## 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. 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 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.

In Chapter Four, we moved our attention to 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 relative to alternative conservation goals that suggest a trade-off between maximising area or diversity. Additionally, we show the inclusion of a social equity goal in site selection decisions may impede 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.

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 suggested endangerment was considered most important when considering conservation interventions, followed by diversity and marketability attributes. Breed part scores across the criteria nodes exhibited high levels of heterogeneity and a PCA showed the multiple criteria nodes explain different aspects of variation in breed scores. Indeed, such information may offer insights for more targeted priority setting and rationalisation of investments in diversity, particularly where (breed) vulnerabilities persist. Breed societies may be ideally poised to guide such investments, given their important role in breed management and promotion (Felius et al., 2015). Lastly, we suggest concerns surrounding conservation triage are redundant when referring to agrobiodiveristy schemes.

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 service providers through auctions. 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 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 compliment improved food security through the addition of option value.

**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.

**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-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, 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). Because buyers and sellers possess better information, improved outcomes can be attained on behalf of both parties. 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 because they are more efficient at supplying diversity.

**Employing triage to rationalise investments in FAnGR may 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 through triage (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.

**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 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.** 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). 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). 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). Indeed, where the drivers of genetic erosion vary across regions/countries alternate policy interventions may be necessary.

While this work explores agrobiodiveristy conservation in the context of PGR and FAnGR, there is an absence of direct comparison between PGR and FAnGR conservation approaches; arguably an area where many synergies may persist. More work is needed to explore such synergies, with particular reference to optimal designs of schemes (Gollin and Evenson, 2003). For instance, as formerly noted gap analysis employed to establish PGR conservation priorities (see Maxted et al., 2008) 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 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 understanding that alternative conservation approaches feature different supply curves and benefits. Further work is therefore needed to model the implications of employing different conservation approaches under varying conservation goals and budgets. Developing conservation frameworks based on such information may further improve the cost effectiveness of conservation policy.

There is a distinct lack of work developing CBA 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 of the TEV spectrum.

A growing battery of 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. In addition, it is unclear how disruptive technologies, such as GE, will affect the future 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.