## 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 addressed 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.

Chapter two provides a review of institutions and instruments to supply diversity is provided, 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 emerged and reflects the broad range of ecosystem services provided by farm animal diversity (Leroy et al., 2018). Different institutions are impacting FAnGR in different ways and this should be acknowledged in future policy instruments for conservation. We suggest the SI agenda should better consider non-use values associated with agrobiodiversity, where currently it is in danger of prioritising efficiency above all other considerations, including the need to retain cultural heritage and option value in farming.

Chapter three employed a survey and CE to explore farmer motivations for keeping rare breeds and preferences for the design of conservation contracts, including minimum WTA to participate in a contractual scheme. We show farmers in Transylvania are intensifying farming practices and this may be accelerating reductions in farm diversity. Increasing farmer awareness and removing barriers to entry for schemes is key to increasing farmer participation in conservation programmes. The choice model indicated heterogeneous preferences for contract attributes between ovine and bovine farmers and we suggest considering these differences could improve the design of schemes and reduce the cost of conservation. Moreover, results demonstrated targeting conservation schemes at marginal production environments, characterised by smallholder and extensive farm systems, may improve scheme cost effectiveness because the opportunity cost of conserving is lower.

In Chapter four, we switch our attention to PGR by measuring the costs of conserving CWR through an on-farm conservation programme that could form part of a NSAP for CWR conservation and sustainable use. Bid offers from the conservation auction were optimised for selection relative to alternate conservation goals. Conservation under multiple selection goals suggests a trade-off between maximising area and maximising diversity in conservation schemes. Additionally, the inclusion of social equity criteria in conservation goals may impact the ecological effectiveness of schemes. The literature provides little guidance on such trade-offs (refs) and there is a need to more explicitly consider the implications of employing different selection goals in programmes (ref). Considerable cost heterogeneity persisted across the different wild relatives modelled, raising broader questions concerning the form of conservation interventions and we suggest alternative conservation approaches (e.g. *ex situ* storage or genetic reserves) may be more appropriate when costs are prohibitive.

In chapter five, an application of MCDA is used to explore how breed incentive support can be rationalised based on different value attributes of breed diversity. Weights derived from stakeholder workshops to inform the MCDA model suggested endangerment was considered most important, followed by diversity and marketability. Breed part scores across the criteria nodes exhibited high levels of heterogeneity, suggesting a need to consider this variation in the design of conservation programmes. A PCA revealed the multiple criteria nodes do explain different aspects of variation in breed scores, implying this information can improve decision making. Allocating conservation funds through an indicator to monitor and prioritise investments in diversity provides a framing that can focus conservation efforts based on different value attributes of diversity. Addressing opponents of conservation triage, we suggest concerns surrounding triage are either irrelevant to agrobiodiveristy conservation or can be carefully navigated through the design of incentive schemes (Bottrill et al., 2008).

In Chapter two, a review of institutions and instruments to supply diversity is provided, alongside discussion of the different economic values that rare breeds encode. The chapter conceptualises the different characteristics of diversity according to biological and genetic measures that denote difference. Against this backdrop, we marry different facets of value to the that are situated amidst the TEV spectrum, according to breed use and non-use values that contribute to different ecosystem services (Leroy et al., 2018). Moving forward, we identify a range of institutions that may be exacerbating or ameliorating declines in FAnGR diversity and the economic and policy drivers associated. We then discuss the potential for corrective market mechanism to incentivise supply before turning our attention to four key drivers of change that are likely to impact future supplies of farm animal diversity; SI, climate change, pest and disease threats and UK Brexit. We suggest there is a need to consider more explicitly consider the multiple value attributes that rarer breeds encode through better targeting of incentive schemes aiming to increase diversity. At the same time, we acknowledge the importance of voluntary collective effort as an informal conservation response that is not undermined by more formal strategies. However, we also note the importance of formal conservation agendas where there is a need to meet specific key performance indicators (e.g. increasing the Ne of breeds). We suggest the SI agenda should better consider the importance of non-productive factors in agriculture, such as cultural and heritage values.

