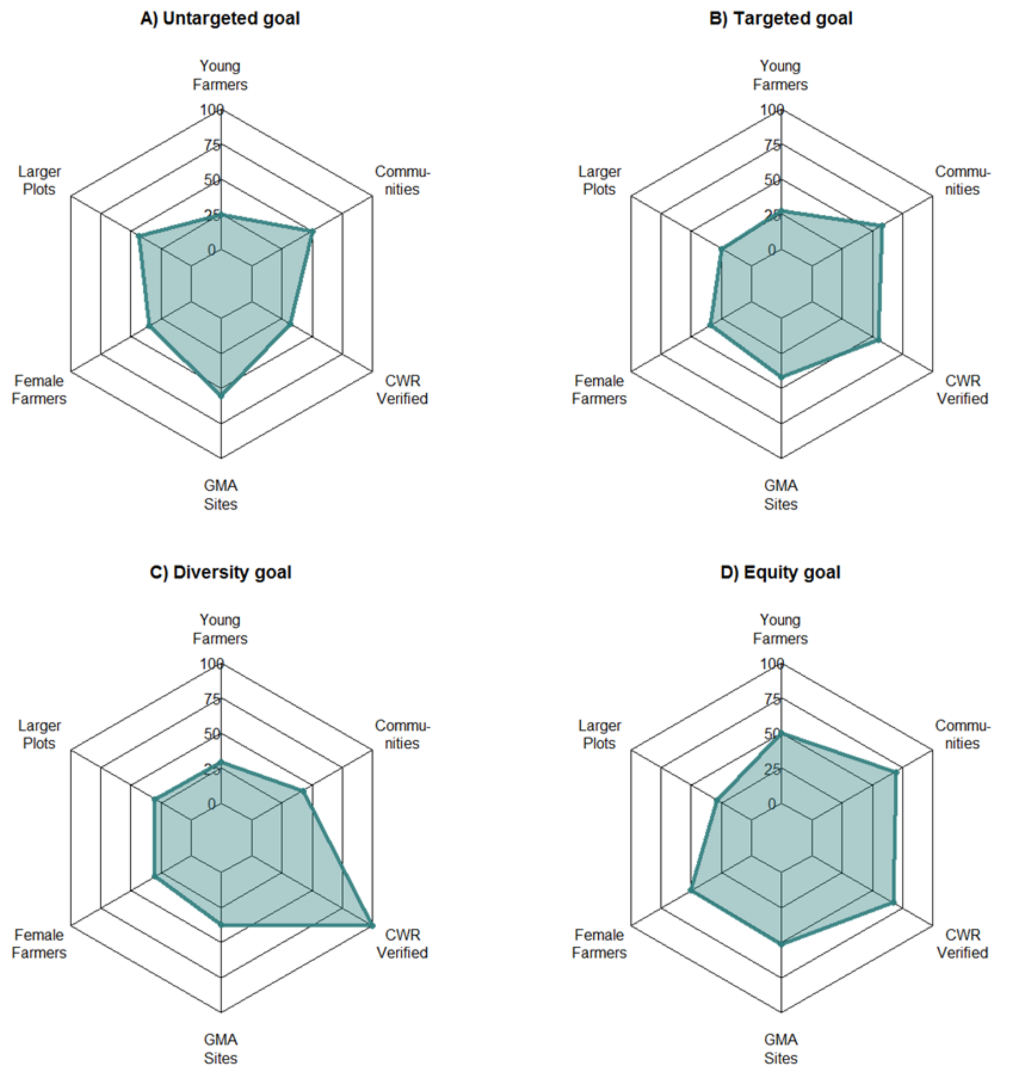

Figure 4.5: Panel of radar plots corresponding to farmer selection under the 'untargeted area', 'targeted area', 'diversity' and 'equity' goals. The 0–100 scale shows the proportion (%) of each parameter in site selection under the different goals.

Overall, the untargeted area goal provided least-cost procurement of conservation services ($2.3 k), followed by targeted area ($5.9 k), social equity ($6.4k) and diversity ($ 9.2k) goals (Table 4.3). Compared to using a uniform payment rule[17], the various model goals provided cost reductions of 87%, 66%, 63% and 48% cheaper per hectare, respectively; although these cost reductions would be reduced the further along the supply curve bid offers were selected. The equity goal selected the most GMA sites (45), female farmers (44), smaller farms (45) and young farmers (44) of all the model goals. The social

[17] The uniform payment was calculated as the average price per hectare across all bid offers.

equity goal therefore provides a basis to improve social equity outcomes but also has the second highest cost. Compared to the most expensive goal (diversity), social equity costs $27/ha or $2.8k per annum less. The diversity goal selected the largest farms and had a mean species richness of 2.66 – the highest species richness of any model goal. The cost per unit species richness[18] ranged from between $3k (untargeted area) to $4.4 k (targeted area) under all model goals. In terms of per unit of species richness, the diversity goal was 18% cheaper than the equity goal.

The targeted area goal selected the most non-GMA and ecoregion 1 sites. Non-GMA sites are associated with lower bid offers (on average) than GMA sites; hence their selection. In addition, the targeted area goal procured more plots than any other selection goal (192) and these plots were on-average 17% smaller than for the untargeted and social equity goal – reporting the highest mean plot size. The untargeted area goal was 75% cheaper on a per hectare basis than the most expensive goal (diversity). If expenditure under the targeted area goal mirrored that of the social equity goal then a further 20% of conservation area, or 17% more sites, could be procured. Similarly, trade-offs between the diversity and equity goal suggest the latter could conserve an additional 50% more conservation area or 40% more sites (with mirrored budgets) but with a 48% reduction in species richness across sites.

Table 4.3: Summary of parameters associated with individual farmer bid offer selection under different model goals.

Parameter	Untargeted	Targeted	Equity	Diversity
Mean cost per ha (USD)	23	58	64	91
Total GMA sites	38	40	45	27
Total non-GMA sites	31	56	43	59
Total ecoregion 1 sites	23	59	50	44
Total ecoregion 2 sites	46	37	38	42
Total farmers	69	96	88	86
Total female farmers	24	33	44	26
Total young farmers	17	26	44	25
Mean farm size (ha)	5	8	8	11
Total smaller farms (< 2 ha)	31	43	45	27
Total number of plots	156	192	166	162
Mean plot size (ha)	0.64	0.53	0.64	0.62

[18] A unit of species richness is taken by dividing the mean species richness (i.e. mean number of priority CWR from the sub-list present at each site) by the total cost for each selection goal.

Total large plots (≥ 0.8 ha)	30	24	25	26
Total communities	13	15	18	12
Mean CWR species richness[1]	0.77	1.34	1.51	2.66
Cost per unit species richness	$ 3,022	$ 4,398	$ 4,232	$ 3,461
Total area (ha)[2]	**100**	**101**	**100**	**101**
Total Cost (USD)	$ 2,327	$ 5,893	$ 6,390	$ 9,206

[1]Mean species richness was calculated based on the number of verified CWR species records (from the sub-set list of nine CWR species) associated with each site selected under that specific selection goal.[2] The model goals were constrained to select between 50 and 51 ha per ecoregion, to allow adequate flexibility to meet all other constraints in the model.

4.4.3 CWR conservation outcomes

An upward sloping supply curve reveals different cost estimates for procuring conservation land for each of the nine priority CWR[19] (Figure 4.6). While the supply curve does not consider overlap in species richness, it is clear sites with higher wild relative diversity would result in lower cost per CWR. Five wild relatives have relatively comparable supply curves; *Vigna dekindtiana*, *Sorghum bicolor*, *Eleusine indica*; *Eleusine coracana* and *Solanum incanum*. The most abundantly conserved CWR by area was *E. coracana* (54 ha) and the least conserved CWR was *Cucumis zeyheri* (3 ha). The rarer CWR tend to feature in less conservation sites and are therefore conserved across less area, suggesting the need for a more targeted approach to capture rare species adequately.

[19] Although 30 CWR were prioritised for conservation in Zambia, only nine priority CWR were verified to be present at our sample sites.

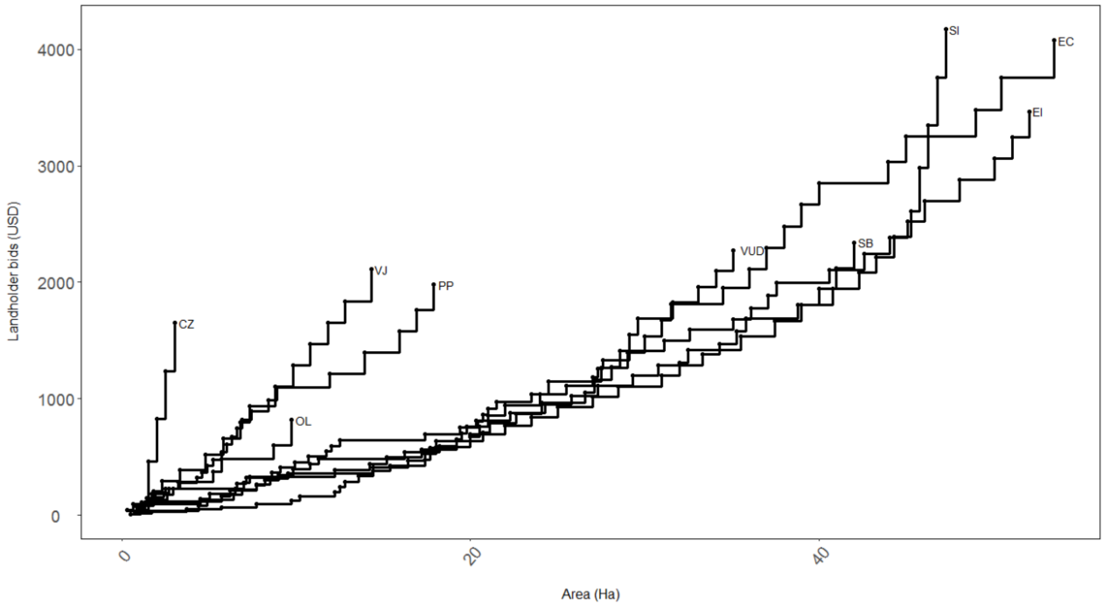

Figure 4.6: Supply curve revealing the cost of procuring conservation area (ha) thought to be inhabited by specific CWR in the diversity goal.

Key: VUD (*Vigna unguiculata* subsp. *dekindtiana*), VJ (*Vigna juncea*), EC (*Eleusine coracana*), SB (*Sorghum bicolor*), SI (*Solanum incanum*), EI (*Eleusine indica*), PP (*Pennisetum purpureum*), CZ (*Cucumis zeyheri*), OL (*Oryza longistaminata*).

Only four priority CWR were found across both ecoregions surveyed (Table 4.4) suggesting the need for more wide-ranging CT surveys. The two most expensive CWR to conserve (under the diversity goal) were *C. zeyheri* ($550 per ha) and *V. juncea* ($148 per ha). Both *C. zeyheri* and *V. juncea* were also the rarest CWR in our sample. The cheapest CWR were *S. bicolor* ($56 per ha) and *V. unguiculata* subsp. *dekindtiana* ($65 per ha). However, these were not the most abundant CWR across our sample, suggesting other factors (beyond rarity) are also driving changes in cost.

The most prolifically conserved CWR for the diversity goal (by number of sites) was *E. indica* (43) while the most sparsely conserved was *C. zeyheri* (5). These correspond to the most, and least, prolific CWR across all farmer sites featuring in our sample, respectively. *E. indica* was conserved across more plots than any other CWR but not the highest area. *E. coracana* was conserved across the highest area (54 hectares) of any wild relative but not the most farmers or plots (this being *E. indica).* This suggests a further potential trade-off between conserving across larger geographical ranges (using farmer numbers as a proxy) and ensuring a greater extent of hectares. Decision makers should be aware of such potential trade-offs when setting conservation goals.

Table 4.4: Summary of conservation parameters according to each CWR for the diversity goal

CWR	No. eco-regions	No. comm-unities	No. Farmers	Total area (ha)	Total plots	Cost/ha ($)	Total cost ($)
Oryza longistaminata	1	1	10	10.2	17	80	817
Cucumis zeyheri	1	1	5	3	5	550	1,651
Pennisetum purpureum	1	3	24	17.9	38	111	1,981
Vigna juncea	1	2	16	14.3	28	148	2,109
Vigna unguiculata subsp. *dekindtiana*	1	3	26	35.1	59	65	2,275
Sorghum bicolor	2	4	28	42	63	56	2,340
Eleusine indica	2	5	43	52.1	85	67	3,466
Eleusine coracana	2	5	38	53.5	68	76	4,078
Solanum incanum	2	4	38	47.3	78	88	4,172

Compared to using a uniform payment rule, the diversity goal resulted in mean cost improvements of 120% per hectare across each CWR, excluding *C. zeyheri* where a uniform payment rule would actually result in a cost reduction of 68%. Cost improvements ranged from 18% for *V. juncea* to 213% for *S. bicolor*, although these cost reductions may be lower if the area goal was increased (i.e. as the model moves up the supply curve).

4.5 Discussion

4.5.1 Working with different types of farmer

The cost-effectiveness gains from optimised site selection reflect the heterogeneity in opportunity costs of different farmers, as revealed in bid offers (Engel, 2016). While selecting at the lower end of the supply curve may reduce cost, the advantages must be weighed against increased transaction costs associated with differentiating payments, as well as fairness and welfare implications (Börner et al., 2017).

Across our sample, farms inputting bid offers comprising greater area and plots were found to be cheaper on a price/ha basis. The proportion of land enrolled in bid offers as a percent of total land ownership was not correlated with farm size, suggesting poorer households (i.e. GMA sites) are able to participate in this PACS scheme at levels similar to those of better-off households – a finding mirrored in work by Pagiola et al. (2010). Bid offers in GMAs were higher in absolute terms as well as per ha and per plot, suggesting poorer members of society do not necessarily “sell cheapest” (Pascual et al., 2014; Narloch et al., 2017). Importantly, these cost differences were not driven by changes in sample sizes between GMA and non-GMA sites, suggesting farmers from GMAs face higher shadow opportunity costs, possibly as a result of greater reliance on agri-production for livelihoods and survival. Additionally, these farmer groups may be aware of the financial benefits that can arise from working with conservationists.

Despite the potentially higher cost of working with poorer farmers it may nonetheless be desirable to engage poorer actors in conservation activities. Working with GMA farmers may strengthen existing relationships between farmers and concurrent conservation programmes (Lindsey et al., 2014). Indeed, farmers living in the GMA may harbour pro-environmental attitudes given their proximity to protected areas (Allendorf et al., 2006) and these benefits may offset the additional cost of working with these groups.

