## 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 nodes 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. Breed societies may be ideally placed to guide such investments, given their important 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 service 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. Additionally, using better information, including proxies, for biological and genetic metrics 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 complement improved food security through the addition of option value.

**Agrobiodiveristy conservation strategies should be complimented 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. Benchmarking conservation performance against KPIs including diversity, marketability and endangerment may therefore improve decision-making.

**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 and incentive schemes that pay farmers for supplying conservation services may be most promising through the application of site selection models that optimise selection decisions under different climatic and species distribution scenarios.

**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). 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. 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.

## 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, 2015). 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 comparing different conservation approaches. Indeed, more work is needed to explore potential synergies between PGR and FAnGR 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. GS) are advancing breed characteristics. 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 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.