In Chapter three, we employ a survey and CE to explore farmer motivations for keeping rare breeds and preferences for the design of conservation contracts, including minimum WTA to participate in a contractual scheme. The case study site was chosen as it forms part of a larger work programme with Operation Wallacea, aimed at conserving public goods in agriculture through policy and incentive mechanisms targeting smallholder and extensive farm systems. We show farmers in Transylvania are intensifying farming practices and we suggest this is homogenising farm diversity. The former threatens breed diversity through cross breeding and heightens the importance of intervention measures to conserve diversity. Farmer motivations for breed choice vary to some degree between those keeping ‘commercial’ and ‘rare’ breeds; most notably rare breed keepers elicit higher preferences for adaptability in breed characteristics. While incentive schemes for rare breed conservation in Romania are implemented through the RDP, we show only 21% of farmers were actually aware of this support while only 8% of farmers actually qualified to meet the contractual obligations. The removal of barriers to entry are key to increasing participation amongst farmers and ultimately improving the status of at-risk breeds. The choice model indicated heterogeneous preferences for contract attributes between ovine and bovine farmers and we suggest considering these differences could improve the design of schemes and reduce the cost of conservation. Bovine and ovine farmers were WTA compensation values of €167year-1 and € 7year-1 respectively, to consider enrolling in a contract and participation estimates suggest the proposed scheme is considered attractive by farmers. Finally, we show targeting conservation schemes at marginal production environments, characterised by smallholder and extensive systems, can result in more cost effective conservation policies.

In Chapter four, we switch our attention to PGR by measuring the costs of conserving CWR through an on-farm conservation programme that could form part of a NSAP for CWR conservation and sustainable use. By employing a competitive tender survey, or conservation auction, we measured farmers minimum WTA to supply conservation services in field borders/margins. An LP model was employed to explore how different farmer selection goals might results in different scheme costs. We showed that farmers from GMA sites had higher bid offers, suggest poorer farmers do not necessarily ‘sell cheapest’ (refs). Conservation under multiple selection goals suggests focusing on maximising area indiscriminately resulted in least cost conservation but with less diversity and with less equitability. Meanwhile, the diversity goal was most expensive but maximises the number sites with verified CWR records attached. While the equity goal sacrifices some diversity aspects, the presence of social equity is greatly enhanced. The former suggests an important trade-off between in PES schemes attempting to maximise conservation effort (e.g. diversity or area conserved) and other socially desirable attributes (e.g. poverty alleviation). The literature provides little guidance on such trade-offs (refs) and there is a need to more explicitly consider the implications of employing different selection goals in programmes (ref). Aside different selection goals, this work also explored cost estimates for conserving each of the nine priority CWR included in this case study. We show considerable cost heterogeneity persists across the different CWR which raises broader questions concerning the form of conservation interventions when costs may be prohibitive. For instance, capturing rare CWR in conservation strategies was not only more costly but also less comprehensive suggesting alternative approaches (e.g. *ex situ* storage or genetic reserves) may be more appropriate. Employing discriminatory payment rule over a uniform payment rule yielded cost effectiveness improvements across almost all CWR, suggesting conservation auctions can procure conservation services more cheaply than alternative mechanisms. Our estimates suggest scaling up the cast study modelled here for a national scale scheme could cost between $41,250 to $82,500 per annum – only a small proportion of the Zambian Wildlife Authority income (Lindsey et al., 2014).

In chapter five, we provide an application of MCDA to explore how breed incentive support can be rationalised based on different value attributes of breed diversity. We identified a range of criteria according to diversity, marketability and endangerment factors that could be used to generate a comprehensive indicator reporting breed risk of extinction and benefit value associated with conservation. Weights derived from stakeholder workshops to inform the MCDA model suggested endangerment was considered most important (50%), followed by diversity (30%) and marketability (20%). Breed part scores across the criteria nodes and overall exhibited high levels of heterogeneity, implying a need to consider this variation in the design of conservation programmes. A correlation between endangerment and diversity suggests highly endangered breeds generally contribute less genetic diversity to conservation programmes meaning endangerment jeopardizes the potential future value of supplying diversity as a public good for so called ‘option value’. A PCA revealed the different criteria nodes do contribute differently to explaining the variation in breed scores (i.e. more information is indeed better). Modelling a hypothetical BIF based on the breed scores obtained in the MCDA model revealed the distributional effects of conserving for different value attributes of diversity. Addressing opponents of conservation triage, we suggest such concerns are irrelevant to agrobiodiveristy conservation or can be addressed through careful design of incentive schemes, as noted by Naeem et al., (2015). Moreover, in the UK Brexit is impacting rural policy frameworks and a growing need is emerging to state value from public funds invested to supply public goods. Our construction of an indicator to monitor and prioritise investments in diversity not only meets this need through transparent and holistic reporting but provides a framing that can focus conservation efforts accordingly. We suggest further exploration in other country contexts may be needed to develop a regional or global benchmark indicator for monitoring FAnGR.

