## Summary

* **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).

* 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.

## Conclusions and recommendations

**There is a need to consider the full range of ecosystem services in the SI agenda, including cultural heritage.** Currently the SI imperative is in danger of prioritising efficiency above all other objective measures, including heritage and option value. There is a need for future guidance to consider these aspects in policy formulation. The origins in SI focus discussion on increasing yield in the face of resource scarcity and environmental challenges (Garnett et al., 2013). Yet, as the SI paradigm has evolved, there is still little mention of preserving cultural and heritage values in agriculture, many of-which have co-evolved with different systems. Ignoring such values is risky and more guidance is needed on multiple policy fronts, including SI, to reflect all value attributes of agrobiodiveristy, many of which compliment improve food security (Poppy et al., 2014).

**Food systems must be fundamentally reoriented around principles of diversity and resilience.** This shift is required in agriculture in order to sustain yields and agro-ecosystems in the wake of future change drivers, including demographic, environmental and climatic change (IPES-Food, 2015). At the same time, agrobiodiversity conservation is increasingly turning towards market-oriented conservation governance, where farmers are seen as producers of ecosystem services taking advantage of emerging market opportunities (Ovaska and Soini, 2017). Marrying these two agendas requires incentives that overcome farmer opportunity cost for producing more unit of output through conventional or uniform production systems. Reducing information rents on the part of the farmer will improve the cost effectiveness of schemes.

**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 showed farmers keeping rare breeds are motivated by adaptability and cultural factors but were not WTA lower subsides for participation in conservation schemes. 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. Funding to develop shorter supply chains for better valorisation opportunities may be most promising to promote breed (and cultivar) conservation in some regions (Ilbery and Maye, 2005).

**The design aspects of incentive schemes, including crowing out, adverse selection and lack of additionality need better consideration in incentive instruments.** There are concerns that incentives schemes may “crowd out” intrinsic motivations, such as people's moral commitment towards nature conservation (Luck et al., 2012). 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 work is needed to better contextualise these issues in the context of agrobiodiversity schemes for better conservation outcomes that generate positive impacts (e.g. by “crowding in” positive actions for conservation) beyond the immediate remit of schemes.

**Improving our understanding of the benefits associated with conserving specific breeds/cultivars through better characterisation and valuation is key for improving conservation scheme design.** A growing battery of genetic technologies are advancing breed characterisation that can inform breeding goals and reduce the generation interval 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 (Bowles, 2015). Promoting better characterisation would advance the valuation agenda, where currently there is poor understanding of the marginal benefits arising from each additional pound invested in diversity. This is important so conservation spending can be optimised for specific factors and monitored accordingly.

**Incentive mechanisms are urgently needed to increase *in situ* (on-farm) conservation of CWR in response to land use changes and climate change threats.** Aside 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 target sites relative to different climatic and species distribution models.

**Using agrobiodiveristy 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).

**Employing triage to rationalise investments in PGR and FAnGR conservation could improve the cost effectiveness of incentive schemes.** Few incentive schemes currently prioritise investments in FAnGR according to different value attributes of breed diversity. On the other hand, rationalisation is already being successfully employed for biodiversity and PGR conservation through gap analysis (N 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 conservation through decision analysis techniques can improve accountability for public spending on public goods, a stated priority for the UK Government (Defra, 2018) and of growing importance in most schemes. This may be particularly important where conservation budgets are constrained and a large number of breeds/varieties persist.

**Better targeting of agrobiodiveristy conservation schemes at specific farmers and production systems may result in win-win outcomes.** 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. Developing novel tools to identify potential agrobiodiversity “hotspots” though GIS applications are now being pursued (see Pacicco et al., 2018) and would allow for more targeted conservation policy.

**Balancing pro-social and pro-environmental goals may be at-odds. Further guidance is needed for establishing site selection goals in PES.** 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.

**Better monitoring in agrobiodiversity conservation schemes is necessary and best practice principles should be established.** Reviews of incentive schemes for FAnGR are often too simplistic and often focus on scheme participation rather than ecological effectiveness (see Natural England, 2016). Conservation programmes that do not employ adequate monitoring are often judged less successful compared to those employing periodic reviews (Börner et al., 2017). Work by Bioversity International (2016) to construct an ‘agrobiodiveristy metric’ may provide a basis for better monitoring and benchmarking of incentive schemes. To this end, there is a need to develop “best practice principles” for PGR and FAnGR programmes, where currently little guidance exists to promote consistent conservation responses.

## Further work

* Refer to the limitations of the studies that may affect the validity or the generalisability of results.

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. Where the drivers of genetic erosion vary across regions/countries alternate policy interventions may be necessary.

Some chapters here use proximate variables to denote conservation benefit from investments in diversity. While these proxies are based on sound scientific reasoning, we suggest further work to determine whether such proximate measures are indeed vectors of conservation benefit needs empirically testing. For instance, in Chapter Four, diversity is approximated by distribution of conservation sites across different ecogeographic regions while in Chapter Five, diversity is denoted by geographic origin (among other factors). Work to verify such proxies would provide a useful grounding to formulate cost benefit analysis frameworks.

Although this work explores agrobiodiveristy conservation in the context of PGR and FAnGR, a limited number of synergies are explored between the two (although I suggest many of our findings in chapters may overlap). 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, particularly where funds are constrained and alternate conservation approaches possess different cost curves and supply different benefits. Further work should explore the optimal contributions of different conservation approaches under varying conservation goals and budgets, with particular relation to *in situ* risks and *ex situ* vulnerabilities. Developing conservation frameworks based on such information may further improve the cost effectiveness of conservation policy.

* Make recommendations for further research.

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 (Bioversity International, 2016).

There is a distinct lack of studies 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 aiming to conserve PGR and FAnGR. 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 arsenal of technologies are changing how the breeding sector operates, for both crops and livestock. Disruptive technologies, such as GE, may affect how diversity is sourced for breeding decisions and ultimately the role of PGR and FAnGR for agricultural resilience (Tixier-Boichard et al., 2015). Work is needed to explore how the option value components of diversity may be impacted and the associated implications for supply-side mechanisms attempting to supply diversity.