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1 Estimating *in situ* conservation costs of Zambian crop wild
2 relatives under alternative conservation goals

3 **Keywords:** Crop wild relatives; Zambia; competitive tender; binary linear programming; payments
4 for ecosystem services; social equity; payments for agrobiodiversity conservation services

5

Abstract

Crop wild relatives (CWR) are a globally threatened group of plants, harbouring valuable genes that are sometimes used to enhance commercial crop varieties and landraces. A lack of recognition in national planning for biodiversity conservation has resulted in inadequate CWR conservation strategies, particularly *in situ*. There is little information on *in situ* conservation costs, and this paper uses a payment for agrobiodiversity conservation services (PACS) approach to estimate the *in situ* costs of conserving CWR in Zambia, where 30 CWR have been prioritised for conservation (of which nine are present in our sample). Competitive tender bid offers were elicited from farmers willing to accept compensation for providing a CWR conservation service. Using data from 26 communities we determined the on-farm cost of conserving CWR, specifically in field margins/borders. Heterogeneity was evident in farmer bid offers, suggesting discriminatory price mechanisms can potentially deliver cost savings over uniform payment rules. Selection of bid offers under four different conservation goals using a binary linear programming (BLP) model reveals conservation costs ranging from US\$ 23 to 91/ha per year. An untargeted area goal provided a least-cost procurement of conservation services (\$ 2.3 k per year), followed by a targeted area goal (\$ 5.9 k per year). The cost of selecting conservation sites increased when other constraints were added to the BLP model, including those concerning social equity (\$ 6.4 k per year), and diversity (\$ 9.2 k per year) goals. Overall, the findings suggest the use of competitive tenders, coupled with CWR data and BLP modelling, can potentially add much to improve the efficiency of *in situ* CWR conservation.

1. Introduction

Population growth and changing diets are expected to increase food demand above projected crop yield gains (Ray et al., 2013; Seto and Ramankutty, 2016). Climate change may reduce agricultural production by 2% each decade (Pachauri et al., 2014), yet demand for agricultural products is expected to increase by 50% between 2012 and 2050 (FAO, 2017). Advances in genotyping technologies and plant breeding to meet yield improvement goals offer one approach to increase global production using fewer inputs (Tester and Langridge, 2010). Such advances have increased the potential for using exotic genetic material, thereby heightening the importance of conserving and using CWR to deliver yield improvements, whilst also enhancing adaptive traits in crops (Dhariwal and Laroche, 2017). In this context, crop wild relatives (CWR), that is, the wild plant species that are genetically closely related to cultivated crops (Maxted et al., 2006) are an increasingly important genetic resource (Zhang et al., 2017). They have provided cultivars with pest and disease resistance, heat and drought tolerance, tolerance of salinity and abiotic stresses, and enhanced nutritional quality (Hajjar and Hodgkin, 2007; Maxted and Kell, 2009; Dempewolf et al., 2014).

Wild relatives are estimated to contribute US\$ 120 billion to increased crop productivity per annum (PriceWaterhouseCoopers, 2013). Despite their importance, CWR have been depleted by agricultural intensification, habitat destruction and a range of other threats including land-use change (Kell et al., 2011). They are known to be a globally threatened group of plant species and efforts to improve conservation are therefore warranted to reduce further loss of diversity (Maxted et al., 2010).

CWR resources are sometimes found in disturbed anthropogenic habitats, e.g. around farms, which should be the focus of some conservation effort (Maxted et al., 2000). Moreover, there is no information on the costs of *in situ* CWR conservation at multiple scales, including the farm level. This constrains our understanding of farmers' willingness to accept (WTA) conservation incentives and ultimately appreciation for heterogeneity in the per unit cost of selecting conservation service providers. This study seeks to demonstrate how the costs of conserving CWR *in situ* (through a measure that restricts farm activities in field margins) can be measured and analysed using a Zambian case study. The paper adds to the literature on the economics of *in situ* plant genetic resources (PGR) conservation and to the growing body of work addressing development of payment for ecosystem services (PES) schemes in developing countries, particularly payment for agrobiodiversity conservation services (PACS) (Narloch et al., 2011a, 2011b, 2013; Krishna et al., 2013). It makes a further contribution by considering distributional aspects of PES (e.g. social equity).