Paying farmers for environmental services provision can itself either reinforce or erode pre-existing intrinsic motivation for conservation (often termed ‘‘crowding-in” and ‘‘crowding-out”, respectively) (Narloch et al., 2013; Midler et al., 2015; Börner et al., 2017). There are many reasons for crowding-in or out, including satisfaction or demotivation with a contractual scheme (Nordén et al., 2013). Consideration regarding such potential impacts should be undertaken with a view to considering how crowding-in positive behaviours could be actively encouraged through scheme design and targeting. A complimentary approach may be to reward farmers by forging public private breeding initiatives to improve their crop landraces and ultimately farmer yields.

4.5.2 Trade-offs in PES

The mean cost of site selection ranged from $23/ha to $91/ha across all selection goals. Similar work on conservation tenders for the maintenance of landraces has obtained mean estimates of US $300/ha to $400/ha in Ecuador and $835/ha in Guatemala (Drucker et al., 2017), $1,228/ha in Bolivia and $3,667/ha in Peru (Narloch et al., 2017). The lower Zambia costs may reflect the reduced opportunity costs associated with conservation in field margins and lower labour costs (Rapsomanikis, 2015).

Using a discriminatory payment rule to select bid offers yielded cost-effectiveness improvements of 87% to 48% per hectare across the various model iterations, compared to a uniform payment rule. Sensitivity analysis indicates these gains in cost-effectiveness persist, albeit at a somewhat reduce level, even when procuring larger conservation areas (i.e. 100 ha. per ecoregion, rather than just 50 ha.) suggesting these findings are robust with regard to the area constraint imposed. The different constraints employed also impact cost effectiveness. The diversity goal yielded the best ecological performance (a 76% increase in mean species richness, compared to the equity goal) but the social equity goal resulted in 69% more female farmers, 76% more younger farmers and 67% more smaller farmers being selected in bid offers. These factors suggest a trade-off between cost-effectiveness, diversity and other socially desirable attributes. Similar work has found comparable trade-offs persist for landrace conservation (Narloch et al., 2011b) and biodiversity conservation in the tropics (Calvet-Mir et al., 2015).

It is therefore of interest to explore the relationship between social equity and the cost-effectiveness of conservation schemes. Factors such as perceived distributional fairness may influence an individual's motivation to engage in conservation programmes (Vatn, 2010; Narloch et al., 2013; Midler et al., 2015) and perceptions of unfairness can undermine the effectiveness of incentives (Sommerville et al., 2010). Debate in the literature has raised questions regarding the appropriateness of using PES programmes to tackle factors such as poverty reduction at the expense of ecological outcomes (Kinzig et al., 2011; Jack et al., 2008). While there are strong arguments for including equity considerations in PES (Wunder, 2007), it can be argued that allocating funds to service providers that are not the most competitive may undermine conservation effort (Börner et al., 2017).

Our work demonstrates imposing fairness considerations would result in additional scheme cost of a relatively modest 8% when compared to the targeted area goal. Although the diversity goal cost an additional 44% more to procure land than the social equity, it was actually cheaper per unit of species richness than the equity and targeted area goal. In other words, the diversity goal is the cheapest approach to maximising species richness out of the selection goals where a minimum diversity constraint is imposed. Multi-criteria approaches may be required to balance environmental effectiveness and fairness considerations and there are strong arguments for not treating environmental and social equity goals as fully separate objectives in PES schemes (Pascual et al., 2014). Good conservation outcomes are often contingent on developing positive local attitudes (Struhsaker et al., 2005) and pro-social behaviour that can improve compliance (Narloch et al., 2017). Our results show it is possible to combine social equity and diversity criteria and the cost implications resulted in a 15% increase. Ultimately, there is a need for such considerations to form part of the establishment of a consensus around the definition of conservation goals and how trade-offs are considered (Zumaran, 2018).

4.5.3 National scale CWR conservation

Establishment of national and global genetic reserves has been identified as a key policy challenge for CWR conservation (Maxted et al., 1997, 2010). Maxted (2015, unpublished) suggests a fully integrated national and global CWR conservation network is required and this Zambia case study reveals maximising diversity may be at odds with conservation area. Our findings therefore support work by Naidoo et al. (2006) that identify trade-offs between obtaining higher levels of a conservation target (i.e. biodiversity) and the increase in cost (or decrease in area) as a result.

Costs for establishing an on-farm conservation site for CWR have been estimated by Maxted (2015, unpublished) at $10k per ecoregion per year. While the total cost of conservation under the diversity maximising goal was estimated at $9.2k p.a. across two ecoregions, if this estimate were extrapolated to cover all ten ecoregions in Zambia (upper bound) or five ecoregions (lower bound) then the costs for establishing a national conservation network would range from $41,250 to $82,500 p.a.[20]. The latter is likely an overestimate since Brown and Briggs (1991) and Fielder et al. (2016) note conserving each CWR at a minimum of five different ecoregions should suffice. In any case we suggest this is a relatively modest sum as it only amounts to between 0.5% and 0.9% of income generated by the Zambian Wildlife Authority (Lindsey et al., 2014).

Eight of the nine priority CWR modelled in this exercise were present in existing PAs. Yet, many populations in PAs receive no active management highlighting the need to establish their management on-farm (Maxted et al., 1997; Lawson et al., 2014). While only *C. zeyheri* was not present within existing PAs, *Sorghum bicolor* and *Solanum incanum* were found to be present in only 20% and 25% of PA sites, respectively (see Appendix 6). In

[20] Based on procuring 50 hectares per ecoregion at the mean cost of $150/ha (this cost is based on the mean price/ha of individual farmer bid offers in the diversity goal). The cost estimate includes an additional 10% monitoring and management cost (as per Lindenmayer et al., 2012).

addition, *C. zeyheri* was not present in any *ex situ* collections while *Sol. incanum* and *S. bicolor* was scarcely stored *ex situ*. This suggests rationalisation is needed and raises broader questions concerning how best to allocate funds across integrated *in situ* and *ex situ* strategies. The high cost of conserving *C. zeyheri*, suggests it may be more cost-effective to prioritise *ex situ* approaches to enable a higher proportion of funds to be allocated to the *in situ* management of other CWR where the cost of conserving is much lower. Alternative *in situ* strategies (e.g. genetic reserves) may also be more appropriate where farmer led conservation is cost prohibitive.

4.5.4 Limitations and further work

Beyond assessment of farm scale cost other cost categories are important determinants of overall scheme cost. Training costs for farmers require approximating (Pagiola et al., 2007) in addition to transaction costs, which have been found to range from 6% to 87% of total costs paid to landholders (Latacz-Lohmann and Schilizzi, 2005). Additionally, monitoring costs were not considered but are necessary to ensure site management is maintaining or enhancing target CWR populations (Maxted et al., 1997; Maxted et al., 2008b). Such costs can be differentiated based on demographic counting of CWR (US$1 k per monitoring event) and genetic characterisation (required every 25–30 years costing $50 k per monitoring event) per ecoregion (Maxted, 2018, *personal communication*).

The constraints employed in this work were reliant on CWR records varying in date, raising questions concerning the reliance attached to such records and the need for additional field surveying to establish renewed population baselines. Additional ecological metrics such as habitat connectivity and sub-populations were not considered but have been shown to be important in other work (Beyer et al., 2016) and incorporating such metrics into future model iterations may promote more integrated conservation approaches. Additionally, the implications of climate change need to be made more explicit in decisions concerning optimal site selection given range shifts that are likely to occur (Phillips et al., 2017).

4.6 Conclusion

SI promotes the use of advanced breeding and genotyping technologies to meet future production challenges, including climate change (Tester and Langridge, 2010). Using novel genetic material, such as CWR, to enhance adaptive traits in crops is likely to become increasingly important and so their conservation (particularly *in situ*) is needed (Tanksley and McCouch, 1997). This work shows on-farm conservation was cheapest in the untargeted area goal (\$2.3 k^{year-1}) and most expensive in the diversity goal (\$ 9.2k^{year-1}) indicating that targeting increases the cost of conservation but with potentially better outcomes.

While more work to clarify our ecological and genetic understanding of CWR distribution and abundance in Zambia is needed, these findings reveal clear opportunities to improve the cost-effectiveness of incipient conservation approaches based on existing data through the use of tender instruments that are capable of identifying least-cost conservation service providers. The costs of conserving CWR (*in situ* on farm) ranged from between US\$ 23-91 per hectare, depending on the selection goal employed. Coupling *in situ* CWR conservation with other social policy goals may require an increase in conservation budgets if they are not to impact the ecological and genetic effectiveness of schemes.

Chapter five

Prioritising support for rare breed conservation using multi-criteria decision analysis

Abstract

Farm Animal Genetic Resources (FAnGR) are threatened by breed homogenisation. Rare breeds may carry important genes that allow breeders to respond to global production challenges including climate change and emerging disease risk. Yet, exploration of approaches to improve cost-effectiveness of investments in farm animal genetic diversity has been limited. We employ multi-criteria decision analysis (MCDA) to investigate how rare breed incentive schemes can be rationalised. A performance matrix was used to score 19 UK cattle native breeds at risk, in terms of diversity, marketability and endangerment criteria, and an expert workshop was used to assign weights for prioritisation. The workshop suggested that criteria pertaining to diversity, marketability and endangerment should be weighted 30%, 20% and 50% respectively. A principal component analysis (PCA) on the criteria suggested that fewer criteria could be used to characterise breed status but that each criteria node contributed effectively in explaining variation in breed scores. Modelling the allocation of a hypothetical breed improvement fund (BIF) revealed the greatest variation in the allocation of incentives occurred when marketability was weighted highest, while least variation occurred when endangerment received the highest weight. We suggest MCDA can support more targeted investments in diversity by considering the multiple factors that may be driving extinction risk in addition to the cultural and diversity attributes that compliment conservation.

5.1 Introduction

FAnGR make an important contribution to food security by ensuring greater adaptive capacity to global production challenges including climate change, emerging disease risk and changing consumption patterns (Eisler et al., 2014; FAO, 2017b). Rare breeds supply option value via the possibility to incorporate new traits into future breeding programmes, in addition to cultural and heritage attributes (Drucker et al., 2001; Dulloo et al., 2017). The failure of markets to reward some of these values has meant breed diversity is often undervalued and is now globally threatened (FAO, 2015a). Policy interventions are needed to correct for market failure, and incentive instruments to reward producers supplying diversity are common in some European countries (Bojkovski et al., 2015).

While incentive schemes are an improvement on the *status quo* (i.e. do nothing), they are prone to cost inefficiencies (Pascual and Perrings, 2007). Numerous approaches may be employed to improve scheme effectiveness including better targeting (Naidoo et al., 2006); collective bonuses (Kuhfuss et al., 2015); results-based approaches (Herzon et al., 2018) and improved monitoring (Lindenmayer et al., 2012). This chapter focuses on developing more targeted conservation approaches, a key policy goal of the Global Plan of Action (GPA) for FAnGR that stresses the need to construct indicators to better monitor breed attributes and develop more systematic conservation responses (FAO, 2007b).

Few advances in indicators have arisen since the GPA with the exception of works using diversity and endangerment metrics (Defra, 2015a; Verrier et al., 2015), and a novel geographical information system (GIS) platform for monitoring FAnGR (Duruz et al., 2017). Earlier work has focused on methodological adaptations of the Weitzman approach (1993) – a methodological framework employing phylogenetics to rationalise investments in diversity (Reist-Marti et al., 2003; Simianer et al., 2003; Zander et al., 2009). While such approaches are useful, there has been limited policy uptake, reflecting the tensions between scientific rigour and practicality. It is therefore important to develop more pragmatic approaches to guide investments.

Here, we develop an indicator detailing breed status by employing MCDA to construct a performance matrix detailing rare breed attributes that are weighted to derive preference scores concerning multiple endangerment and benefit criteria. Breed scores are subsequently used to allocate a hypothetical breed improvement fund (BIF) across breed societies. The fund aims to improve the status of at-risk breeds through more targeted conservation investments.

As a methodological approach, MCDA improves decision making power since it can combine technical information and stakeholder preferences to score alternative options, in this instance breeds (Huang et al., 2011). Existing applications of MCDA in the conservation literature have focused on site selection decisions (e.g. Phua and Minowa, 2005; Regan et al., 2007; Strager and Rosenberger, 2006) and there have been few applications to agrobiodiversity conservation problems. This study therefore fills two literature gaps. First, the construction of a composite indicator to monitor breed status and second, the application of MCDA to prioritise incentive support for rare breeds through the allocation of the BIF, using the UK as a case study.

The UK is currently exploring a range of policy options for future agricultural and environmental support following withdrawal from the EU (Defra, 2018). The state of UK FAnGR is particularly concerning, where 80% of native breeds are now classified as at risk (Defra, 2017a). Exploring cost effective breed conservation policies is therefore important and consistent with the UK Government strategy of providing '*public funds for public goods*' from agriculture (Defra, 2018).

The chapter is structured as follows. Section two details the MCDA approach and methods. Section three presents results of the MCDA application and the implications for resource allocation. Section four discusses criteria to monitor breeds, breed indicators and approaches to differentiate breed support. Section five presents conclusions.

5.2 Methods

5.2.1 The case study

The UK harbours over 700 breeds spanning sheep, goats, pigs, horses, ponies, cattle and poultry (Defra, 2013); equating to approximately 9% of global livestock breeds. Some 133 of these are native to the UK, of which 80% are classified as a native breed at risk (NBAR) (Defra, 2016). A breed may be classified as NBAR if it satisfies both genealogical and heritage attribute[21]s pertaining to origin and numerical population thresholds (Defra, 2013). We used a case study of 19 NBAR cattle across the UK; their geographical origins are noted in Appendix 7. The breeds were selected based on data availability relating to the criteria that would be used in the MCDA model.

5.2.2 Multi criteria decision analysis

MCDA relies on the integration of attribute measures for criteria relevant to decision makers' objectives and preferences (Strager and Rosenberger, 2006). At its most basic level, an alternatives performance relative to certain criteria can be reported in a table, known as a "performance matrix". Usually, MCDA follows a formal modelling approach, and there are three main methods; outranking, goal-based techniques and weighted linear combinations (see Marsh et al., 2017 for a review).

This study uses a weighted linear combinations approach, which usually combines preference weights (w_i) and criterion scores for alternatives (x_i) in a suitability index *S*. For such an approach, the criteria should exhibit mutual independence of preference (Adem Esmail and Geneletti, 2018). This means the judged strength of preference for an alternative on one criterion will be independent of its judged strength of preference on another (Dodgson et al., 2009). The criteria themselves must also be orthogonal (i.e. no double counting). The MCDA decision-making problem can be formulated through multiple, ordinal tasks with different research inputs (Figure 5.1).

