Economic instruments for supplying agrobiodiversity conservation

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Declaration

I, Warwick Wainwright, declare that:

1. This thesis was composed by myself
2. The work contained herein is my own, except where clearly stated
3. The work has not been submitted for any other degree or professional qualification
4. Included publications are my own work

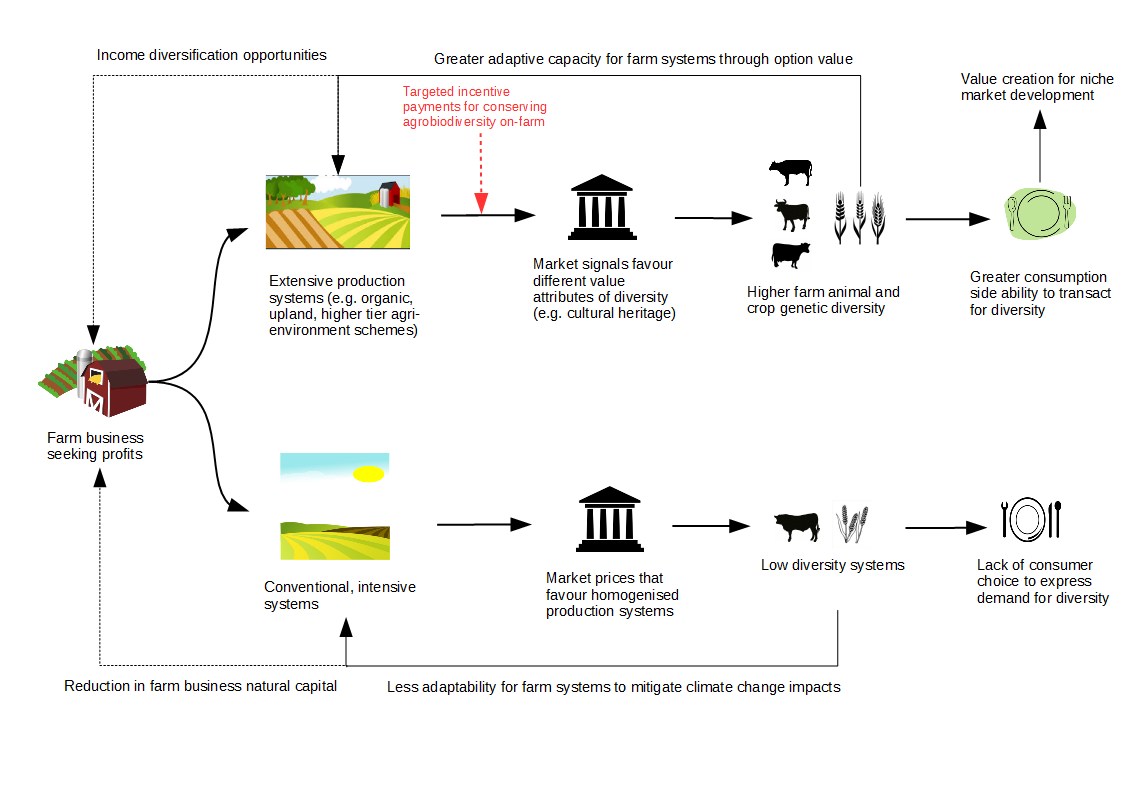
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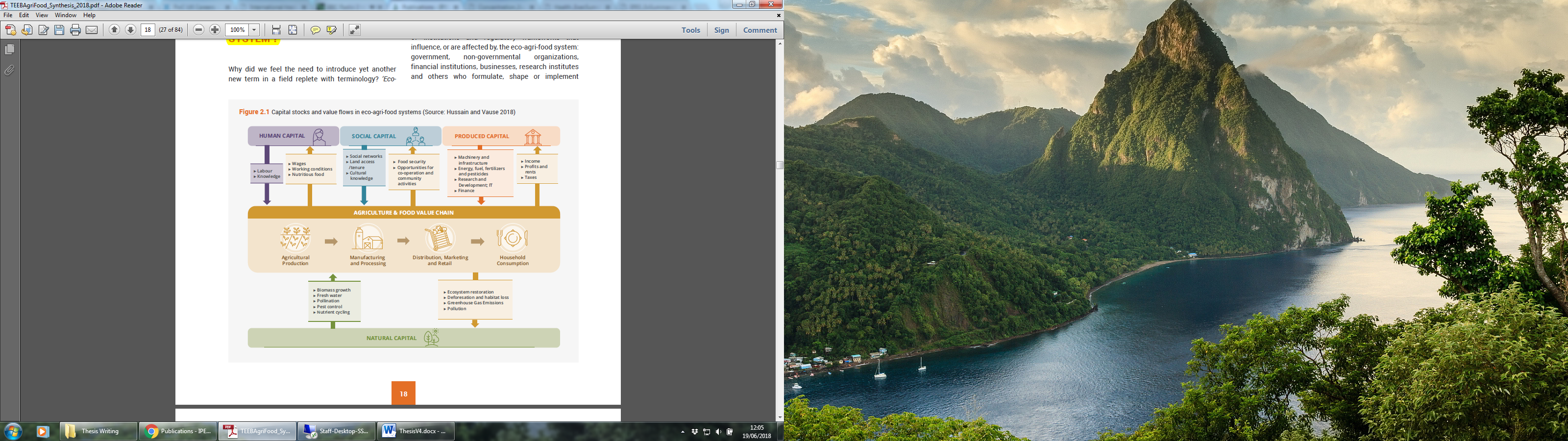
Abstract