69 The paper is structured as follows. Section two provides background relating to CWR in
70 Zambia, the use of incentives, conservation tenders and site selection models. Section three describes
71 the research sites and outlines the methodological and modelling approach used. Section four provides
72 an overview of the results and a discussion of these follows in section five, with the identification of
73 further work necessary to improve future cost estimates. Section six presents conclusions.

74 **2. Background**

75

76 *2.1 CWR conservation in Zambia*

77 Zambia was chosen for this case study given its participation within a wider project in the
78 South African Development Community (SADC) addressing *in situ* conservation and use of CWR
79 (<http://www.cropwildrelatives.org/sadc-cwr-project/>). A previous exercise (see Ministry of
80 Agriculture, 2016) identified 30 priority CWR species in Zambia for conservation to address food
81 security. Using a sub-set of this priority list (see S1 for case study CWR species), we examine the cost
82 of selecting farmer managed sites for conservation containing priority CWR. The nine CWR species
83 were selected based on their verified presence in the sampling frame for the economic surveys. The
84 need to conserve is driven by threats posed to CWR in sub-Saharan Africa primarily from climate
85 change (Jarvis et al., 2008; Maxted and Kell, 2009) and land use change, including intensification of
86 farming practices and alien invasive species (Burgess et al., 2006; Ford-Lloyd et al., 2011)

87 *2.2 Payment for ecosystem services (PES) and competitive tender auctions*

88 PES has emerged as a key voluntary incentive mechanism to reduce biodiversity loss by
89 paying landowners for actions that sustain or enhance ecosystems (Börner et al., 2017). The
90 introduction of PES type schemes for agrobiodiversity conservation has been limited but a growing
91 body of work suggests this is becoming more widely applied, including in Bolivia, Peru, Ecuador,
92 Guatemala and India (Narloch et al., 2011a, 2011b; Krishna et al., 2013; Midler et al., 2015; Drucker
93 et al., 2017). This work provides an application of PES that compensates farmers for conserving CWR
94 in field borders. A hypothetical competitive tender (CT) survey measured farmer WTA monetary
95 rewards for conservation effort. CTs are a reverse auction mechanism, whereby agents submit a bid
96 offer for a pre-defined conservation contract supplying, in this instance, CWR conservation services.

97 Relative to fixed price approaches CTs are incentive compatible in allowing participants to
98 reveal their true opportunity costs (Stoneham et al., 2003), which is likely to include both market and
99 non-market values and preferences. This allows identification of least-cost suppliers through the
100 formulation of cost curves that reveal differences in agents' opportunity costs. CT mechanisms have

101 been used to determine the costs of agrobiodiversity conservation (e.g. Bertke and Marggraf, 2005;
102 Narloch et al., 2011a) though none have been applied to the case of CWR.

103 2.3 Binary linear programming (BLP)

104 This work combines CT cost elicitation with BLP modelling to optimise selection of farmer
105 sites for CWR conservation under alternative conservation goals. BLP is a calculation process that
106 finds the optimal solution to a problem with multiple attributes and constraints using a branch and
107 bound algorithm (Messer, 2006). Many reserve selection problems are formulated as BLP problems
108 because site selection decisions can be modelled with binary variables [0,1] which reflects the yes/no
109 decision-making context associated with site selection (Beyer et al., 2016). Much previous work in
110 reserve site selection has sought to solve the problem of maximising the expected number of species
111 included in a reserve network subject to a restriction on network size or cost (Donaldson et al., 2017).
112 BLP takes into account the benefits and costs of each site and evaluates all possible purchase
113 combinations of sites, selecting sites that yield the highest possible aggregate conservation value
114 (Williams et al., 2005). BLP thus facilitates determination of least-cost suppliers of conservation
115 services under various objective functions (Haight and Snyder, 2009).