[21] A breed may be classified as NBAR if it satisfies both genealogical and heritage attributes pertaining to origin and numerical population size associated with at-risk thresholds (Defra, 2013).

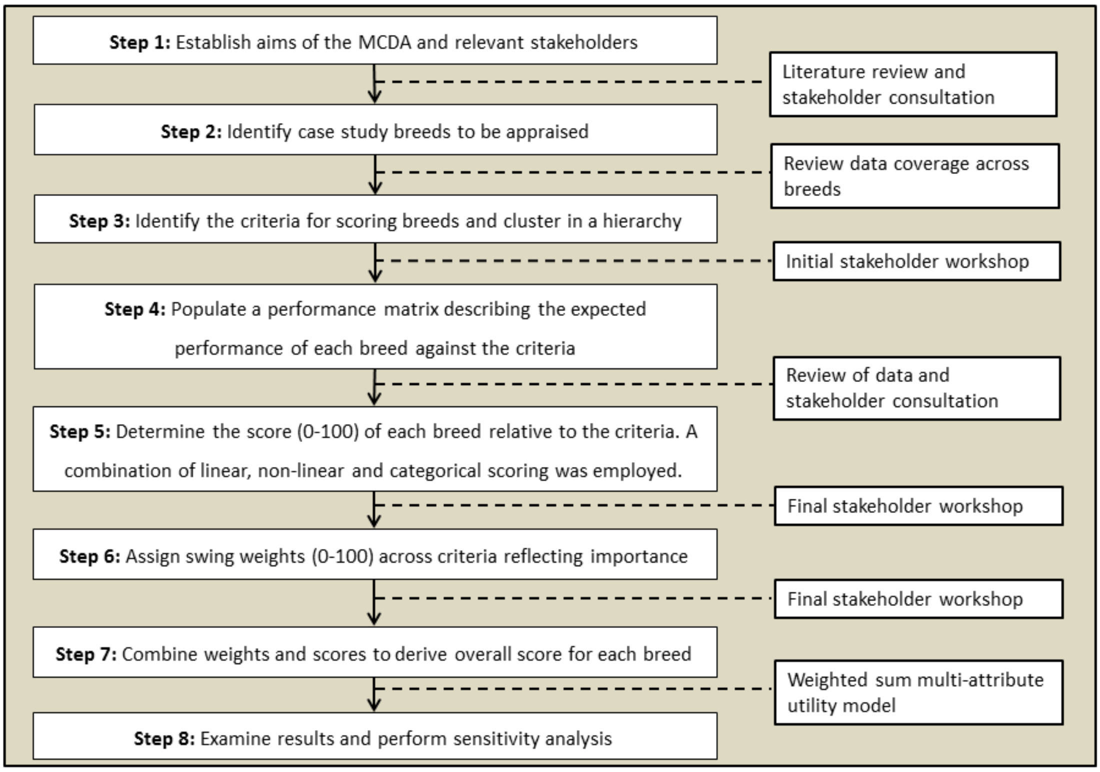

Figure 5.1: Formulation of the MCDA problem through ordinal steps (left) and research inputs (right) used in this work.

5.2.3 Identifying the criteria

Initially, a set of criteria was formulated based on literature reviews and stakeholder consultations. A requirement of all criteria is that the data were readily available and they were relatively simple to calculate, to ensure the method may be applied to other livestock species in future applications with relative ease. A workshop held with 10 expert stakeholders spanning academia, industry and NGOs then refined this initial criteria list (see Appendix 8 for delegate information). Discussions concerned the ‘practicality’, ‘suitability’ and ‘data availability’ associated with each criterion, which was scored (1-10) relative to these factors. It was therefore possible to determine both the highest scoring criteria and the level of agreement amongst stakeholders. A final set of criteria were then structured into a hierarchical value tree (Figure 5.2).

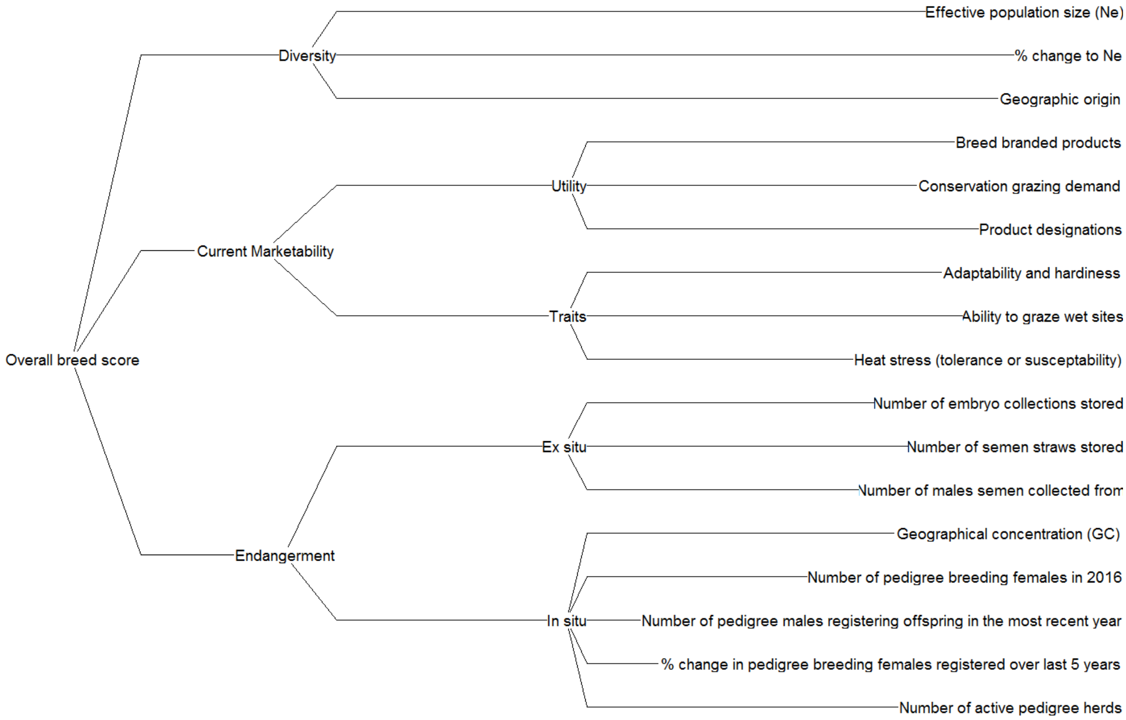

Figure 5.2: A hierarchical value tree of criteria and sub-criteria

The criteria were grouped by diversity, marketability and endangerment nodes and a performance matrix was populated containing breed performance data for each criterion. A detailed description of the criteria is provided in Appendix 9. The criteria nodes were developed to show what actions breed societies could implement to improve breed scores. For instance, if a breed scored low in diversity, then a society might respond by implementing a new breeding programme to increase diversity (Pattison et al., 2007).

Diversity criteria were selected to represent both within and between breed diversity. Rege and Okeyo (2006) suggest around 50% of farm species diversity arises from within breeds and a further 50% between breeds. Ne was used to measure within breed diversity; recalling that Ne is a metric that accounts for the total number of animals in a population, but also their breeding structure. A low Ne signifies a greater risk of declining genetic diversity within populations (Falconer and Mackay, 1996). Ne was calculated from a formula proposed by Wright (1931) using numerical population data. In addition, geographic origin of breeds was used as a proxy for between breed diversity (Lenstra et al., 2017; Parker et al., 2017).

Marketability approximates the use and non-use values of breeds and is clustered under two nodes: ‘utility’ and ‘traits’. Utility suggests how well a breed fits current market requirements, and traits refer to the characteristics that a breed may possess for it to become valued by markets. Note, the traits identified in this study are not definitive, but data constraints restricted the number of traits it was possible to evaluate.

Endangerment criteria were split between two nodes, *in situ* and *ex situ*. The sub-criteria we consider relate to *ex situ* storage of genetic material in the UK Heritage Genebank, and multiple *in situ* population metrics (e.g. number of pedigree breeding females). Appreciating the severity of threats posed to breeds through *in situ* and *ex situ* endangerment criteria means conservation responses can be focussed accordingly.

5.2.4 Scoring the alternatives

A final workshop, held with FAnGR experts in April 2018, scored the alternative breeds (see Appendix 8 for delegate information). Their experience with breed conservation spanned both technical and policy aspects of conservation. A decision conference format was employed to generate shared understanding of the criteria and open discussion (Phillips and Stock, 2003). The group reviewed the performance matrix and discussed the suitability of each criterion and their definitions. The criteria were deemed preferentially independent of each other, thus permitting the use of a weighted linear model (Dodgson et al., 2009).

The breeds were scored (Table 5.1) relative to the criteria based on three approaches, direct linear scoring, categorical scoring, and a preference value function (Mendoza and Martins, 2006). The scoring approach adopted differed depending on the criteria being assessed (see Appendix 9). Across all approaches, breeds were allotted a value score out of 100 points, with 100 assigned to the breed with the best level of performance on a specific criterion and 0 to breeds with the lowest performance.

Table 5.1: Value functions used in the MCDA study

Value Function	Description
Linear	Normalises continuous data input in the performance matrix for a specific criterion into the 0-100 scale that is directly proportional to their values.
Categorical	Normalises discrete data, to generate a discrete value function.
Preference	A non-linear scoring technique formulated graphs that reflected participant preferences concerning the normalisation of continuous data for each criterion.

All scoring methods employed a relative scale, meaning the differences in scores have consistency within each criterion. Since it is a relative scale, it is important to acknowledge only relative differences in value can be compared (Greco et al., 2016). Thus, if a breed is scored 25, then its performance preference should be half that to a breed scoring 50. Scoring was checked for consistency to ensure values were plausible. This took the form of a question to participants, asking "*based on these scores, you should be equally happy with the difference between breed x and y (scoring 30 and 50, respectively) as the difference between breed y and z (scoring 50 and 70, respectively)*". If there was disagreement, further discussion was facilitated. This helped reduce any bias and ensured realism in scoring (Nutt et al., 2010).

An evaluation matrix $\boldsymbol{P}$ was then constructed consisting of standardised alternative scoring p for i criteria, from all criteria I, across j alternatives from all alternatives J:

$$\boldsymbol{P} = \begin{bmatrix} \boldsymbol{p_{11}} & \cdots & \boldsymbol{p_{1J}} \\ \vdots & \ddots & \vdots \\ \boldsymbol{p_{I1}} & \cdots & \boldsymbol{p_{IJ}} \end{bmatrix} \tag{5.1}$$

The matrix was populated such that breeds with the highest diversity received the highest score in each criterion (assuming more diversity is a public benefit). For marketability, breeds that were most marketable received the highest score (assuming such breeds possess a higher utility value). For endangerment, breeds most endangered received the highest score to ensure scoring reflected extinction risk.

5.2.5 Weighting the criteria

Weighting ensures the units of criteria on the different value scales are equivalent, thus enabling scores for breeds to be compared and combined across criteria (Nutt et al., 2010). Criteria were weighted using swing weights, a method recommended by UK Government (Dodgson et al., 2009). The swing method is an algebraic, decomposed direct procedure where participants evaluate the 'swing' in breed performance in each criterion based on the range of values, and assign a weight to indicate the relative strength of preference (Wang et al., 2009). The weight on a criterion therefore reflects both the range of difference of the breeds, and how much that difference matters (Vollmer et al., 2016).

Workshop participants assigned weights to criteria within each node of the value tree. The criterion within a node that had the biggest swing and was considered most important was assigned an arbitrary value of 100. Thereafter, additional criteria were judged against the top scoring criterion, and were correspondingly scored to reflect the perceived difference in importance. The weights were then normalised to sum to 100.

A vector of weights ***W*** consisting of preference weights *w* for each criteria *i* (Jankowski and Richard, 1994) was then constructed:

$$\boldsymbol{W} = (\mathbf{w_1}, \boldsymbol{w_2}, \dots, \boldsymbol{w_n}), \sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{I}} \boldsymbol{w_i} = \mathbf{100} \tag{5.2}$$

Consistency checks on the weights were undertaken to help improve their validity. These involved comparing similar scoring criterion weights, relative to the swing in performance of the breeds. Scores and weights were input to the Hiview 3 software, which calculated the final weighted scores of each breed (Catalyze, 2018). The total breed weighted sum *S* was calculated by the followed linear additive model:

$$\mathbf{S} = \sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{n}} \boldsymbol{x_i}\, \boldsymbol{w_{iy,}} \quad \boldsymbol{i} = \mathbf{1}, \mathbf{2}, \dots \mathbf{17} \tag{5.3}$$

where x_i refers to the breed score for the *i*-th criterion and w_{iy} refers to the swing weight associated with the *i*-th criterion and the *y*-th node. A final grouped decision matrix for *m* breeds across *n* criteria was expressed as:

$$X = \begin{array}{cc} & \begin{array}{ccccc} Criteria & c_1 & c_2 & \cdots & c_{17} \\ Weights & w_1 & w_2 & \cdots & w_n \end{array} \\ Alt.breeds & - \quad\; - \quad - \quad - \quad - \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_{19} \end{array} & \begin{bmatrix} x_{11} & x_{12} & \cdots & x1_n \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{array} \tag{5.4}$$

where x_{mn} is the performance of the *m-th* alternative breed for the *n-th* criteria and w_n is the *n-th* weight applied to the criteria (Wang et al., 2009). Sensitivity analysis was employed to test the stability of the results with regard to variations in the preference scores and criteria weights (Ferretti and Comino, 2015). This allowed uncertainty in the performance matrix and criteria weights to be contextualised.

In addition to using expert derived weights, we considered three additional weighting scenarios to contrast different conservation priorities. Firstly, the weights for the criteria nodes were held equal. In a second scenario, the diversity node was weighted 50 while endangerment and marketability were each weighted 25. The third scenario ensured marketability was favoured (50) while diversity and endangerment were each weighted 25.