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 UK and 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 tools in the context of PGR and FAnGR 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. Our findings suggest optimising subsidy support relies on three key factors. First, institutional and incentive support offered to farmers for conservation should reflect local circumstances, including addressing barriers-to-entry in conservation schemes. 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 rationalised investments in diversity. Policy responses to address declining FAnGR and PGR 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 and ultimately balance the use and non-use values of diversity that are supplied through 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 is discussed.

Graphical abstract



SCHMETIC REPRESENTATION OF OF THE MAIN AGENT PROCESSES AND INTERACTIONS WITHIN THE BREEDING SECTOR???



Lay summary

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List of abbreviations

AES Agri-environment scheme

ASC Alternative specific constant

BLP Binary linear programming

CE Choice experiment

CWR Crop wild relatives

FAnGR Farm Animal Genetic Resources

LP Linear programming

MCDA Multi-criteria decision analysis

Ne Effective population size

RPL Random parameters logit

PACS Payments for agrobiodiveristy conservation services

PCA Principal component analysis

PES Payments for ecosystem services

WTA Willingness to accept

WTP Willingness to pay

Chapter one

# Introduction

## 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, where and how much consumers consume. 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). Meanwhile, the Food and Agriculture Organization (FAO) has estimated annual global production of crops will need to increase by 60% from 2006 levels to 2050 to keep pace with rising demand (FAO, 2016).