116 3. Methods

117 3.1 The study sites

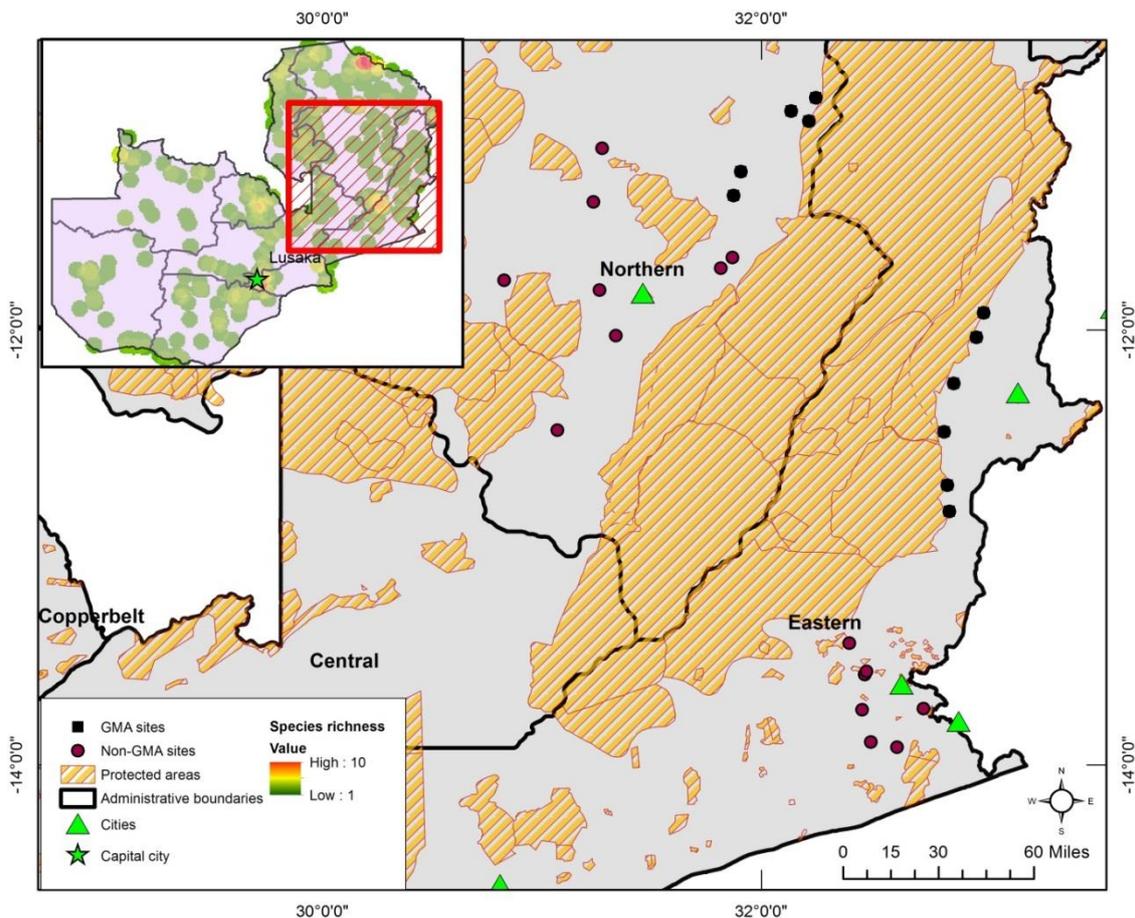
118 The study regions were selected based on a review of records of populations for all 30 priority
119 CWR species (held by the Zambia Agriculture Research Institute (ZARI)) (Ng'uni et al., 2016). After
120 assessment of occurrence records we identified two study areas likely to contain the highest
121 distribution of priority CWR species; Eastern Province and Northern Province (Figure 1). Historical
122 records (obtained from herbarium collections varying in date) in these areas included wild relatives of
123 melon and cucumber (*Cucumis* spp.), yams (*Dioscorea* spp.), millets (*Echinochloa* spp., *Eleusine*
124 spp., *Pennisetum* spp.), sweet potato (*Ipomoea* spp.), rice (*Oryza* spp.), eggplant (*Solanum* spp.),
125 sorghum (*Sorghum* spp.), and cowpea (*Vigna* spp.) (Ng'uni et al., 2017).