5.2.6 Differentiating breed support

One option for future breed support is to establish a central fund to support the initiatives of breed societies to improve the status of rare breeds. A hypothetical £10 million (5-year duration) BIF was allocated across the 19 case study breeds based on the breed indicator scores. The budget represents 33% of NBAR conservation grazing subsidies allocated to farmers by Natural England between 2006 and 2015 (Natural England, 2016). Breed societies were nominated as the beneficiary given their important institutional role for breed management and priority setting (Lauvie et al., 2014). Funding allocations were calculated by:

$$\boldsymbol{v} \in \boldsymbol{V} = \prod \left(\frac{\sum_{i=1}^{n} \boldsymbol{x_i} \, \boldsymbol{w_i}}{\boldsymbol{Z_i}} \right) \boldsymbol{q} \tag{5.5}$$

$$\textbf{subject to } \left(\frac{\boldsymbol{v_i k}}{\sum \boldsymbol{m_i f_i}} \right) \leq \pounds\mathbf{200} \tag{5.6}$$

Where V refers to the allocation of a hypothetical BIF across each breed v, Z_i is the total of all breed scores from index I of all breeds and q is the overall improvement fund budget. In (6) this is subject to a constraint where v_i refers to the funding allocation for breed k and m_i and f_i refer to the estimated number of pedigree breeding males and females respectively. The constraint ensures the pro-rata BIF doesn't exceed £200 per animal$^{\text{year-1}}$ and is therefore similar to mean subsidy allocations for rare breed conservation schemes across Europe (Kompan et al., 2014). The BIF was allocated according to the four weighting scenarios formerly noted, to reveal how a change in conservation priorities could impact funding distribution.

5.2.7 Principal component analysis

Principal component analysis (PCA) was employed to analyse the variance of the criteria and criteria nodes used in the MCDA model. PCA is a multivariate technique that analyses a data table representing observations described by several dependant variables that are generally inter-correlated (Abdi and Williams, 2010). The goal is to express information in the data table as a new set of orthogonal variables, called principal components (PC). The principal components are a linear combination of variables that can be used to reduce the original set of variables (Ayyadevara, 2018).

The aim was to determine which criteria and criteria nodes explained most of the variation in breed scores, as indicated by a value of > 1 for the eigenvalues that accord to the different PCs. The unweighted variables were scaled to have standardized unit variance and were mean centred prior to analysis. The calculation was done using a correlation matrix. The first two PCs were plotted using a bi-plot for all the criteria and the criteria nodes. The analysis was conducted using R v.3.5.0. For further background on PCA see (Jolliffe, 2011)

5.3 Results

5.3.1 Criteria and weights

This study used MCDA to score a selection of case study breeds relative to multiple criteria clustered under three nodes (diversity, marketability and endangerment). The weights assigned to the criteria are presented in Appendix 10 for both local and global weight scaling (local referring to the weight under each node, global being the overall weight). As expected, endangerment received the highest weight (50), followed by diversity (30) and marketability (20). Note that diversity encompasses the least sub-criteria of all nodes while endangerment includes the most.

In the marketability node, equal weight was assigned to the ‘utility’ and ‘trait’ nodes as experts suggested both contributed equally to the value of breeds. For endangerment, the *ex situ* node received much less weight (15) than *in situ* (85) because experts suggested genebank storage was effectively insurance to *in situ* conservation and therefore is less important than ensuring viability of actual breeding populations. The sub-criteria receiving the highest global weight overall were Ne (12) and percentage change to Ne over last 5 years (12) while all criteria relating to *ex situ* storage (no. of embryos, semen straws stored and males collected from) scored least (2.5 each).

5.3.2 Breed scores

Figure 5.3 shows the total weighted breed scores for the 17 criteria based on the three criteria nodes. As formerly, noted, high scores in diversity and marketability nodes are desirable while for endangerment low scores indicate a lower extinction risk. The highest scoring breeds for diversity were the Luing (18), Red Ruby Devon (17) and Dexter (14). For marketability, the Highland (18), British White (14) and Red Poll (14) scored highest. The most endangered breeds were the Vaynol (46), Whitebred Shorthorn (44) and Gloucester (42). Across all nodes the Whitebred Shorthorn (67), Red Poll (61) and Vaynol (61) scored highest. The difference between the highest and lowest scoring breed was 31, while the standard deviation across the total scores was 8. This deviation was least in the marketability node (3.6) and highest for endangerment (8.2). A sensitivity analysis demonstrated the model is structurally stable (see Appendix 11 for results).

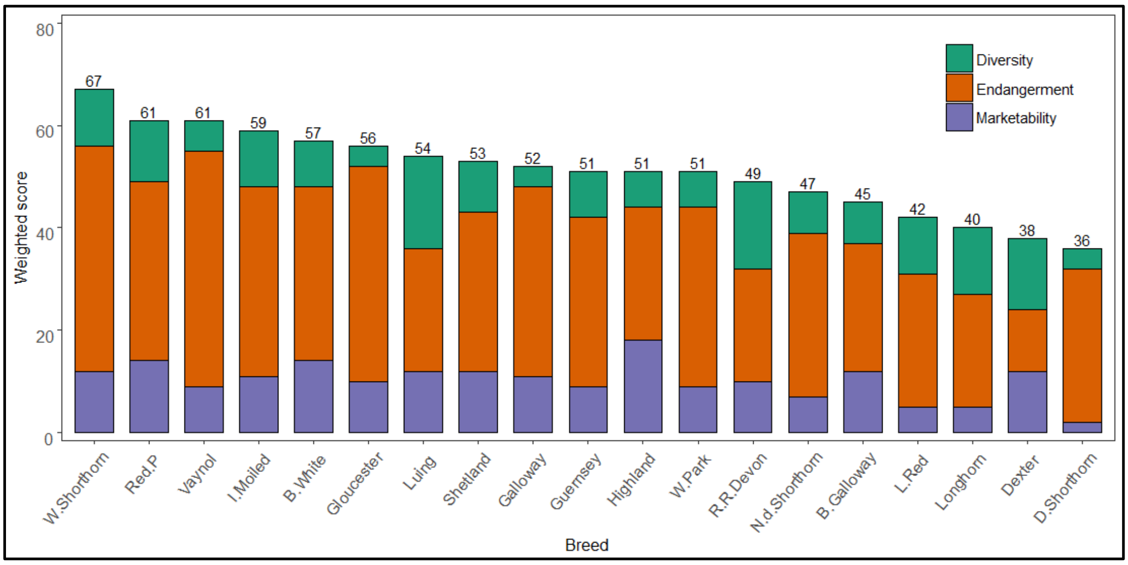

Figure 5.3: Breeds ordered by globally weighted scores for diversity, endangerment and marketability criteria. Note the Y axis scale is 0-80.

The contributions of mean part scores associated with each criterion suggests number of active herds (7.8) and percentage change to number of pedigree breeding females over the last 5 years (6.4) were the highest contributors to breed scores (Figure 5.4). Criteria with the lowest mean part score were product designations (0.1) and number of males' semen was collected from (1.3). The difference between the mean highest and lowest contributing criteria was 7.7.

The highest scoring breed for Ne was the Red Ruby Devon while the Luing scored most for percentage change to Ne over the last 5 years. Multiple breeds scored the same for geographic origin. Three breeds scored highest for product branding (Gloucester, Guernsey and Highland) whilst only one breed scored highest for product designations (Gloucester). Several breeds scored the same for conservation grazing demand, adaptability and hardiness, ability to graze wet sites, heat stress tolerance or susceptibility and number of embryo collections stored. Breeds scoring highly for adaptability and hardiness tended to score highly for conservation grazing demand.

The highest scoring breed for number of semen straws stored was the Luing, followed by the Dexter. The Luing also scored highest for number of males semen collected from, followed by the Belted Galloway. For geographical concentration, the Gloucester, Vaynol and Whitebred Shorthorn scored highest. The Northern Dairy Shorthorn, Dairy Shorthorn and Vaynol all scored highest for number of pedigree breeding females while the Vaynol and Gloucester scored highest for number of pedigree breeding males. For percentage change to female pedigree breeding population during last 5 years, the Highland and White Park scored highest. Lastly, the Vaynol and Northern Dairy Shorthorn scored highest for number of active herds registering offspring during the last three years.

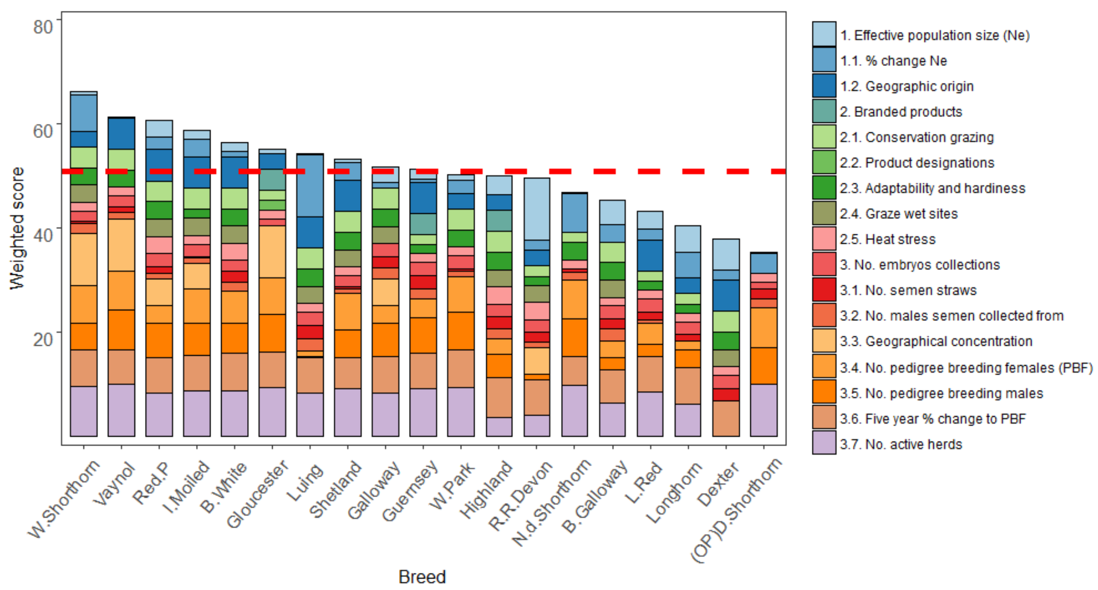

Figure 5.4: Global weighted scores for each breed ordered by the criteria nodes. The dashed red line indicates the mean breed score. Note (OP) refers to original breeding population.

The relationship between endangerment and marketability is plotted in Figure 5.5. The Highland and Dexter breeds effectively resemble the ‘efficient frontier’ i.e. breeds with least endangerment and highest marketability scores. The breed with the least marketability was the Dairy Shorthorn. There was no relationship between endangerment and marketability scores (r^2 = 0.0) suggesting other factors may be driving endangerment status. Conversely, breed diversity was (weakly) negatively correlated with endangerment (r^2 = 0.3), suggesting as endangerment increases so diversity decreases, or *vice versa*.

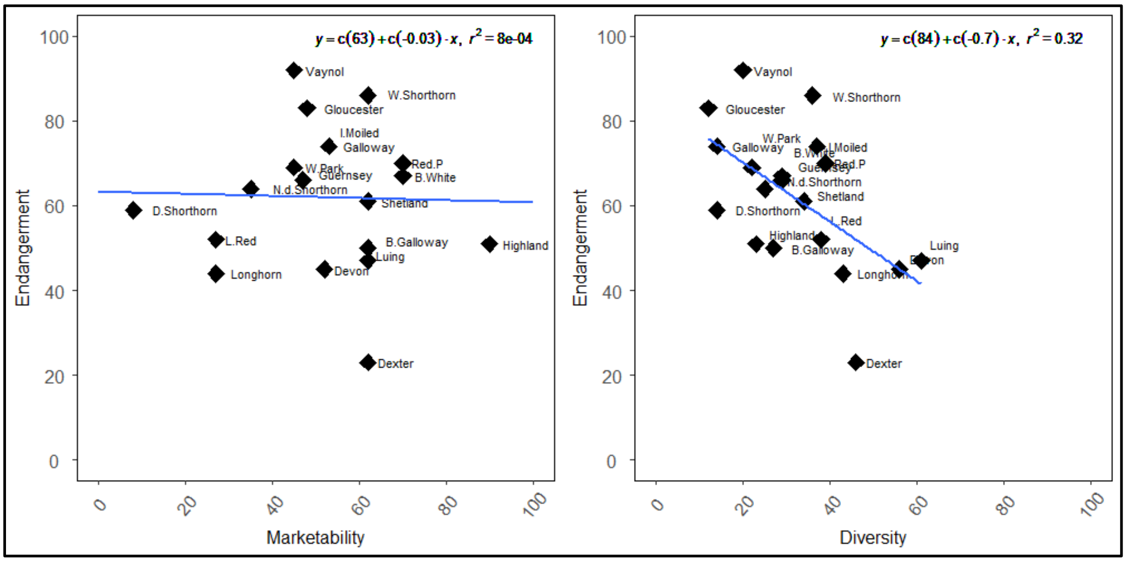

Figure 5.5: Scatter plots showing breed endangerment and marketability (left) and endangerment and diversity scores (right) with trend line. The regression equation and r^2 is also provided.

5.3.3 Principle component analysis

The relationship between the different criteria used for scoring breeds is explored using PCA and is plotted using a bi-plot in Figure 5.6. In this plot, the variables are plotted as vectors and the observations (i.e. breeds) are plotted as points (or scores) that correspond to the different principal components. The closer the points are to one another the more similar they are in terms of variable scores. The relative importance of the variables in explaining variation in breed scores is shown based on their distance to the origin, the point where the two axes cross at zero. The cosine of the arrows is directly proportional to the correlation between the variables and their length corresponds to the strength of that effect.

For Plot A, the first and second principle components (PC1 and PC2) accounted for 31% and 16% of the variation in breed scores, respectively. Out of the 17 PCs, five had eigenvalues >1 suggesting these five PCs explain most of the variation in the variables (see Appendix 12 for summary statistics). The loadings (see Appendix 13) for PC1 show three variables positively correlated with PC1; pedigree breeding females (PBF); number of active herds (NAH) and pedigree breeding males (PBM). This suggests breeds scores situated in the positive spectrum of PC1 tend to be those most endangered *in situ*. For PC2, Ne; breed branded products (BP) and product designations (PD) are all positively correlated with PC2. Breed scores situated in the positive spectrum here tended to have a higher utility benefit, although the interpretation is complicated since this PC only explains 16% of the variation in scores.

The variable vectors show PBM, PBF and NAH are strongly negatively correlated with number semen straws stored (NSS) and Ne, suggesting diversity and *ex situ* storage decrease as factors pertaining to *in situ* endangerment increase. Additionally, a number of variables are strongly positively correlated, including PBM and PBF; NAH and PBM; number of males semen collected from (NMSC) and percentage change to number of pedigree breeding females during last 5 years (CPBF); geographic origin (GO) and CPBF. This suggests the number of criteria employed in the indicator to explain breed status could be reduced in future iterations. Additionally, some variables trend together including adaptability and hardiness (AH) and conservation grazing demand (CG), demonstrating more hardy/adaptable breeds are indeed preferred for conservation grazing.