* Make some kind of holistic assessment/judgement/ claim that pertains to the whole project (i.e., more than a descriptive summary)

On the supply side, the chapters points to the need for more targeted conservation policies that explicitly consider landholder preferences for the design of schemes and measures to consider cost more accurately, including through tenders. On the demand side, there is a need to consider public values for diversity that can be appropriated through rationalised investments in diversity which consider the TEV framework. Coupling these emerging themes means schemes may supply conservation services more cost effectively, thus reducing the per unit cost of interventions. Additionally, the full range of benefit values associated with conserving agrobiodiversity can be actively targeted through supply-side incentives that are prioritised according to the marginal benefit of conservation. Employing these approaches with greater information concerning biological and genetic metrics that denote difference may improve the ecological effectiveness of investments in diversity.

## Recommendations

* Assess the value/relevance/ implications of the key findings in light of existing studies and literature.

A recent review of the Aichi biodiversity targets suggests they are unlikely to be met by 2020 (Tittensor et al., 2014). Better conservation approaches are needed and this work suggests incentive mechanisms can be optimised to improve cost effectiveness. In this context, there is a need to enhance the scientific foundations of incentive instruments, specifically through the inclusion of metrics reporting risks and opportunities for managing agrobiodiveristy (Naeem et al., 2015). Work by (Bioversity International, 2016) to develop an agrobiodiveristy index is meeting this need and may be useful to rationalise future incentive schemes.

Two key agents are linked by preferences for livestock products – consumers, by the prices paid for products and producers, by selection decisions concerning breeding stock. Each can be motivated by a personal set of considerations (Boaitey et al., 2018). Genomic selection relies on information from entire genomes and can accelerate the rate of genetic change through reductions in generation intervals (Goddard and Hayes 2007). Given genomic information, a large number of farmers selecting for a narrow set of identical traits could lead to losses in genetic diversity, possibly leading to increased vulnerability to new disease outbreaks, or other stresses (Boaitey 2016).Unlike crop production where breeding is often managed by plant breeders, livestock breeding is managed by a large number of individual producers and this suggests a different incentive framework may be required for promoting conservation.

Agrobiodiversity conservation is increasingly turning towards market-oriented conservation governance, where farmers are seen as producers of ES taking advantage of emerging market opportunities (Ovaska and Soini, 2017). In purely economic terms, farmers are motivated to keep low-yielding local breeds, if they receive full compensation for their lost income, either from the state or as products or services. Yet, in the former case, agro environmental support has not been sufficient to compensate for the lower yield of the breeds (Karja and Lilja 2007; Tilzey and Potter 2008), and in many agroenvironmental schemes, livestock even remain neglected (Evans and Yarwood 1995; Evans and Yarwood 2008). Hence, the reasons, for keeping local breeds, go beyond their role in primary agricultural production. These reasons include social and cultural values that the breeds represent, as well as their contribution to biodiversity (Evans and Yarwood 2000; Yarwood and Evans 2000; Karja and Lilja 2007; Ovaska and Soini 2011; L\_opez Moreno 2014; Martin-Collado et al. 2014).

From Broner et al (2017)

Environmental effectiveness is defined as the change in provision of services induced by the program, compared to a counterfactual without PES. Effectiveness will be determined by four main factors. First, program costs—i.e., transaction and implementation costs net of PES transfers—which determine the number of contracts that can be offered for a given program budget and payment level. Second, the direct changes in land/resource-use among participants induced by the program, compared to a baseline of ‘‘no PES” (i.e., additionality). Third, the indirect effects (positive or negative) of the program on land/resource use and environmental service (ES) provision outside of contracted land (spillovers). Fourth, the effects these changes in land/resource-use among participants and nonparticipants have on the actual provision of environmental services.

Reducing information rents therefore requires differentiating payments to better match ES providers’ opportunity costs (Engel, 2016). This can be achieved, for example, based on proxies for opportunity costs (e.g., biophysical land characteristics), screening contracts, or procurement auctions (Ferraro, 2008).