126 Eastern Province (herein referred to as Ecoregion 1¹) has a population of 1.3 million and a
127 land area of 51,476 km² (Ministry of Local Government and Housing, 2017). The province houses
128 Zambia's most fertile land and consequently the majority of the country's large-scale commercial
129 farms (Chikowo, 2018). The province has a higher human population and lower land availability than
130 other areas in Zambia resulting in the application of more intensive farming practices that are
131 impacting biodiversity (Eroarome, 2009). Northern Province (herein referred to as Ecoregion 2)
132 occupies a land area of 87,806 km² and with a population of 712,000 people is sparsely populated

¹ Ecoregions were subsequently used in the site selection model outlined further in Section 3.6.

133 (Zamstats, 2010). The province sits on the Muchinga Escarpment and is characterised by large tracts
134 of miombo woodland with predominantly small-scale agriculture. Land is relatively abundant and
135 shifting cultivation (slash and burn) was widespread until recently (Grogan et al., 2013).

136 The areas selected for the CT exercise (within the study regions) were communities far from
137 Game Management Areas² (herein referred to as ‘non-GMA’ sites) and communities adjacent to
138 Game Management Areas (herein referred to as ‘GMA’ sites). People in GMAs are generally poorer
139 and less educated than the national average, and these areas are associated with lower agricultural
140 potential and fewer alternative livelihood opportunities (Manning, 2011). By contrast, non-GMA sites
141 were considered better-off, with improved access to economic infrastructure. In both areas,
142 agricultural production plays a crucial role in farmer livelihoods. An optimal conservation strategy
143 may specify a combination of sites across both areas to ensure a diverse ecogeographic range of plant
144 populations (e.g. those with restricted ranges and sub-populations) are captured for conservation
145 (Rodrigues et al., 2004). Additionally, conservation in GMAs may enhance gene flow and dispersal
146 from protected areas (PAs) whilst non-GMA sites may provide sanctuaries for species establishment
147 outside formal designations. Both areas are therefore desirable for CWR conservation.



148

² Game Management Areas are transitional zones that serve as protected areas (PAs) for the management of wildlife adjacent to national parks.

149 **Figure 1:** Map of sample sites detailing protected areas (PAs). Inset map shows the location of the
150 sample area (red hatch) and species richness of all 30 priority CWR species (red areas are CWR
151 hotspots). Source data (Ng’uni et al., 2016).

152

153 *3.2 Focus group discussions*

154 Focus group discussions (FGDs) were held in selected farming communities and participants
155 were invited by agricultural extension officers that regularly engage with community groups. Five
156 FGDs were conducted with 10–15 participants in each encompassing a mix of genders, age groups,
157 and wealth status. The FGDs sought to understand the degree of recognition of CWR within
158 communities, CWR status and conservation management and community farm management practices.
159 Specific activities (and associated costs, as perceived by community members) that would need to be
160 implemented in order to attain a desirable (as determined by a conservation programme) level of
161 CWR conservation management were discussed. Further information concerning the focus group
162 discussions and cost estimates related to local farming practices and conservation activities are
163 provided in S2.

164

165 *3.3 Competitive tender design*

166 Data from the FGDs and expert consultation informed the design of the area management
167 option that would underpin the hypothetical tender. Expert consultation suggested that the tender
168 should support CWR interventions through habitat-based conservation measures in field
169 borders/margins – a habitat that has been shown to support CWR (Meilleur and Hodgkin, 2004;
170 Maxted and Kell, 2009; Jarvis et al., 2015).

171 The area management option prohibited application of herbicides within 3m of the field
172 perimeter or on the field border, and the field border was to be left undisturbed for the duration of the
173 scheme. These activities are most likely to benefit CWR that may inhabit field borders as weeds
174 (Jarvis et al., 2015). In addition, bids were also accepted for conservation in crop fields and on
175 communal land areas but are beyond the scope of analysis of the current paper. The tender required
176 farmers to detail the number of land plots and total area (in local land units) that they would be willing
177 to enrol in the conservation programme, along with a monetary bid for providing the associated
178 conservation service per annum. Additional information collected included gender, age and farm size
179 (a proxy for wealth).

180

181 3.4 *Competitive tender workshops*

182 Farmers were invited to take part in the tenders by agricultural extension officers. Tender
183 workshops were held at 26 different communities between April and May 2016, with a total
184 attendance of 358 participants. This corresponded to 11 community GMA sites and 15 community
185 non-GMA sites. The workshops used a format similar to the FGDs.