For Plot B, PC1 accounts for 48% of the variance while PC2 explains 24% of variance in breed scores. Of the five PCs, two had eigenvalues >1 (see Appendix 12). The loadings for PC1 (see Appendix 13) show three variables are positively correlated with PC1; diversity, *ex situ* and traits. Breed scores in the positive spectrum of PC1 therefore scored higher for these factors and were generally less endangered. For PC2, utility and traits had the highest loadings, suggesting they were positively correlated with PC2. Breeds scoring positively for PC2 can generally be considered more marketable and the top right hand quadrant of Plot B reflects this.

The variable vectors show *in situ* and diversity are fairly strongly negatively correlated. This suggests breeds with a high diversity score were generally less threatened in situ – a logical finding given a reduction in population size can cause genetic erosion. Additionally, *in situ* and *ex situ* are also negatively correlated, suggesting breeds most at risk *ex situ* (i.e. least genetic material stored) were also at lower risk of extinction *in situ*, demonstrating collection of genetic material is indeed rationalised by *in situ* extinction risk. None of the criteria nodes were correlated, suggesting these five factors are important determinants of breed status.

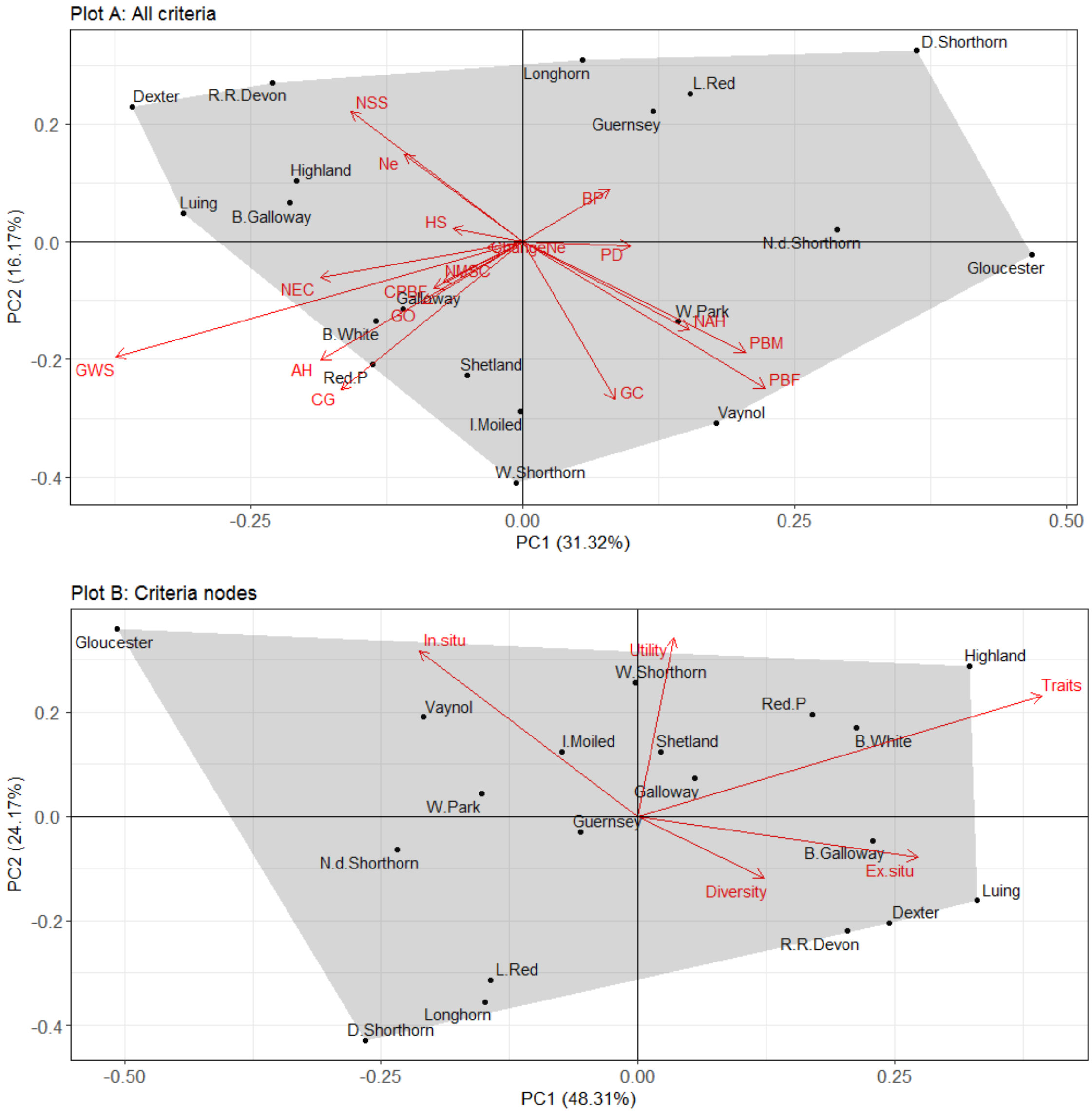

Figure 5.6: A bi-plot showing principle components one and two for unweighted breed scores based on the 17 different criteria (Plot A) and the 6 different criteria nodes (Plot B). Key: Ne = effective population size; ChangeNe = percentage change to Ne; GO = geographic origin; BP = breed branded products; CG = conservation grazing demand; PD = product designations; AH =

adaptability and hardiness; GWS = ability to graze wet sites; HS = heat stress tolerance or susceptibility; NEC = number of embryo collections stored; NSS = number of semen straws stored; NMSC = number of males semen collected from; GC = geographical concentration; PBF = number of pedigree breeding females in 2016; PBM = number of pedigree breeding males registering offspring in most recent year; CPBF = percentage change to number of pedigree breeding females during last 5 years; NAH = number of active herds contributing offspring in any of the last three years.

5.3.4 Allocation of a 'breed improvement fund'

Funds to support the initiatives of breed societies were allocated based on a basic formula that considers the breed indicator scores and constraints relating to breed population size. The hypothetical BIF was allocated according the four weighting scenarios outlined in Section 5.2.5. In Figure 7, we present results from two of these scenarios ('equal weight' and 'expert weight'). A summary of results from all scenarios are presented in Appendix 14. The pro rata budget constraint (per animal equivalent) meant the full budget could not be allocated and total spend was therefore £8.4 million; £8.5 million; £8.5 million and £8.2 million across the four scenarios.

For the total budget allocation under equal weight (Plot A), the Red Poll (£651 k) and Luing (£619 k) received the most funding while the Vaynol (£10 k), and Dairy Shorthorn (£54 k) received the least funding. The standard deviation of payments around the mean is £101 k. For expert weight (Plot B), the Red Poll (£631 k) and Irish Moiled (£611 k) received the highest budget allocation. Likewise, the Vaynol (£10 k), and Dairy Shorthorn (£54 k) received the least funding. The standard deviation of payment allocations was highest in the expert scenario (£185 k). Across both scenarios, the breeds with the highest budget allocation range were the Dexter (£ 84 k) and the Highland (£ 80 k).

For the pro rata allocation, under equal weight (Plot C) the Dairy Shorthorn, Northern Dairy Shorthorn, Gloucester, Vaynol and Whitebred Shorthorn all received the maximum budget allocation (£1 k $^{\text{animal year-5}}$) while the Dexter (£58 $^{\text{animal year-5}}$) and Red Ruby Devon (£70 $^{\text{animal year-5}}$) received the least. For expert weight (Plot D), the same breeds received the maximum budget allocation and likewise the Dexter (£48 $^{\text{animal year-5}}$) and Red Ruby Devon (£66 $^{\text{animal year-5}}$) received the least. The results demonstrate the different weighting scenarios have subtle differences on budget allocation, suggesting structural stability in the model. Moreover, the BIF allocation demonstrates the importance of applying a pro rata budget constraint; highlighting the sensitivity of the model to breed population estimates.

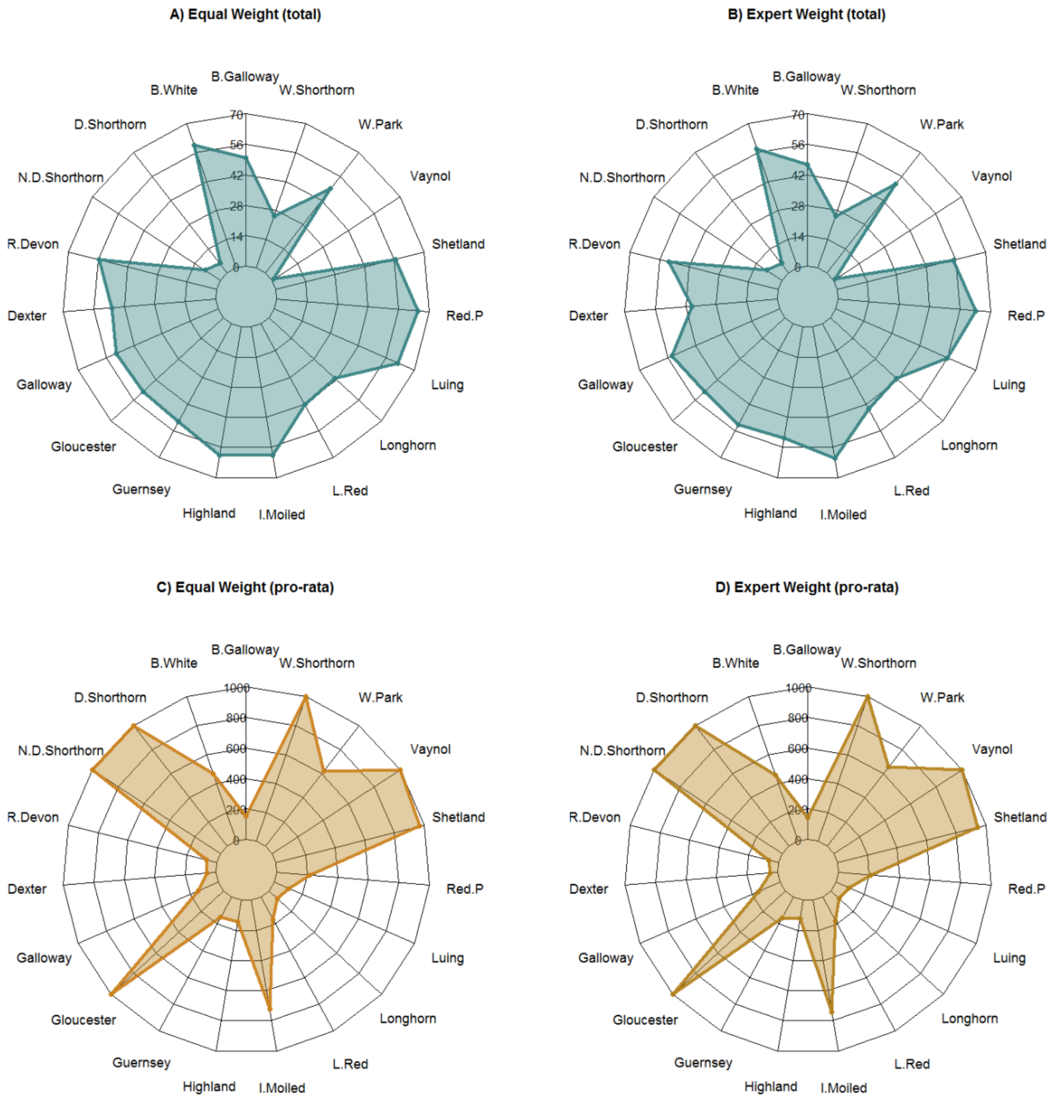

Figure 5.7: Radar chart showing the allocation of a £10 million ‘breed improvement fund’ to breed societies based on breed scores under two alternative weighting scenarios. Plots A and B show the total budget allocation while plots C and D show the pro rata budget allocation based on a population constraint. For plots A and B the axes are in ‘£ 0000 k’.

5.4 Discussion

5.4.1 Criteria to monitor rare breeds

Criteria to monitor breed status can be extensive (Eaton et al., 2006). During expert workshops a clear trade-off emerged between the desired scientific rigour of approaches to monitor breed status and the need for more realistic, often proximate measures. Perhaps most complex to measure is diversity. The variation that exists within and between breeds can be captured through different metrics including measures of inbreeding (usually to monitor genetic drift), introgression (to monitor genetic purity) and genetic difference (through phylogeny or genomics).

Simplistic measures of diversity assessment have been employed by Defra (2017b, 2015a) to calculate Ne based on Wright's (1931) formula using numerical population data. However, the Wright equation assumes random selection and Poisson distributed progeny sizes, which are unlikely assumptions for most livestock populations (Gandini et al., 2004). This means it can produce an estimate of Ne that is higher than would be produced by a calculation using pedigree data (Hall, 2016). However, such data are not readily available for many native breeds and Verrier et al., (2015) found only 56% of native breeds had enough pedigree information to allow Ne to be calculated based on coancestry records. Thus, Defra data using Wright's formula (2017b, 2015a) were employed for this application but this is a limitation of the analysis.

Moving to genetic difference, work by Blott et al., (1998) and Lenstra et al., (2017) among European cattle and goat breeds shows genetic relationships between breeds does reflect their geographic origin and common ancestry. No studies have yet employed genetic techniques (e.g. phylogenetic analysis) to measure difference across all UK native cattle breeds, with the exception of smaller case studies (e.g. Wiener et al., 2004). Consequently, we used origin as a proxy to estimate the genetic difference across breeds but we acknowledge the limitations inherent in such an approach.

The two nodes of marketability (utility and traits) received lowest weight by experts, partly reflecting limitations of the input data. Additional criteria contributing to utility could include a variable denoting the presence of a rare breed in farm parks to capture cultural value as proximate to public demand for seeing a rare breed. Such cultural and heritage attributes may be at odds with maximising diversity (Lenstra et al., 2017) suggesting a need to consider these criteria in conservation and monitoring strategies seeking to supply the range of different value attributes that rare breeds encode, situated on the TEV spectrum. Aside non-use values, criteria to measure direct use-value associated with marketability and consumption can be approximated through product branding and designations, including geographical indicators - e.g. PDO. The latter may act in perverse ways to concentrate breeding stock if a geographical production constraint is imposed (e.g. Single Gloucester PDO) thus undermining conservation effort. There is therefore an explicit need to consider such criteria in a broader framework, as demonstrated here.

While option value is promoted for conservation (Drucker, 2010; Hoffmann, 2011) the characterisation of productive and adaptive traits in native breeds are often poorly documented (Bowles, 2015). The limited number of breed traits reported in this work reflects this knowledge gap, suggesting more work is needed to characterise breeds through the application of genotyping technologies, including whole genome sequencing (Tixier-Boichard et al., 2015).

