## Summary

This research 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 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 considered through scheme design.

Chapter Two provides 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). Different institutions are exacerbating or ameliorating threats to FAnGR diversity in diverse ways and this must be reflected in the design of 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.

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 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 animal diversity. Increasing farmer awareness and removing barriers to entry for RDP schemes is key to increasing farmer participation in conservation programmes. The choice model indicates 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. Moreover, the results demonstrate targeting incentives at marginal production environments (often characterised by smallholder and extensive farm systems) may be more cost effective than conventional RDP approaches 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 on-farm conservation programme that could form part of a NSAP for CWR conservation and sustainable use in Zambia. Bid offers from the conservation auction were optimised for selection relative to alternative conservation goals that suggest a trade-off between maximising area and maximising diversity. Additionally, in site selection we show the inclusion of a social equity goal may impact the ecological effectiveness of schemes. 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). Moreover, considerable cost heterogeneity persists across sites when selecting for specific CWR, raising broader questions concerning the optimal form of conservation interventions. We suggest alternative conservation approaches (e.g. *ex situ* storage or genetic reserves) may be more appropriate when on-farm 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 diversity. Weights derived from stakeholder workshops to inform the MCDA model reveal endangerment was considered most important, followed by diversity and marketability criteria. Breed part scores across the criteria nodes exhibit high levels of heterogeneity and a PCA shows the multiple criteria nodes explain different aspects of variation in breed scores, suggesting this information can be used to implement more targeted conservation approaches. Prioritising investments in diversity relative to the composite indicator constructed here provides a framing that can focus conservation efforts where vulnerabilities persist. Using breed societies as a vehicle to deliver breed improvements may have a greater effect on conservation outcomes given their important role in breed management and promotion. Focusing our attention on conservation triage we suggest concerns surrounding triage are either immaterial to agrobiodiveristy due to coevolution or can be carefully navigated through the design of incentive schemes (Bottrill et al., 2008).

Overall, the chapters point to the need for more targeted conservation policies that explicitly consider landholder preferences for the design of incentive schemes and incorporate new 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. Coupling these emerging themes means schemes may supply conservation services more cost effectively, thus reducing the per unit cost of interventions. Underpinning these approaches with better information concerning biological and genetic metrics that denote difference may improve the ecological effectiveness of investments in diversity.

## Conclusions and recommendations

**There is a need to consider the full range of ecosystem services in the SI agenda, including cultural heritage.** The origins in 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 compliment improved food security (Poppy et al., 2014).

**Food systems need to consider diversity and resilience metrics for improved food security.** Resilient agroecological systems are needed in order to sustain yields in the wake of future pressures, including demographic, environmental and climatic change (IPES-Food, 2015). At the same time, agrobiodiversity conservation is increasingly turning towards market-oriented mechanisms, where farmers are seen as suppliers of diversity vis a vis resilience. But there is a growing need to enhance the scientific foundations of incentive instruments (Naeem et al., 2015) and work by Bioversity International (2016) is seeking to address this gap by developing a so-called ‘Agrobiodiveristy Index’ to measure agrobiodiveristy in diets, food production and genetic resources. The inclusion of a more specific PGR and FAnGR metric may be necessary to benchmark conservation performance against KPIs, where such KPIs should consider diversity, marketability and endangerment criteria that we show are indicators of genetic resource risks and management opportunities.

**Understanding farmer motivations for breed/variety choice could help inform conservation strategies.** Farmers may be motivated to keep rare breeds for a range of economic and non-economic reasons, including cultural tradition and land-use constraints (Gandini et al., 2010). Surveys from this work show farmers keeping rare breeds are motivated by cultural tradition and adaptability traits but were not WTA lower subsides for participation in conservation schemes. Moreover, productivity was still the main factor driving farmer decisions concerning breed selection, while the absence of local markets for selling heritage goods was cited as a key issue for the local economy. Marrying the need to farm for profit with the absence of local markets suggests developing shorter supply chains for valorisation opportunities may be most promising to promote breed conservation (Ilbery and Maye, 2005).

**Incentive mechanisms 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-farmconservation 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 where currently few persist. Incentive schemes are ideally poised to pay farmers for supplying CWR conservation services and could employ site selection models that optimise selection under different climatic and species distribution models.

**Using conservation auctions, or competitive tenders, can facilitate 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). Because buyers and sellers possess better information, improved outcomes can be attained on behalf of both parties. Buyers can identify least cost service 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 can play a pivotal role in reducing further declines in agrobiodiversity because they are more efficient at supplying diversity.