186 The first section of the workshop ‘Existence and Management’ prompted farmers to consider
187 where CWR occur on their communal and farmed lands. Participants were asked to identify a set of
188 CWR from photographs and describe where these occurred (if at all) on communal or farmed land.
189 Respondents were then asked to consider how these might be managed and the implications of this
190 management. The next section ‘Conservation Management’ asked farmers what activities might be
191 required (on an annual basis) to maintain CWR on farmed lands, such as seed collecting, late burning
192 of fields, selective weeding and training. The cost implications of these activities were discussed.

193 Next, a CT training exercise facilitated discussion and learning among the farmer groups
194 regarding how a CT works in practice and what the rules and selection criteria of this particular tender
195 were. For instance, the competitive nature of the tender was emphasised alongside other variables (not
196 conveyed to participants) that would be considered in the selection process. All farmers were
197 encouraged to participate in the exercise, including those not present at the workshops. An example of
198 the CT bid offer form was then completed with participants, after which the actual bid offer forms
199 were distributed and collected some days later to allow farmers time to deliberate.

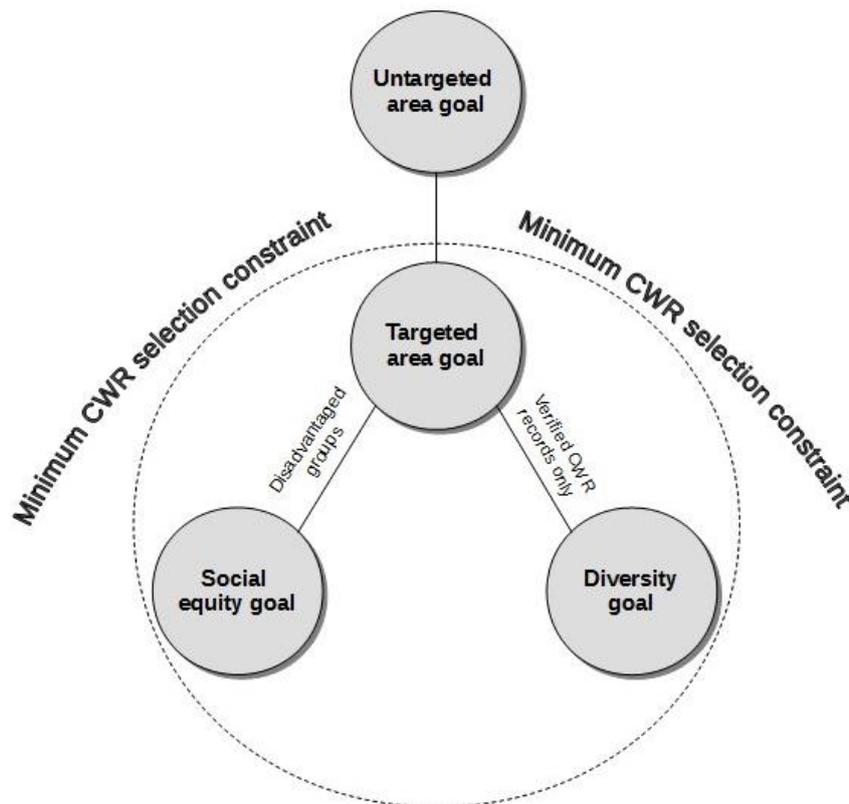
200
201 3.5 *CWR surveys*

202 Alongside the CT workshops, 26 simple line transect surveys (Buckland et al., 2007) were
203 undertaken at randomly selected communities in both the Eastern and Northern provinces. The aim
204 was to develop a better understanding of CWR abundance and species richness across different
205 community and farmer sites. A 100 meter line walking transect was undertaken through different
206 habitats at selected communities. The habitats consisted of field borders, croplands and communal
207 bush land. A ZARI staff member walking the transects identified most of the CWR found. Any CWR
208 not identified on-site were photographed and reviewed later. These survey data was subsequently
209 used, in conjunction with occurrence data obtained from Dickson et al. (2016) in the site selection
210 model.