Turning to endangerment, although *ex situ* conservation was considered least important by stakeholders, it nonetheless serves as an important risk reduction strategy (Hiemstra, 2015). Yet, our understanding of the legitimacy of current accessions is poor and the criteria we employ merely quantify the material stored, rather than providing broader analytics concerning quality attributes. Developing proxies pertaining to the efficacy of material stored in genebanks would provide more accurate assessment of germplasm safeguards. For *in situ* populations, this assessment was limited to breed data reported to Defra and stored in their breed inventory.[22] But a range of additional parameters may also reveal risk, including global breed population estimates and demographic trends concerning breeders – e.g. number of young entrants to a breed (Alderson, 2010). Further exploration of these factors is needed in future prioritisation models.

5.4.2 Breed indicators

Multiple indicators have been constructed for diversity (DEFRA, 2015b; European Environment Agency, 2007; Villanueva et al., 2010) and endangerment (Gandini et al., 2004; Eaton et al., 2006; Alderson, 2009, 2010; Verrier et al., 2015) but few have combined factors spanning diversity, marketability and endangerment to more holistically measure status. This is perhaps related to the incommensurability of many biological criteria which makes them difficult to compare on common scales without the use of analytical frameworks like MCDA.

[22] For the breed inventory see https://www.gov.uk/government/statistics/uk-farm-animal-genetic-resources-fangr-breed-inventory-results

Although endangerment received the highest overall weight in this indicator, our results demonstrate the inclusion of other criteria nodes is equally important for decision making. This is highlighted where the Vaynol received the highest endangerment score but was ranked 3rd overall because the total benefit of conservation was considered less. Alternative weighting scenarios reveal how these conservation priorities may change through a focus on different value attributes. This raises broader questions concerning who should assign criteria weights and how periodically they should be reviewed for composite indicators to be robust.

To develop this indicator, multiple expert discussions were needed to systematically construct a list of criteria that could be used to measure and report breed status. However, the PCA suggests some criteria could be omitted in future iterations due to correlation (e.g. number of pedigree breeding females / males and number of active herds)) that would simplify future assessment. Yet, data concerning these criteria are readily available in the UK suggesting little benefit in dropping them from the indicator. Of more value, would be the identification of correlation in “hard to measure” criteria to reduce the monitoring burden providing reporting accuracy is retained.

The PCA also shows that each criteria node contributes differently to explaining the variance in overall breed scores, suggesting these criteria nodes are actively important for determining breed status. Construction of composite indicators can also reveal relationships between criteria that can be used to test the validity of the results. For instance, the PCA shows conservation grazing demand for cattle is indeed linked to the traits of grazing animals (i.e. breeds with greater adaptability are used more by grazers). This demonstrates the value of a rare breed is indeed partially linked to their adaptability and hardiness characteristics, a finding often promoted in the literature (e.g. Leroy et al., 2018) but with little empirical basis. Additionally, we show the collection and storage of germplasm in genebanks is rationalised by *in situ* endangerment risk (both via population metrics and geographical concentration) suggesting recommendations outlined by the FAO (2012) concerning rationalisation of *ex situ* collections are indeed being implemented by conservationists.

5.4.3 Differentiating breed support

The preservation of biodiversity, including breed diversity, is hindered by the absence of a workable, cost effective model for determining preservation priorities (Metrick and Weitzman, 1998). The defining limitation is the lack of an overarching objective to guide investments that has led to untargeted policy interventions seeking to preserve diversity indiscriminately. While empirical work has explored prioritisation, both for FAnGR (Reist-Marti et al., 2003; Simianer et al., 2003; Zander et al., 2009) and PGR conservation (Maxted et al., 2012; Vincent et al., 2013) the policy landscape is still dominated by uniform payment mechanisms that incentivise conservation actions.

Conceptually, this MCDA model suggests differentiated breed support could improve the cost effectiveness of conservation strategies through the distribution of a BIF prioritised by breed indicator scores. Approaches in the UK currently preserve rare breeds through conservation grazing subsidies (Natural England, 2017) but breeds or species that are not employed for conservation grazing are ultimately under-supplied through such initiatives. Broader support measures are therefore necessary to supply more diversity.

Differentiated support can also facilitate more targeted interventions, which our results suggest are necessary given that the contribution of each breed to the criteria nodes is heterogeneous. For instance, the Red Ruby Devon scored high in diversity but relatively low in marketability, suggesting investments in breed promotion may be more effective at improving breed status (rather than collecting germplasm, for instance).

Although the important role of breed societies has been acknowledged in previous work (e.g. Felius et al., 2015; Ramsay et al., 2003) we are the first (to our knowledge) to promote the allocation of conservation funds across societies. Importantly, the BIF ensures all breeds receive some proportion of funding. While the proposed BIF can differentiate well between breeds with similar population sizes, it is less effective for breeds with particularly small populations because the pro rata allocation constraint means final funding allocations are very low Alternative approaches to the to the prioritisation of breeds for conservation (e.g. Simianer et al., 2003) suggest only breeds where the conservation potential is greatest (i.e. where the product of extinction probability and marginal diversity is maximum) should receive support. We argue such approaches are perhaps defeatist and is an ethically pernicious approach to decision making (see Noss, 1996 and Vucetich et al., 2017 for broader discussion concerning triage).

While prioritisation focusing solely on phenotype or genotype "uniqueness" is too limited in scope, this study addresses such limitations through the inclusion of a marketability node that attempts to capture option and cultural value in addition to diversity and endangerment characteristics. Beyond these factors, this MCDA model does not imply abolishing support for redundant or overlapping diversity; it simply suggests a step change on the supply-side that prioritises preferences exhibited on the demand side.

5.5 Conclusion

Financial resources for species and livestock conservation remain significantly below what would be required to meet the Aichi biodiversity targets (McCarthy et al., 2012). The opportunity cost of conservation (i.e. what else could be achieved with the same funding resources) is rarely reported or evaluated, yet potential reductions in UK conservation funding as a result of Brexit mean such trade-offs are likely to become more explicit. However, Brexit also creates an opportunity to adjust how the UK Government supports the public good properties of rare breeds that span the TEV framework.

Better informed decision-making should consider information on the values of breeds held by stakeholders, the expected benefit to diversity from investments, and the cost of action. Considering these factors through the prioritised allocation of a BIF to breed societies could better guide investments in FAnGR that promote the longer-term sustainability of breeds. The former relies on empowering breed societies to selectively fund initiatives aimed at improving breed status relative to the multiple values that rare breeds encode. Prioritising conservation activities is important because extinction risk may take a number of different forms, including introgression, inbreeding depression and genetic drift (Berthouly-Salazar et al., 2012).

A key feature of MCDA is its emphasis on the judgement of the decision making team and the subjectivity that pervades this can be a matter of concern. While we have attempted to account for such limitations through multiple stakeholder workshops and sensitivity analysis, it should be appreciated that different stakeholder views may produce conflicting results. The way in which questions are posed to elicit criteria weights may also affect outcomes (Choo et al., 1999) and we have mitigated such concerns by following the recommended methodological approach for MCDA by the UK Government (Dodgson et al., 2009). The sample size in this application is small (19 breeds) and we appreciate that further piloting is needed to validate this approach across different species. The criteria employed in this study reflect circumstances in the UK and different criteria may be needed for application in other regions and especially developing countries, where the available information and primary causes of genetic erosion vary (Verrier et al., 2015).

Lastly, this work shows large gaps in information persist for rare and native breeds which impedes characterisation of FAnGR. There is a need to define key phenotypic traits and characteristics (particularly those involved in local adaptation) so FAnGR can be evaluated through comparable data sets, which is important for climate change adaptation (Irene Hoffmann, 2010; Bruford et al., 2015). A growing arsenal of increasingly sophisticated genetic technologies are now falling in price (e.g. DNA sequencing) and there is a clear need to apply such approaches to better appreciate locally adapted breed traits for conservation and sustainable use.

Chapter six

Conclusion and recommendations

6.1 Summary

This thesis has explored how the design of agrobiodiveristy conservation schemes could be made more cost-effective. The modelling approaches provide empirical assessment of different scheme designs and costs to meet demand for diversity attributes that include use and non-use values. This is important because the application of economic models to improve cost-effectiveness of PGR and FAnGR schemes is scarce, despite farm-scale intensification that threatens agrobiodiveristy. The thesis therefore explored how the supply and demand side aspects of conservation could be optimised as a function of biological, genetic and economic factors.

Chapter Two provided a review of institutions and instruments to supply diversity alongside discussion of the different economic values that rare breeds encode. A growing need to more explicitly supply the different value attributes of breed diversity has emerged, and reflects the broad range of ecosystem services provided by farm animal diversity (Leroy et al., 2018). By considering how institutions mediate or respond to wider societal preferences for conservation, the chapter reveals how different forms of market failure appear to be exacerbating breed status. We suggest that policy instruments and the SI agenda should better consider the range of use and non-use values associated with breed diversity.

Chapter Three employed a survey and CE to explore farmer motivations for keeping rare breeds and preferences for the design of conservation contracts, including assessment of farmer WTA to participate in a contractual scheme. Results suggest farmers in Transylvania are intensifying farming practices and this may be accelerating reductions in farm animal diversity. Increasing farmer awareness and removing barriers to entry for RDP schemes is key to increasing farmer participation in rare breed conservation. The choice model indicated farmers have heterogeneous preferences for contract attributes and these vary depending on farm species kept. Considering these preferences could improve the design of schemes and reduce the cost of conservation.

Chapter Four considered PGR by measuring the costs of conserving CWR through a hypothetical on-farm conservation programme that could form part of a NSAP for CWR conservation and sustainable use in Zambia (Ministry of Agriculture, 2016). Bid offers from the conservation auction were selected based on alternative conservation goals. The former suggested a potential trade-off between maximising area or diversity in site selection decisions. Additionally, we show the inclusion of a social equity goal in site selection decisions may compromise ecological effectiveness. While the literature provides some guidance on such trade-offs, more empirical work is needed to quantify the socio-economic and ecological implications of employing alternate selection goals in programmes (Engel, 2016). Calculating the mean cost of site selection relative to each CWR, we showed considerable cost heterogeneity persisted, raising broader questions concerning appropriate forms of conservation intervention when costs are prohibitive.

Chapter Five presented an application of MCDA to explore how breed incentive support can be better targeted towards specific value attributes of diversity. Weights derived from stakeholder workshops suggested endangerment was considered most important when considering conservation interventions, followed by diversity and marketability attributes. Breed part scores across the criteria exhibited high levels of heterogeneity and a PCA showed the multiple criteria nodes explain different aspects of variation in breed scores. Such information may offer insights for more targeted priority setting and rationalisation of investments in diversity, particularly where (breed) vulnerabilities persist. Allocating a hypothetical BIF across breed societies, we suggest a potential framework for differentiating incentive support for rare breeds. We suggest breed societies are ideally placed to guide such investments, given their instrumental role in breed management and promotion (Felius et al., 2015).

Overall, the chapters point to the need for more targeted conservation policies that (on the supply side) exploit the power of market competition to facilitate identification of least-cost conservation providers through auctions. On the demand side, there is a need to consider private and public values for diversity that can be appropriated through better-targeted investments in agrobiodiversity. Coupling these themes means schemes may supply conservation services more cost effectively.

6.2 Conclusions and recommendations

There is a need to consider the full range of ecosystem services in the SI agenda, including cultural heritage. The origins of SI focus discussion on increasing yield in the face of resource scarcity and environmental challenges (Garnett et al., 2013). Yet, while the SI paradigm has evolved, there is a conspicuous absence of cultural and heritage values in agenda setting. Ignoring such values is risky and more guidance is needed on the multiple policy fronts of SI to include these value attributes, many of which complement improved food security through the addition of option value.

Agrobiodiveristy conservation strategies should be complemented by diversity and resilience metrics for improved food security. Resilient agroecological systems are needed in order to sustain yields ahead of future change drivers including demographic, environmental and climatic change (IPES-Food, 2015). Work by Bioversity International (2016) is seeking to develop a so-called 'Agrobiodiveristy Index' to measure diversity in diets, food production and genetic resources. The establishment of a distinct PGR and FAnGR metric is necessary for more systematic conservation responses that consider elements of diversity, marketability and endangerment. .

Incentive schemes are needed to increase *in situ* (on-farm) conservation of CWR in response to land use changes and climate change threats. Aside *in situ* conservation in genetic reserves and protected areas, on-farm conservation of CWR has been neglected, despite growing concerns surrounding range shifts of wild relatives in response to climate change that exceeds current geographical coverage of protected areas (Aguirre-Gutiérrez et al., 2017; van Treuren et al., 2017). Moreover, land use changes (e.g. agricultural intensification) threaten many wild relative populations that persist outside protected areas (Maxted et al., 2011; Jarvis et al., 2015). To meet these challenges, on-farm conservation strategies are needed via incentive schemes that pay farmers for supplying conservation services. The application of site selection models that optimise selection decisions under different climatic and species distribution scenarios are needed.

Using conservation auctions enables identification of least cost conservation service providers. Conservation auctions allow buyers of ecosystem services (usually governments) to reduce the effects of adverse selection and information asymmetries since the competitive nature of auctions avoids information rents, allowing measurement of minimum WTA (de Vries and Hanley, 2016). Buyers can identify least cost providers, whilst suppliers with a comparative advantage can secure contracts by revealing their true opportunity cost. The cost effectiveness improvements associated with auctions over fixed priced schemes has been documented in other work (Schilizzi and Latacz-Lohmann, 2007; Windle and Rolfe, 2008;

Stoneham et al., 2010; Rolfe et al., 2017) and may play a pivotal role in reducing further declines in agrobiodiversity.

Identifying agrobiodiversity hotspots may result in win-win outcomes though more targeted conservation responses. Extensive and low-input systems, often characteristic of smallholder and semi-subsistence farms, are likely to have a comparative advantage when supplying agrobiodiveristy conservation services due to topographical and ecological characteristics that constrain land use (e.g. Transylvania). At the same time, traditional breeds/cultivars are often better adapted to these systems where biophysical characteristics restrict production with improved breeds and varieties. The development of novel tools to identify agrobiodiversity "hotspots" through GIS applications is now being pursued (see Pacicco et al., 2018) and would allow for more targeted conservation policy where the opportunity cost of conserving is least and positive attitudes towards conservation may already persist.

Balancing pro-social and pro-environmental goals in PES site selection decisions may be at-odds with cost effectiveness. Employing different selection goals in PES has been a controversial topic but there are good arguments for not treating environmental and social equity goals as separate objectives. Yet, we show that combining the two may result in a reduction of ecological effectiveness (e.g. diversity captured, land area conserved) or increased cost. At the same time, reduced social and poverty focus may undermine the effectiveness of PES schemes through negative behaviours due to perceptions of unfairness that can lead to crowding-out, non-compliance and negative spill overs/indirect effects (Hanley and White, 2014; Pascual et al., 2014). Ultimately, there is a need to established guidance around how such trade-offs are managed for better conservation outcomes.