The losses in environmental effectiveness due to adverse selection can be reduced by targeting payments, based on (imperfect) information on ES provision threats and benefits (Engel, 2016).

First, the gains from targeting will naturally be high when potential program participants exhibit

large variability in the outcome (e.g., threat of noncompliance, environmental benefits, or opportunity costs) (Engel, 2016; Engel et al., 2008; Ferraro, 2008; Persson & Alpizar, 2013; Wu¨nscher et al., 2008). Second, gains will be higher if program managers target payments based on a combination of proxies for threat, benefit, and opportunity costs (i.e., targeting areas where the provision of high value ES is substantially threatened by land uses with low economic returns) (Newburn, Reed, Berck, & Merenlender, 2005). Third, the gains from targeting will be larger, the higher the adverse selection risk (e.g., high pre-program compliance or low expected take-up rates in the program) (Persson & Alpizar, 2013).

Finally, additionality gains from targeting again need to be weighed against increased administrative

costs, risks for negative spillovers, and trade-offs with equity and welfare impacts (see below). Additionality of PES may also be compromised by noncompliance among program participants (moral hazard), especially if monitoring is costly and compliance comes with high opportunity costs (Hanley & White, 2014; Hart & Latacz- Lohmann, 2005).

The choice between paying ES providers for certain actions

(e.g., not clearing forests) or observed proxies for ES provision

(e.g., forest cover maintained), rather than actual outcomes in

terms of ES provision (e.g., additional tons of carbon stored)

can strongly influence PES effectiveness (Gibbons, Nicholson,

Milner-Gulland, & Jones, 2011; Hanley & White, 2014; Zabel

& Roe, 2009). The benefits of paying for outcomes rather than

actions are higher the more uncertain are the linkages between

the two. Often land users know best which among alternative

use options can be adopted at least cost. In such cases, paying

for outcomes enables program participants to choose the

activity that most cost-effectively increases ES provision

(Hanley & White, 2014; Zabel & Roe, 2009).

A common concern about PES programs is the long-term

impact when payments are discontinued. Pagiola, Honey-

Rose´s, and Freire-Gonza´lez (2016) examined this issue following

the termination of a four-year PES program that paid

ranchers in Colombia to adopt silvopastoral practices that

had biodiversity benefits. They found that even though payments

had ceased years ago, the positive land use changes were

maintained

More recent reviews squarely focused on the relationship

between PES design principles and environmental effectiveness.

Classifying 22 PES cases in Germany and the US according

to multiple-criteria, Sattler, Trampnau, Schomers, Meyer,

and Matzdorf (2013) substantiated some of the additional conjectures of the Wunder, Engel, and Pagiola (2008) and earlier

reviews: positive environmental outcomes are associated

with the involvement of trustworthy intermediaries, sufficiently

long contracts, social co-benefits (well-being, public

image) and voluntary participation.

They subsequently ran a logistic

regression of a binary additionality measure on design factors,

such as the degree of spatial targeting (on ecosystem service

density and degradation threat), enforcement of conditionality

(through monitoring and sanctioning), and differentiation of

payments, confirming their positive contribution to environmental

effectiveness.

* Outline implications of the study (for theory, practice, further research).

PES implementation to date has lacked sufficient grounding

on ecological systems thinking and data collection, which

should enable practitioners to test the relationship between the

PES-induced ecosystem management practices and the targeted

ecosystem services.

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 “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).

more food will need to be produced on the planet in the next 50 years than has been produced in the past 400 years,4 with the additional constraint of ensuring that key environmental planetary boundaries are not exceeded in the process.2

As efforts are made to increase food production, achieving a balance between intensification and diversity of production has become increasingly important from a resilience and nutritional perspective.

From a socioeconomic perspective, a shift in the typical development of small farms needs to occur to ensure that agricultural intensification in low-income and middle-income countries, which is usually promoted through the use of a few cereals and legumes, does not lead to reductions in agrobiodiversity

* 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.

There is a need to develop an agrobiodiveristy index to guide future investments in agrobiodiversity. Work by (Bioversity International, 2016) is currently seeking to do this.

(IPES-Food, 2015) note food systems must be fundamentally reoriented around principles of diversity, multi-functionality and resilience. This shift is required in agriculture in order to sustain yields and agro-ecosystems in the wake of future change drivers, including economic perturbations and environmental and climatic shifts.