212 3.6 Site selection model

213 The model focuses on optimizing decisions for CWR conservation site selection while
214 minimising cost subject to area, diversity and social equity constraints. The model accounts for a basic
215 requirement to conserve at least 50 ha of field borders in each ecoregion, an area considered capable
216 of capturing safe minimum populations for a range of CWR diversity (Maxted et al., 2008). The
217 model was implemented in OpenSolver for MS Excel 2010 using a branch-and-bound procedure with
218 the Simplex algorithm (Mason, 2012).

219 Initially, an untargeted area goal was developed to represent a simple method of site selection,
220 based on procuring conservation sites at minimum cost, subject to the minimum area requirement per
221 ecoregion. Three further conservation goals (different versions of the model) were then constructed:
222 (i) a targeted area goal that uses a minimum CWR selection constraint³ (ii) a social equity goal that
223 ensures socially vulnerable groups are well represented and; (iii) a diversity goal that maximises the
224 likelihood of capturing greater CWR diversity and species richness (Figure 2). Here, species richness
225 refers to the number of priority CWR species (from the sub-list of nine CWR species) inhabiting each
226 site.



227

228 **Figure 2:** Schematic diagram of the different model goals

³ The minimum CWR selection constraint ensures that each CWR is conserved in at least three different community sites per ecoregion and 5 farmer sub-sites per community, wherever possible.

229 Bid offers were selected using a discriminatory payment rule (Wünscher and Wunder, 2017),
 230 with a view to improving cost-effectiveness relative to using a uniform payment rule (Windle and
 231 Rolfe, 2008). For the untargeted area goal, the objective function (1.1) was to minimise the cost of
 232 selecting farmer sites for conservation, subject to a constraint (1.2) concerning the minimum area (50
 233 ha) to be procured for conservation services from each ecoregion. The model notation is:

234

$$\text{Min } Z = \sum_{i \in I} c_i x_i \quad (1.1)$$

235 Subject to

$$\sum_{i \in I} a_i e_i x_i \geq 50 \text{ ha} \quad (1.2)$$

236

$$x_i \in \{0, 1\} \quad \text{for all } i \in I \quad (1.3)$$

237

238 Where a_i refers to the conservation area associated with site i , where $i \in I = \{1, 2, \dots, 448\}$, e_i is
 239 a binary variable that indicates whether site i is located in either ecoregion 1 or 2. The ecoregions
 240 were categorised based on a data set obtained from WWF (2004) and original work by Olson et al.,
 241 (2001). The binary decision variable $X_i = \{0, 1\}$ is used to determine selection of the parcels; 1 if the
 242 i th parcel is selected, 0 otherwise.

243 A set of additional constraints in the targeted goal (2.1) ensures that each priority CWR from
 244 the sub-set list⁴ is conserved in at least three different community sites per ecoregion and five farmer
 245 sub-sites per community, wherever possible⁵ (note not all CWR species were present at both
 246 ecoregions). Ideally, this genetic reserve design structure would be replicated across five distinct
 247 ecogeographic zones (Maxted et al., 2008) although data were only available for two (Ecoregion 1
 248 and 2). The additional constraints are summarised below:

$$\text{for all } n \in N \quad \sum_{i \in I} n_i e_i d_i x_i \geq 3 d_i x_i + 5 f_i x_i \quad (2.1)$$

⁴ A list of the priority CWR verified to be present at the sample sites and used in the modelling exercise is provided in S1.

⁵ The proposed conservation design structure ensures CWR are conserved at different sub-plots per community (i.e. different farmers lands in each community) and per ecoregion, to capture different meta-populations and changes in local ecological conditions. Given limitations concerning the extent of our tender surveys, conservation to these requirements was not feasible for all CWR in the model.

$$\sum_{i \in I} m_i x_i \geq 0.4 \sum x_i \quad (3.1)$$

249

$$\sum_{i \in I} p_i x_i \geq 0.3 \sum x_i \quad (3.2)$$

250

$$\sum_{i \in I} v_i x_i = \sum x_i \quad (3.3)$$

251

$$\sum_{i \in I} q_i s_i y_i g_i x_i \geq 0.5 \sum x_i \quad (4.1)$$

252

253 The diversity goal (equations 3.1, 3.2 and 3.3) employs the same constraints as the targeted
 254 area goal plus ensures CWR should be conserved in GMA sites at least 40% of the time. This is to
 255 facilitate active management of CWR in areas close to PAs. An additional constraint (3.2) specifies at
 256 least 30 % of sites selected contain plots that are ≥ 0.8 ha in size (based on an assumption that larger
 257 sites are better suited to maintaining species and population genetic diversity) (Lindenmayer and
 258 Burgman, 2005). All sites selected (3.3) should have verified CWR populations present⁶.