**Employing triage to rationalise investments in FAnGR conservation could improve conservation outcomes.** Few incentive schemes currently prioritise investments in FAnGR according to different value attributes of breed diversity. Yet, rationalisation is already being successfully employed for biodiversity and PGR conservation through gap analysis (Maxted et al., 2008; Vincent et al., 2013) and systematic priority setting (Maxted et al., 2012; Reinecke and Kilham, 2015). Employing similar approaches for FAnGR by differentiating breed support may improve conservation outcomes and is particularly important where conservation funding is limited and a large number of breeds/varieties persist. Additionally, differentiating support by farm species is also warranted given some incentive schemes suffer from poor targeting (Bojkovski et al., 2015) and farmer preferences for entering into conservation agreements are heterogeneous across farm species.

**Identifying agrobiodiversity hotspots may result in win-win outcomes though more targeted conservation responses.** Extensive and low-input systems, often characteristic of small-holder and semi-subsistence farms, are likely to face a comparative advantage when supplying agrobiodiveristy conservation services due to topographical and ecological characteristics that constrain land use. 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” though GIS applications is now being pursued (see Pacicco et al., 2018) and would allow for more targeted conservation policy, for the establishment of evolutionary agricultural reserves (Thrall et al., 2011).

**Balancing pro-social and pro-environmental goals in PES site selection decisions may be at-odds with cost effectiveness.** The effectiveness of PES schemes can be determined by four key factors; transaction and implementation costs, direct changes in resource use among participants, indirect effects of the programme and the effects on actual provision of ecosystem services (Börner et al., 2017). Many of these factors can be addressed through the design of PES schemes (Hanley and White, 2014; Engel, 2016). 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 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 crowing-out, non-compliance (moral hazard) and negative spillovers/indirect effects (Hanley and White, 2014; Pascual et al., 2014; Börner et al., 2017). Ultimately, there is a need to established guidance around how such trade-offs are managed for better conservation outcomes.

## Limitations and further work

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

The application of proximate variables denoting conservation benefits from investments in diversity requires clarification. While these proxies are based on sound scientific reasoning, we suggest further work to determine whether such proximate measures are indeed robust needs empirically testing. For instance, in Chapter Four, diversity is approximated by the distribution of conservation sites across different ecogeographic regions while in Chapter Five, diversity is partly denoted by geographic origin. Work to verify such proxies would provide a useful grounding to formulate future cost benefit analysis frameworks.

While this work explores agrobiodiveristy conservation in the context of PGR and FAnGR, I recognise there is an absence of direct comparison between both components of diversity where many lessons may be learnt. More work is needed to explore what PGR can learn from FAnGR conservation approaches and vice versa (Gollin and Evenson, 2003). For instance, as formerly noted gap analysis employed to establish PGR conservation priorities (see Maxted et al., 2008) may provide 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 both approaches are complimentary, there has been little exploration of their optimal contributions (i.e. proportion of *in situ* vs *ex situ* preservation) for conservation strategies. This has been particularly evident in the management of FAnGR and to a lesser extent PGR, despite the fact alternate conservation approaches feature different supply curves and benefits. Further work is needed to model the implications of employing different conservation approaches under varying conservation goals and budgets, with particular relation to *in situ* risks and the efficacy of *ex situ* collections. Developing conservation frameworks based on such information may further improve the cost effectiveness of conservation policy.

There is a distinct lack of work developing cost benefit analysis frameworks for establishing investment priorities in agrobiodiveristy conservation. This is a defining limitation for approaches that seek to explore the cost effectiveness of different policy interventions. While this work has attempted to consider both costs and benefits in conservation decisions for rare breeds (Chapter Five) more work is needed to quantity the monetary benefits arising from diversity that accord to different value attributes located on the TEV spectrum.

A growing battery of advanced genetic technologies (e.g. GS) are advancing breed characterisation capabilities. The former can be used 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). To meet this need, better characterisation of (rare) genetic resources is needed through targeted research to develop an evidence base for conservation decision-making, where currently there is a poor understanding of the marginal benefits arising from investments in diversity (ref Bruford). In addition, it is unclear how disruptive technologies, such as GE, will affect the utilisation of genetic resources for agriculture. Fostering harmonised applications of GE that compliment conservation activities through sustainable utilisation of PGR and FAnGR should be seen as a priority for future work.