6.3 Limitations and further work

Much of this thesis has focused on country-specific case studies. There is a need to extrapolate these findings to other country contexts, where differences between developed and developing countries may be more acute (FAO, 2015b). For instance, the drivers of genetic erosion may vary across regions meaning alternate policy interventions are necessary.

While this thesis explores agrobiodiveristy conservation in the context of PGR and FAnGR, insights may be acquired by exploring potential synergies between PGR and FAnGR conservatism approaches (Gollin and Evenson, 2003). For instance, gap analysis (Maxted et al., 2008) and systematic priority setting (Maxted et al., 2012; Reinecke and Kilham, 2015) employed to establish PGR conservation priorities may provide a useful framing for FAnGR priority setting.

This work has largely focused on *in situ* conservation measures, whilst acknowledging the important role of *ex situ* approaches as an insurance mechanism. While a combination of both approaches is recommended in early work (e.g. Lömker and Simon, 1994) more advanced modelling has shown a clear trade-off emerges between conservation strategy employed, efficacy of gametes stored, extinction risk and cost (Boettcher et al., 2005). Further exploration of the optimal contributions associated with *in situ* and *ex situ* approaches under varying cost and benefit functions may improve the cost effectiveness of interventions.

A growing battery of genetic technologies (e.g. genomic selection) are changing breed characteristics more rapidly than ever before. Indeed, technological progress has improved our ability to select for novel traits and reduce generation intervals in plant and crop breeding (Hickey et al., 2017). Yet, these technologies are seldom applied to “unimproved” genetic resources, which constrains interpretation of option value in traditional breeds/varieties (Bowles, 2015). Better characterisation of (rare) genetic resources is therefore needed through selective sampling of specific populations. In addition, it is unclear how disruptive technologies, such as gene editing, will affect the future utilisation of genetic resources for agriculture. Fostering harmonised applications of GE that compliment conservation through sustainable utilisation of PGR and FAnGR should be seen as a priority for future work.

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Appendix

Appendix 1: The respondent questionnaire for farmers in Romania

Farm Questionnaire

Name: ________________________________Date:_______________

Location & GPS: ____

Section A: About you & your farm

1. Which livestock species do you currently farm with?

Species	Breed?	Total animals?
Sheep		
Goat		
Pigs		
Buffalo		
Cows		
Poultry		
Other		

2. How big is your farm?

1-2 hectares ☐ 3-6 hectares ☐ 7-20 hectares ☐ >20 hectares ☐

3. Do you currently farm with rare or traditional native breeds (not cross breeds)?

Yes ☐ No ☐

4. If answered YES to question 3, which rare or traditional breeds do you keep?

____

5. If you keep rare breeds, why do you maintain them?

Cultural significance ☐ Quality of products ☐

Level of endangerment ☐ Ease of management ☐

Level of hardiness ☐ Adaptability ☐

Tradition ☐ Tourism ☐

6. **If you now keep cross breeds instead of rare / traditional breeds then why is this?**

Better yields ☐ Better quality products ☐

Perceived reputation ☐ Social status ☐

7. **If you do not currently farm with rare / traditional breeds, would you consider doing so in the future if conservation subsides were in place?**

Yes ☐ No ☐

8. **If you answered YES, which species would you consider keeping?**

Sheep ☐ Buffalo ☐ Cows ☐ Goat ☐
Horses ☐ Pigs ☐

9. **Which traits do you consider most important when deciding which breed to farm? Please rank these statements (1=most important, 8= least important) according to how important they are to you.**

	Rank
Cultural tradition associated with the breed	________________
Level of yield (e.g. milk)	________________
Fertility and ease of breeding	________________
Adaptability to terrain	________________
Resistance to disease and parasites	________________
Low veterinary bills	________________
Ease of management & handling	________________
Quality of products produced	________________

10. **If you farm or would consider farming with rare breeds, we want to know which factors you think are most important for ensuring their continued preservation. Please rank the following statements (1=most important, 6= least important) according to how important they are to you.**

	Rank
Maintaining traditional farming practices	________________
Cultural and historic factors associated with the breed	________________
Ensuing continued supply of genetic material	________________
Potential contribution of breed to tourism	________________
Maintain adaptive traits for future breeding programmes	________________
Continued production of traditional, local products	________________

Section B: Rare breeds and conservation support measures

11. **Do you currently receive Romanian agri-environment support payments on your farm?**

Yes ☐ No ☐

12. **If you answered yes, which payments do you receive?**

(e.g. HNV)____

13. Did you know there is currently support available for farming with rare breeds under Romania's Rural Development Programme (RDP)?

Yes ☐ No ☐

14. Would you consider applying for this support in the future if you decide to / are farming with rare breeds?

Yes ☐ No ☐

If no, why not?

1)____

Section C: Future Options for conservation schemes

Choice set: ____

Choice Task 1:

I prefer: Option A ☐ Option B ☐ Nothing ☐

Choice Task 2:

I prefer: Option A ☐ Option B ☐ Nothing ☐

Choice Task 3:

I prefer: Option A ☐ Option B ☐ Nothing ☐

Choice Task 4:

I prefer: Option A ☐ Option B ☐ Nothing ☐

15. Which statement best describes how you made your choice of Option?

- I chose randomly ☐
- I chose the 'Nothing' plan because I wouldn't benefit from conserving rare breeds ☐
- I never chose the 'Nothing' plan because I don't want to see breed diversity decline ☐
- I chose the most expensive option ☐
- I chose the plan which provided the greatest overall benefits relative to my opportunity cost ☐
- I chose the plan which provided greatest overall benefits irrespective of my opportunity cost ☐
- Other (Please specify)………………………………………………………………… ☐

Section D: About you

16. **Gender**

Male ☐ Female ☐

17. Please tell us which age group you are in

Under 20	☐	50 - 59	☐
20 - 29	☐	60 - 69	☐
30 - 39	☐	Over 70	☐

40 - 49 ☐

18. What is the highest level of education you have attained?

Secondary ☐ University degree ☐

Foundation degree/HND ☐ Professional qualification ☐

19. Please indicate your main sources of household income. Please rank your income sources from a scale of most to least (1=most)

EU support payments ☐ Off farm income ☐

Sale of milk ☐ Sale of meat products ☐

Sale of local food products ☐ Government subsides ☐

Other, please state: ______________________________________

20. Please indicate your monthly household income (Lei / month)

Less than 200 ☐ 201-400 ☐

401 - $800 ☐ 801-1,600 ☐

1,601-3,000 ☐ More than 3,000 ☐

Appendix 2: Background information concerning rare breeds supported in the Romanian RDP.

Breed	**Risk Status**	**Estimated Population**	**Support level (per annum)**
		Bovine	
Steppe Grey	In danger of extinction	312 heads	€ 200 / head
Romanian Buffalo	In danger of extinction	289 heads	€ 200 / head
		Ovine	
Merinos of Suseni	In danger of extinction	300 heads	€ 13 / head
Transylvanian Merinos	In danger of extinction	268 heads	€ 13 / head
Merino of Cluj	In danger of extinction	203 heads	€ 13 / head
Ţigaie –ferruginous variety	Vulnerable	1120 heads	€ 13 / head
Raţca	Vulnerable	3888 heads	€ 13 / head
Karakul of Botoşani	Vulnerable	2694 heads	€ 13 / head
Merinos of Palas	Vulnerable	4364 heads	€ 13 / head
Ţigaie with black Teleorman head	Vulnerable	2988 heads	€ 13 / head
		Caprine	
Banat White	In danger of extinction	972 heads	€ 6 / head
Carpatina	Vulnerable	1492 heads	€ 6 / head
		Equidae	
Lipizzan	In danger of extinction	350 heads	€ 200 / head
Arabian Shagya	In danger of extinction	111 heads	€ 200 / head
Furioso North Star	In critical condition	47 heads	€ 200 / head
Huțul	In critical condition	88 heads	€ 200 / head
Gidran	In critical condition	36 heads	€ 200 / head
Nonius	In critical condition	45 heads	€ 200 / head
Romanian semi-heavy	In critical condition	91 heads	€ 200 / head
		Pigs	
Bazna	In critical condition	22 cap	€ 88 / head
Mangalița	In critical condition	50 cap	€ 88 / head

Data sourced from Draganescu (2003)

Appendix 3: Results summary from the multinomial logit models for bovine and ovine farmers

Attribute	**Bovines**		**Ovines**	
	Coefficient	SE	Coefficient	SE
[CL] Contract Length	-0.279***	0.067	-0.453***	0.090
[SS] Scheme Support	0.060	0.079	-0.224**	0.111
[SOS] Structure of Scheme	-0.426***	0.079	-0.311***	0.106
[COS] Subsidy	0.013***	0.001	0.245***	0.030
[N0] Nothing option	1.090***	0.177	0.092***	0.222
Model summary				
No of observations	464		324	
Log likelihood	-405.252		-271.767	
R^2	0.193		0.217	

Note: ***; ** indicates significance at 1% and 5% respectively. SE=standard error

Appendix 4: Competitive tender bid offer form

Competitive Tender Bid Offer Sheet

Internal information (ZARI only)

Team members present……………………………………………Date…………

Province ……………………………… **District** …………………………………...

Community …………………………..**No. of participants** …………………...........

GPS (N)………………………………(E)……………………………............

Instructions for participants – group tender on individual lands containing CWR:

1. Please write your name, age, gender and farm size in the table provided
2. Specify the area of land to be included for each conservation activity in the Area Management Options (AMO's)
3. Specify the number of land plots proposed under each AMO scenario
4. Document the rewards required in Kwacha for each AMO

Table 1: Individual tender bid offers

No	Name	Age	Total Farm size	Gender		Area Management Option (AMO)	
				M	F	A (field border)	B (within crops)
1			Lima			plots Lima Kw	plots Lima Kw
2			Lima			plots Lima Kw	plots Lima Kw
3			Lima			plots Lima Kw	plots Lima Kw
4			Lima			plots Lima Kw	plots Lima Kw
5			Lima			plots Lima Kw	plots Lima Kw
6			Lima			plots Lima Kw	plots Lima Kw
7			Lima			plots Lima Kw	plots Lima Kw
8			Lima			plots Lima Kw	plots Lima Kw
9			Lima			plots Lima Kw	plots Lima Kw
10			Lima			plots Lima Kw	plots Lima Kw

No	Name	Age	Total Farm size	Gender		Area Management Option (AMO)	
				M	F	A (field border)	B (within crops)
11			Lima			plots	plots
						Lima	Lima
						Kw	Kw
12			Lima			plots	plots
						Lima	Lima
						Kw	Kw
13			Lima			plots	plots
						Lima	Lima
						Kw	Kw
14			Lima			plots	plots
						Lima	Lima
						Kw	Kw
15			Lima			plots	plots
						Lima	Lima
						Kw	Kw
16			Lima			plots	plots
						Lima	Lima
						Kw	Kw
17			Lima			plots	plots
						Lima	Lima
						Kw	Kw
18			Lima			plots	plots
						Lima	Lima
						Kw	Kw
19			Lima			plots	plots
						Lima	Lima
						Kw	Kw
20			Lima			plots	plots
						Lima	Lima
						Kw	Kw

Instructions for participants – group tender on communal lands containing CWR:

1. **Please specify the area of land to be included for the communal land conservation activity (AMO D)**
2. **Specify the distance of communal lands from communities, the location characteristics and number of participants to be enrolled in this AMO**
3. **Document the total community rewards required in Kwacha for this AMO**

Table 2: Bid offer on communal lands

Information	**Area Management Option (AMO)**
	C (community conservation area)
Total area proposed	Lima
Distance from community centre	km
Current use of land (please specify)	…………………………………………………………………………
Type of area management (please list as appropriate)	______ ______ ______
Location characteristics (please tick)	☐ Flat land ☐ Hilly land
	☐ Near water source (i.e. stream, river) ☐ Far from water source
	☐ Land is grazed by farm animals ☐ Not grazed by farm animals
	☐ Could be used for farming ☐ Could not be used for farming
Total number of participants to be involved	
Level of reward required (Kwacha)	

Instructions for participants - Communal and individual lands total summary:

1. **Please total up the area of land to be included for conservation on the individual and community lands (Tables 1 and 2) within each AMO**
2. **Total up the number of participants to be enrolled in each AMO (Tables 1 and 2)**
3. **Total up the individual and community land rewards required in Kwacha for each AMO (Tables 1 and 2)**

Table 3: Summation of bid offers

Information	**Area Management Option (AMO)**		
	A	**B**	**C**
Total area proposed	Lima	Lima	Lima
Total number of participants			
Level of reward required (Kwacha)			
Grand total	Kw	Kw	Kw

Training for CWR conservation – please specify and rank preferred type of training

No	**Information related to rewards of CWR's**	**Which three among the listed types of support would be most helpful? [A=highly preferred, B=2nd most preferred, C=3rd most preferred]**
1	No support needed	
2	Generation and documentation of local CWR diversity	
3	Access to seed of CWR's	
4	Training to improve crop yields and value addition to increase incomes	
5	Training to improve management of CWR	
6	Fairs, awards and recognition for “custodianship”	
7	Opportunities to participate in governmental monitoring and verification activities	
8	Other (specify……………………….)	

Rewards for CWR conservation – please specify and rank preferred type of rewards

No	Information related to rewards of CWR's	Which three among the listed types of rewards do you may most prefer? [A=highly preferred, B=2nd most preferred, C=3rd most preferred]
1	No support needed	
2	Access to educational materials and literature (including for schools)	
3	Access to agricultural machinery, farm inputs and other farm infrastructure	
4	Access to general infrastructure (i.e. bricks, cement, school desks, etc)	
5	Access to transport (i.e. Push-bikes)	
6	Access to value addition infrastructure at a reduced cost	
7	Fairs, awards and recognition for “custodianship”	
8	Access to credit / crop loan	
9	Other (specify……………………….)	

Appendix 5: List of priority CWR used in the modelling exercise and distribution across community and farmer sites.