259 The social equity goal (equation 4.1) employs the same constraints as the targeted area goal
 260 plus ensures that vulnerable groups, such as women, younger farmers and the poor have a minimum
 261 representation of 50% across the total selected conservation area. The social equity parameters
 262 specifically relate to the following:

- 263 • Number of female farmers, recognising the important role women play in the management of
 264 genetic resources (Escobar et al., 2017) as well as women's empowerment being considered
 265 a prerequisite for global food security (Quisumbing et al., 2014).
- 266 • Number of farmers aged ≤ 35 years of age. This contributes to the objective of motivating
 267 younger farmers to remain in farming – where the average age of farmers in Zambia is
 268 increasing (Brooks et al., 2013).
- 269 • Number of farms ≤ 2 hectares in size (a proxy for poorer farmers).
- 270 • Number of sites that are located in GMA areas, where the population may be up to 30%
 271 poorer than the national average (World Bank, 2007).

⁶ Note, the presence of CWR at all farmer sites had not been directly verified by botanical surveys or species occurrence records held by ZARI. Thus, procuring conservation sites solely based on farmer identification of CWR provides less certainty of ensuing the presence of CWR, despite training received at the project workshops.

272 A description of the decision variables and parameters is provided in Table 1.

273 **Table 1:** Description of model parameters and associated notation used for different model goals

Notation	Parameter description
<i>Decision variable</i>	
x_i	[0,1] variable, 1 if site i is selected for conservation services from I index of all sites, 0 otherwise (unknown)
<i>Untargeted area model</i>	
a_i	area (ha) associated with site i from index I of potential sites for conservation services
c_i	the cost of selecting site i for conservation services
e_i	[0,1] parameter: 1 if site i is located in ecoregion 1, 0 otherwise
Z	objective function value (unknown)
<i>Targeted area goal</i>	
d_i	community corresponding to farmer f at site i from index D of all communities
f_i	farmer f corresponding to site i from index F of all farmers
n_i	[0,1] parameter: 1 if site i is associated with species n from index N of all species, 0 otherwise
<i>Social equity goal</i>	
g_i	[0,1] parameter: 1 if site i is located in a GMA area 1, 0 otherwise
q_i	[0,1] parameter: 1 if farmer f is female, 0 otherwise
s_i	[0,1] parameter: 1 if the size of farm i is ≥ 2 hectares, 0 otherwise
v_i	[0,1] parameter: 1 if farmer f is <35 years old, 0 otherwise
<i>Diversity goal</i>	
m_i	[0,1] parameter: 1 if site i is located in a GMA area 1, 0 otherwise
p_i	[0,1] parameter: 1 if plot p associated with site i is >0.8 ha in size, 0 otherwise
v_i	[0,1] parameter: 1 if site i contains verified priority CWR, 0 otherwise

274

275 4. Results

276

277 4.1 Summary statistics and bid offers

278 A total of 132 male and 88 female farmers submitted bid offers at non-GMA sites; whilst 170
 279 male and 58 female farmers submitted offers at GMA sites across the 26 communities visited. Bid
 280 offers totalled \$110,154 (USD) and encompassed 632 hectares. A significant difference between
 281 GMA and non-GMA sites was found for a range of variables, using a two sample t-test (Table 2). The
 282 GMA sites had smaller farms and their socio-economic status index score⁷ was lower, suggesting this
 283 group of farmers are indeed generally poorer. Mean number of plots included in bid offers at GMA
 284 sites and the mean size of plots was higher than non-GMA sites, suggesting such farmers were willing

⁷ This refers to the FAO Richness Index (UN FAO, 2010) and represents the level of economic wellbeing associated with regions across Africa in 2010. This is measured from categories one (poorest areas) to six (wealthiest areas).