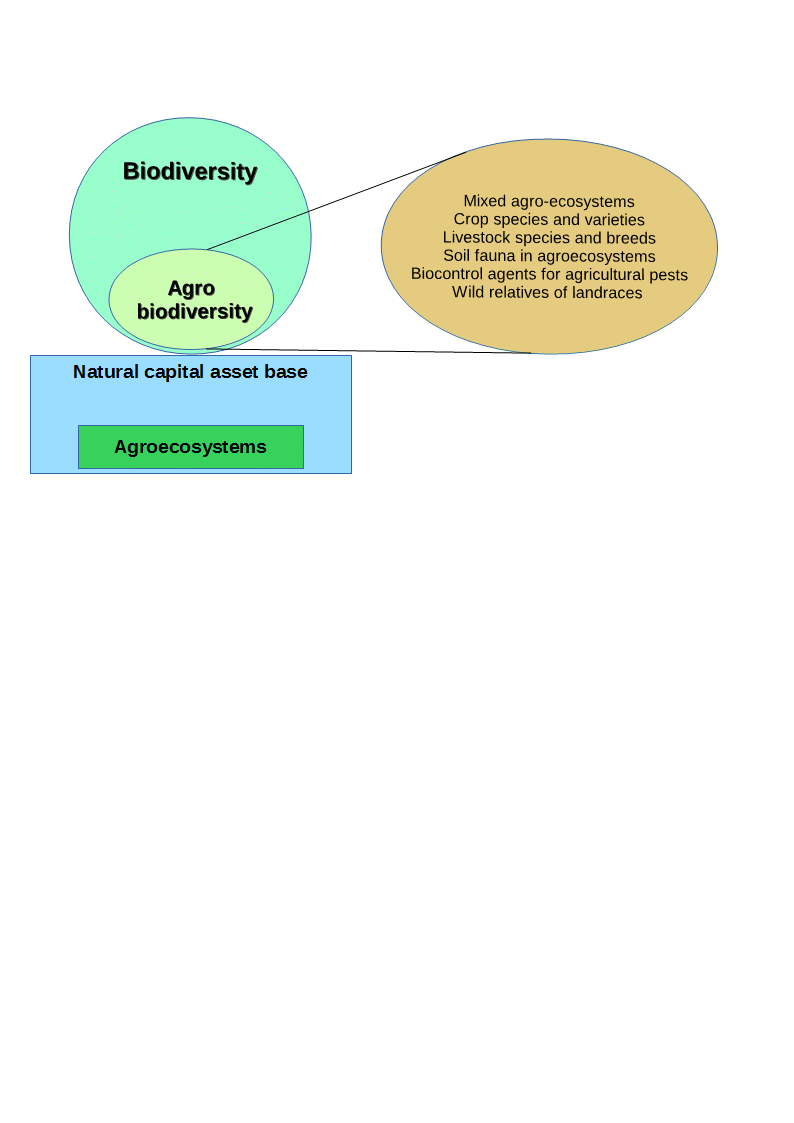
Potential yield gains for crops and livestock are hindered by widespread land degradation, land scarcity, and climate change that threaten where and how much food we can produce. A review conducted for the Intergovernmental Panel on Climate Change (IPCC) suggests climate change will adversely affect 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 extent and prevalence (Nardone et al., 2010; Bett et al., 2017) and water availability (Thornton et al., 2009; Havlík et al., 2015). Bommarco et al. (2018) suggests retaining ecosystem services in agriculture is 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). Yet, 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).

## Agrobiodiversity and undersupply

Agrobiodiversity (see Figure 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 (ref - Pascual et al., 2011). The former is declining primarily in response to farm intensification that has eroded natural capital in many agroecosystems (Chaplin-Kramer et al., 2015; Tsiafouli et al., 2015).

Today, an increasingly constrained set of plant and animal diversity is relied upon for global agricultural production. Only 15 animal species worldwide account for 90% of livestock production (Villanueva et al., 2004). For crops, just 12 plant species worldwide provide more than 70% of all human calorific intake (Frison et al., 2012). Within these species, increasingly few breeds and varieties are responsible for the overwhelming 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. Work by Rojas-Downing et al. (2017) suggests crop and animal diversification are the most promising adaption measures and this can be mooted in the context of farm animal genetic resources (FAnGR) and plant genetic resources (PGR) for agriculture.



**Figure 1:** Biodiversity and agrobiodiversity are reliant on sustaining natural capital and agroecosystems. The various elements that comprise agrobiodiveristy (biodiversity of relevance to food and agriculture) 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 by markets and this can be appreciated via the economic conceptual framework. The former indicates diversity is a public good not captured by markets because it lacks an explicit market value (Pearce and Moran, 1994). Thus, it is not reflected in the true cost of food production and hence is undersupplied (Sustainable Food Trust, 2017). The resulting market failure has homogenised production landscapes worldwide (IPES-Food, 2016) and corrective measures are therefore necessary to supply more diversity through policies that govern food production and biological resource use.