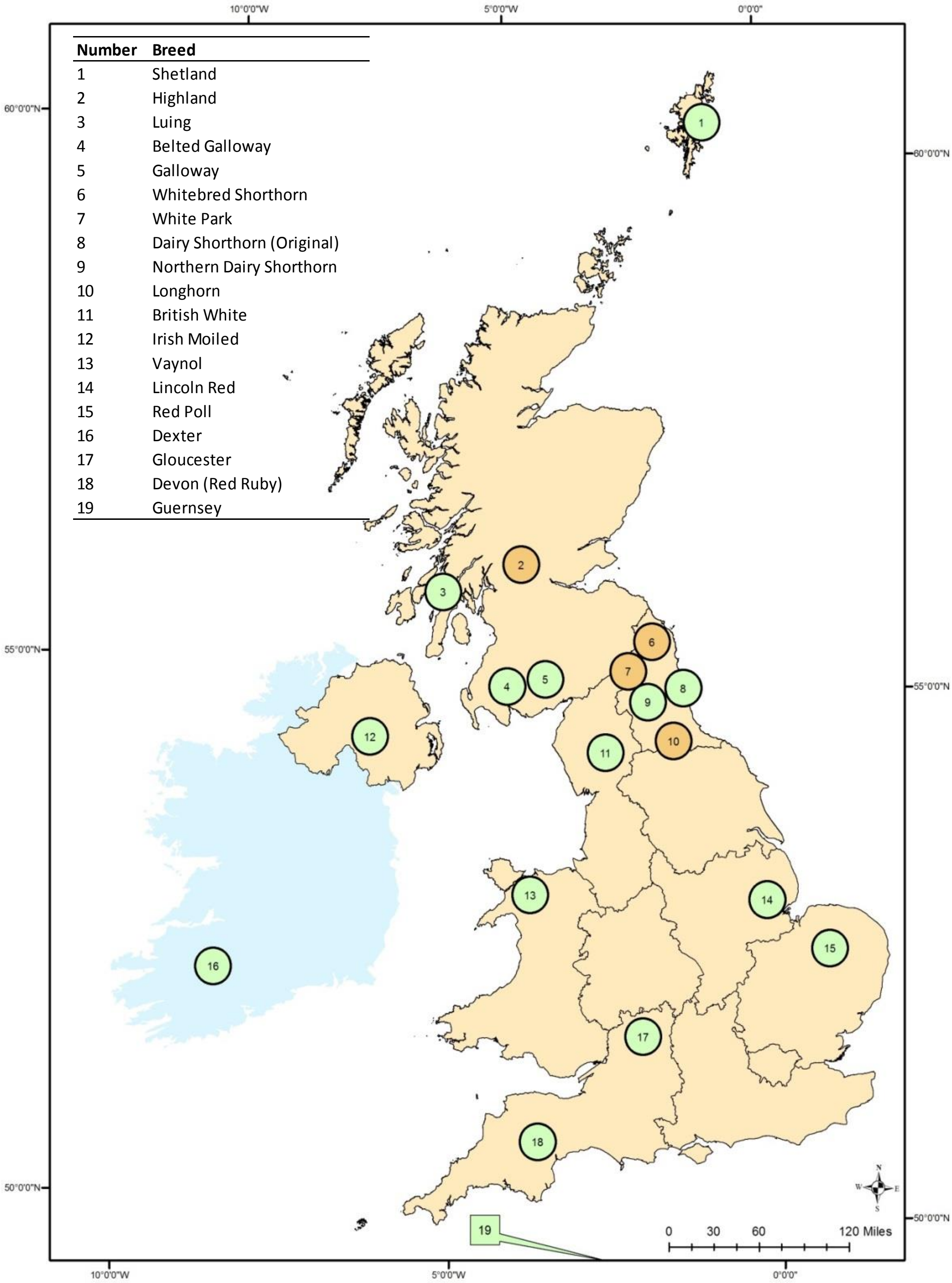
CWR	Related crop	No. of community locations	No. of sites
Cucumis zeyheri	Cucumber	1	20
Eleusine coracana	Finger millet	5	78
Eleusine indica	Finger millet	5	87
Oryza longistaminata	Rice	1	30
Pennisetum purpureum	Pearl millet	4	65
Solanum incanum	Egg plant	4	80
Sorghum bicolor	Sorghum	2	50
Vigna juncea	Cowpea	2	20
Vigna unguiculata subsp. *dekindtiana*	Cowpea	3	43

Appendix 6: *In situ* and *ex situ* coverage of priority CWR in existing Zambian PAs and genebank collections.

CWR	Populations covered in PAs	% of populations covered in PAs	Accessions in national genebank	Accessions in international genebank
Cucumis zeyheri	0	0	0	0
Eleusine coracana	34	23	0	137
Eleusine indica	4	36	3	3
Oryza longistaminata	102	51	56	112
Pennisetum purpureum	4	50	0	5
Solanum incanum	1	25	0	1
Sorghum bicolor	1	20	0	2
Vigna juncea	6	19	0	13
Vigna unguiculata subsp. *dekindtiana*	30	32	20	86

Data from Zambian Ministry of Agriculture (2017)

Appendix 7: Map showing geographical origin of NBAR cattle used in the case study.



Appendix 8: List of institutions and roles of participants attending both workshops

Person position	Institution
Initial workshop	
Chief exec	RBST
Field officer	RBST
Chair of Conservation Committee	FAnGR Committee
Advisor	FAnGR Committee
Associate Professor in Human Geography	Plymouth University
Breed society chief exec	Gloucester Beef Society
Specialist Breeding Advisor	Signet (ADHB)
Breed secretary	The Dexter Cattle Society
Chief Exec	British Pig Association & FAnGR Committee
Breed Census and Records rep	Traditional Herefords Breeders Group
PhD Student	SRUC
Research Economist	SRUC
Final weighting and scoring workshop	
Field officer	RBST
Field officer	RBST
Conservation Grazing	Natural England
RBST Chairman	RBST
Trainee Vet	AB Europe
Conservation officer	Natural England
Conservation Grazer	Pasture-Fed Livestock Association
PhD Student	SRUC
Research Economist	SRUC

Appendix 9: Summary of criteria and sub-criteria used in the MCDA model

Criteria	Sub-criteria	Scoring approach	Description
Diversity	* Effective population size (Ne)	Linear	Ne is a metric that takes account of the total number of animals in a population but importantly also their breeding structure. A low Ne signifies a greater risk of declining genetic diversity within breeding populations.
	* % change to Ne over last 5 years	Linear	This criterion determines % change to Ne over last 5 years. This is to determine the trend of Ne for each breed.
	* Geographic origin	Categorical	Maximising difference in geographic origin may aid wider capture of genetic diversity.
Marketability (utility)	* Product designations	Categorical	Product designations - e.g. PDO may be used to promote production methods that employ traditional breeds.
	* Breed branded products	Categorical	The sale of breed specific products across the "big seven" major retailers in the UK.
	* Conservation grazing demand	Categorical	Demand for the breed in conservation grazing schemes.
Marketability (traits)	* Adaptability and hardiness	Categorical	Is breed considered adaptive to different production environments and is it hardy.
	* Ability to graze wet sites	Categorical	Can the breed maintain condition while grazing wet/marshy sites?
	* Heat stress	Categorical	Does the breed harbour tolerance or susceptibility to heat stress?
Endangerment	* No. of embryos collections stored in cryobank	Preference value	An embryo collection consists of two embryos collected per female.
	* No. of males collected from	Preference value	The number of different males with semen collected from and stored in cryobank.
	* No. of semen straws stored in cryobank	Preference value	Total number of semen straws stored from breed.
	Geographical concentration	Categorical	The percentage of a breed's total population that is concentrated within a 65km from the mean centre of each breed.
	* No. of pedigree breeding females in 2016	Preference value	Estimated by multiplying the average number of female registrations over the previous three complete years by standard Defra multipliers for each species.
	* No. of pedigree breeding males registering offspring in 2016	Preference value	Number of pedigree sires which produced pedigree registered offspring in most recent year.
	* % change in number of pedigree females during last 5 years	Preference value	Based on % change between in number of pedigree registered females during last 5 years.
	* No. of active herds	Preference value	Number of herds which have registered pedigree offspring in any of the past three years

Appendix 10: Criteria weights used for scoring the breeds.

Diversity - [30]		Effective population size (Ne) - [40] - (12)
		% change to Ne - [40] - (12)
		Geographic origin - [20] - (6)
Current marketability - [20]	Utility - [50] - (10)	Breed branded products - [40] - (4)
		Conservation grazing demand - [40] - (4)
		Product designations - [20] - (2)
	Traits - [50] - (10)	Adaptability and hardiness - [33] - (3.3)
		Ability to graze wet sites - [33] - (3.3)
		Heat stress - [33] - (3.3)
Endangerment - [50]	*Ex situ* - [15] - (7.5)	No. of embryo collection stored - [5] - (2.5)
		No. of semen straws stored - [5] - (2.5)
		No. of males semen collected from - [5] - (2.5)
	In situ - [85] - (42.5)	Geographical concentration - [20] - (10)
		No. pedigree breeding females in 2016 - [15] - (7.5)
		No. pedigree males registering offspring in the most recent year - [15] - (7.5)
		% change in pedigree breeding females registered over last 5 years - [15] - (7.5)
		No. active pedigree herds - [20] - (10)

Key: [local weight scaling] and (global weight scaling).

Appendix 11: Breed sensitivity analysis

Criteria sensitivity to an increase or decrease in cumulative weight and which breed would be next highest scoring.

Breed	Decrease cum.weight	Criteria	Increase cum. weight	Breed
		Effective population size (Ne)	++	R.R Devon
Vaynol	++	% change to Ne	+	Luing
		Geographic origin	++	Vaynol
		Breed branded products	++	Gloucester
		Conservation grazing demand	+	Vaynol
		Product designations	++	Gloucester
		Adaptability and hardiness	+	Red Poll
		Ability to graze wet sites	+	Red poll
		Heat stress	++	Red poll
		No. of embryo collection stored	+	Red poll
		No. of semen straws stored	++	B.White
		No. of males semen collected from	+	Luing
B.Whitee	++	Geographical concentration	+	Vaynol
		No. pedigree breeding females in 2016	+	Vaynol
		No. pedigree males registering offspring in the most recent year	++	Vaynol
		% change in pedigree breeding females registered over last 5 years	+	Highland
		No. active pedigree herds	+	Vaynol

Key: '+++' = cumulative weight change of >5 points would change preferred breed; '++' = cumulative weight change of 5-15 points would change preferred breed; '+' = cumulative change of <15 points to change preferred breed.

Appendix 12: Summary statistics for each principal component for all the breed scoring criteria (top table) and criteria nodes (bottom table).

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Eigen value	4.874	2.800	2.507	1.510	1.171	0.976	0.866
Proportion of Variance	0.287	0.165	0.147	0.089	0.069	0.057	0.051
Cumulative Proportion	0.287	0.451	0.599	0.688	0.757	0.814	0.865
	PC8	PC9	PC10	PC11	PC12	PC13	PC14
Eigen value	0.685	0.500	0.478	0.251	0.192	0.107	0.040
Proportion of Variance	0.040	0.029	0.028	0.015	0.011	0.006	0.002
Cumulative Proportion	0.905	0.935	0.963	0.978	0.989	0.995	0.998
	PC15	PC16	PC17				
Eigen value	0.025	0.017	0.001				
Proportion of Variance	0.001	0.001	0.000				
Cumulative Proportion	0.999	1.000	1.000				

	PC1	PC2	PC3	PC4	PC5
Eigen value	2.208	1.285	0.712	0.515	0.280
Proportion of Variance	0.442	0.257	0.142	0.103	0.056
Cumulative Proportion	0.442	0.699	0.841	0.944	1.000

Appendix 13: The variable loadings (rotations) for each principal component

Only PCs with eigen values > 1 are shown for all breed scoring criteria (top table) and criteria nodes (bottom table).

	PC1	PC2	PC3	PC4	PC5
Ne	-0.290	0.355	0.004	0.084	-0.154
ChangeNe	-0.035	-0.245	-0.323	0.333	-0.135
GO	-0.115	-0.034	0.295	0.169	0.581
BP	0.086	0.248	0.234	-0.519	0.018
CG	-0.239	-0.384	0.315	0.005	-0.043
PD	0.226	0.246	0.302	-0.017	-0.292
AH	-0.249	-0.415	0.070	0.010	0.073
GWS	-0.325	-0.183	0.094	-0.052	-0.181
HS	-0.148	0.140	0.136	-0.145	0.483
NEC	-0.287	-0.080	0.175	-0.233	-0.192
NSS	-0.258	0.101	-0.289	-0.405	0.068
NMSC	-0.080	-0.342	-0.239	-0.488	-0.135
GC	0.139	-0.057	0.382	0.060	-0.413
PBF	0.373	-0.255	0.087	-0.031	0.124
PBM	0.342	-0.167	0.147	-0.300	0.078
CPBF	-0.215	-0.072	0.429	0.084	-0.028
NAH	0.347	-0.289	-0.022	-0.048	0.096

	PC1	PC2
Diversity	0.520	-0.257
Utility	-0.098	0.781
Traits	0.452	0.433
Ex.situ	0.469	0.294
In.situ	-0.544	0.227

Note*:* the loadings are essentially the coefficients of the PCs and show how the variables correlate to the principal components.

Appendix 14: Hypothetical allocation of a 'breed improvement fund' across breed societies under different scenarios.

Breed	Budget: S1	Budget: S2	Budget: S3	Budget: S4	High/low difference
B.Galloway	499,457	487,515	535,332	465,839	69,493
B.White	597,177	582,640	631,692	579,710	51,982
D.Shorthorn	53,720	53,720	53,720	53,720	0
N.D.Shorthorn	85,053	85,053	85,053	85,053	0
R.R.Devon	553,746	618,312	546,039	517,598	100,713
Dexter	477,742	523,187	513,919	393,375	129,812
Galloway	510,315	463,734	524,625	538,302	74,569
Gloucester	500,640	463,734	500,640	500,640	36,906
Guernsey	510,315	511,296	503,212	527,950	24,738
Highland	597,177	558,859	674,518	517,598	156,920
I.Moiled	597,177	594,530	578,158	610,766	32,608
L.Red	423,453	463,734	385,439	445,135	78,295
Longhorn	412,595	463,734	374,732	414,079	89,001
Luing	618,893	689,655	620,985	559,006	130,649
Red.P	651,466	642,093	663,812	631,470	32,342
Shetland	564,604	570,749	581,467	548,654	32,812
Vaynol	9,693	9,693	9,693	9,693	0
W.Park	488,599	463,734	481,799	517,598	53,865
W.Shorthorn	250,893	250,893	250,893	250,893	0
Total	**8,402,714**	**8,496,863**	**8,515,728**	**8,167,081**	**348,647**
Stdev	191,564	195,021	199,757	184,698	-
High/low difference	641,772	679,962	664,825	621,777	-

In 'S1' the weights are equal; in 'S2' the diversity node was weighted 50 while endangerment and marketability were each weighted 25; in 'S3' marketability was weighted 50 while diversity and endangerment were each weighted 25; in 'S4' endangerment was weighted 50, diversity 30 and marketability 20.