The thesis therefore brings this issue into focus by first exploring the private and public good values of plant and animal genetic resources and second; by exploring measures to increase their global supply. 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]](#footnote-1). The former have identified challenges including the need to design appropriate incentive mechanisms for conservation and develop decision support tools to guide investments in diversity (FAO, 2007, 2009).

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 agro-biodiversity for future food security (TEEB, 2018). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2018) further stresses this need and suggests such investments make sound economic sense, i.e. the benefits generally far outweigh the costs.

But while much work has explored the costs and benefits of preserving “naturally occurring” 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, implementation and rationalisation of incentive schemes for PGR and FAnGR conservation.

## 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; thus correcting for market failure (Tietenberg and Lewis, 2018). Incentive instruments have become an increasingly popular way to address a range of environmental problems, including biodiversity loss and have been promoted 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). Incentives are a more efficient means of achieving environmental goals, it is argued (Hanley et al., 2013).

This focus has been particularly evident in 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, a major constraint is funding limitations (McCarthy et al., 2012; Waldron et al., 2013). Moreover, buyers of conservation services (usually governments) often face uncertainty as to how the costs of supplying diversity are distributed across landowners. Meanwhile, the conservation benefits can also vary across sites (and genetic resources). This framing poses challenges to the design of incentive mechanisms in being both effective and efficient at sustaining agrobiodiveristy improvements. It is therefore of interest to explore how the design of incentive schemes could be made more effective.

In Europe, the use of incentive schemes for FAnGR conservation provide fixed payments (usually per animal) to landowners for conserving rare breeds (Kompan et al., 2014). The 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 lack of information asymmetries (de Vries and Hanley, 2016). Additionally, fixed price schemes may not appeal to agents that provide the greatest conservation benefit. The challenge of revealing suppliers true opportunity cost (effectively the producer surplus) has given rise to a range of empirical approaches that can be used to better inform the policy arena.

Choice modelling has been particularly powerful to elicit landowner preferences for the design of conservation schemes and 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, otherwise termed competitive tenders, are an incentive based mechanism that can potentially deal with the issues of adverse selection and poor cost effectiveness by promoting price competition amongst landowners opting to supply conservation services (Windle and Rolfe, 2008; Whitten, 2017). Such approaches have been shown to outperform fixed priced schemes through determination of agents minimum WTA a contractual scheme (e.g. Rolfe et al., 2017). Lastly, decision support tools, such as multi criteria decision analysis (MCDA), have emerged as a systematic methodology to combine technical information and stakeholder values to appraise costs/benefits of different projects alternatives (Adem Esmail and Geneletti, 2018). The development of simple decision making frameworks to guide investments in agrobiodiveristy has been lacking, despite an urgent need to rationalise investments for more effective conservation outcomes. The application of MCDA may therefore compliment wide ranging applications in the field of environment and conservation (Huang et al., 2011).

Advancing our understanding of the cost effectiveness associated with different scheme designs is necessary and while this has been relatively well studied for some aspects of biodiversity conservation it remains comparatively underexplored in the context of agrobiodiveristy. To improve conservation outcomes, it is necessary to explore how the design of future incentive instruments can be improved. Additionally, the use of incentive schemes raises broader questions concerning fairness and distribution effects (Wunder, 2007; Jack et al., 2008; Narloch et al., 2013) as well as how investments in agrobiodiveristy should be rationalised to reduce redundancy and maximise return.

## Aims and objectives

The contribution of this thesis lies in the exploration of incentive instruments and policy-support tools that could be used to enhance PGR and FAnGR conservation outcomes. The former is a response to research and policy challenges outlined by Cardellino and Boyazoglu, (2009) and (FAO, 2015b), namely stressing the need to optimise resource allocation in conservation activities.

The thesis will provide a clearer picture of the private and public good values attached to rare breed conservation and how institutions may be working to ameliorate or exacerbate farm-diversity. This work 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, both in developed and developing countries.

The thesis provides a multidisciplinary assessment of the economic, genetic and policy framework governing conservation of farm animal and plant genetic resources. The thesis aims to:

* Explore the measurement of “diversity” as a public good, with a focus on genetic metrics that denote difference and variation
* Determine the use and non-use values of breed diversity and evaluate how such values are supplied across different institutions, including the market
* Outline key proximate threats to FAnGR, and consider how these threats can be ameliorated by different supply side conservation responses
* Explore the factors driving farmer choice of breed and motivations for participating in conservation activities in small-scale farm systems
* Measure farmer WTA contracts for conserving rare breeds in Romania through different contract options using a choice experiment and estimating participation rates in contracts relative to different scenarios
* Explore cost heterogeneity for supplying PGR conservation services using a competitive tender mechanism and provide a national scale cost estimate for implementing an incentive based scheme for conserving crop wild relatives (CWR) in Zambia
* Develop a decision analysis framework to rationalise investments in FAnGR 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 an existing agri environmental scheme (AES). Additionally, the use of stand-alone schemes (e.g. PES) is explored and the implications of including fairness and distribution effects in scheme design are considered. On the demand side, the use of differentiated support for supplying breed diversity is assessed using decision analysis through allocation of a hypothetical breed support fund rationalised by different value attributes.

The thesis is comprised of four studies. In Chapter 2, a review of public good characteristics associated with rare breeds is complimented by discourse surrounding how institutions are acting to exacerbate or ameliorate certain public good values embodied in rare breeds. Multiple proximate threats to diversity and issues pertaining to the use of incentive support schemes are discussed. Chapter 3 employs a CE 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 willingness to accept (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.

In Chapter 4, a competitive tender survey is applied in Zambia to identify least cost conservation service providers for crop wild relatives (CWR) conservation. A linear programming (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.

Chapter two

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

Chapter three

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

Chapter four

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

Chapter five

# Prioritising rare breeds for incentive support: An application of multi-criteria decision analysis

Chapter six

# Conclusion and recommendations

## Main conclusions

* **Remind the reader of the research problem and purpose and how they were addressed.**

This research explored how the design of agrobiodiveristy conservation schemes could be made more (cost) effective. The modelling approaches (CE, BLP and MCDA) provide empirical assessment of different scheme designs and costs to meet demand for diversity value 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 are scarce, despite farm-scale intensification that threatens agrobiodiveristy. I address such a literature gap by exploring how supply and demand side aspects of conservation can be optimised as a function of biological, genetic and economic factors, including farmer preferences for conservation contracts.

* Briefly summarise what has been covered in the paper, by chapter.
* Make some kind of holistic assessment/judgement/ claim that pertains to the whole project (i.e., more than a descriptive summary)

There are concerns that incentives schemes may “crowd out” intrinsic motivations, such as people's moral commitment towards nature conservation (Luck et al., 2012) while others suggest incentives can induce “crowd in” positive actions for conservation Additionally, the use of incentive based schemes raises broader questions concerning fairness and distribution effects (Wunder, 2007; Jack et al., 2008; Narloch et al., 2013) as well as how cost effective different schemes designs prove to be. Other problems may include lack of additionality (i.e. paying for activities that would have been conducted anyway) and leakage (i.e. shifting environmentally-damaging activities elsewhere).

## Recommendations

* Assess the value/relevance/ implications of the key findings in light of existing studies and literature.
* Outline implications of the study (for theory, practice, further research).
* Make claims for new knowledge/ contribution to knowledge.

## Further work

* Refer to the limitations of the studies that may affect the validity or the generalisability of results.
* Make recommendations for further research.

# References

# Appendix

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. [↑](#footnote-ref-1)