285 to enrol significantly more land. Bid offers at GMA sites were significantly higher in total, as well as
 286 per ha and per plot. No significant differences were found for age of farmers and the proportion of
 287 lands enrolled. Additionally, bid offers were disaggregated by gender and age. Analysis by gender
 288 reveals a significant difference for total bid offer and bid offer per plot but not for bid offer per ha. For
 289 age, no significant differences were noted.

290 **Table 2:** Summary of descriptive statistics and t-tests for multiple parameters associated with farmer
 291 bid offers from GMA and non-GMA sites plus disaggregation by farmer gender and age.

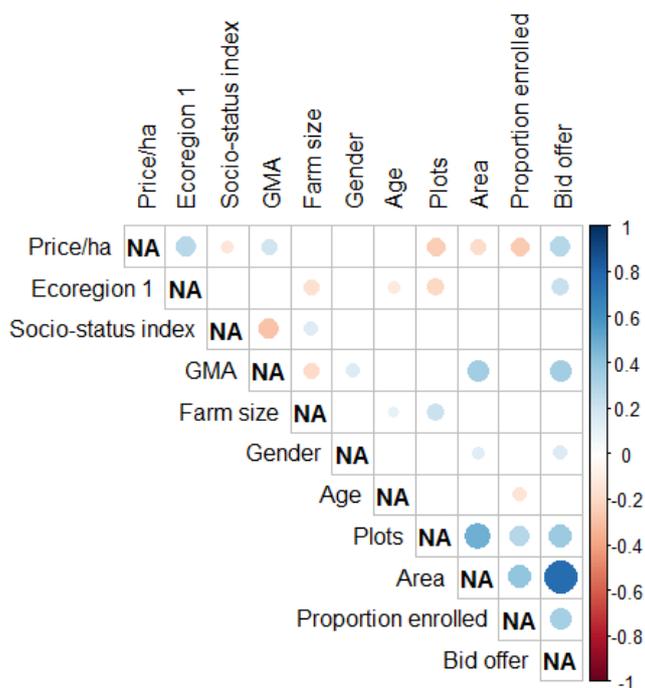
Variables	Mean	Std	Mean	Std	Two sample t-test	
	GMA		non-GMA		Obs	P value
Socio-economic status index ⁷	4.4	1.0	4.9	0.8	427	***
Farm size (ha)	4.0	4.1	9.9	21.7	211	***
Age	42.4	12.0	43.2	12.5	422	ns
Number of plots bid	2.4	1.8	2.0	1.7	394	**
Average size of plot (ha)	1.0	1.2	0.3	0.3	216	***
Area bid (ha)	2.2	2.8	0.7	0.6	252	***
Proportion of land (%)	30.9	20.7	28.8	18.9	420	ns
Bid offer (USD)	396.7	560.1	96.5	73.3	237	***
Bid offer (USD per ha)	304.5	360.4	193.5	144.9	308	***
Bid offer (USD per plot)	213.0	205.3	64.2	56.1	223	***
	Male		Female			
Bid offer (USD)	302.6	506.3	160.1	209.0	421	***
Bid offer (USD per ha)	261.5	307.5	234.3	235.7	427	ns
Bid offer (USD per plot)	152.2	180.0	105.4	129.3	312	**
	Older farmers		Younger farmers			
Bid offer (USD)	263	475.3	240.1	320.6	427	ns
Bid offer (USD per ha)	241.8	268.3	282	329.5	177	ns
Bid offer (USD per plot)	129	158.2	163.3	188.8	155	ns

Note: 'Std' = standard deviation, 'Obs' = observations. *** = P<0.01, ** = P<0.05, NS = not significant. Welch's t-test was used where Fisher's F-test indicated heteroscedasticity (unequal variance).

292

293 A correlation matrix reports the strength and direction of relationships between variables that
 294 may explain bid offer characteristics (Figure 3). Price/ha is negatively correlated with plots, area (ha)
 295 and proportion of land enrolled in the tender, suggesting as area, plots and the proportion of farmer
 296 lands in bid offers increases, so the price/ha of bid offers decreases. Bid offer is positively correlated
 297 with area and, to a lesser extent plots, suggesting higher bid offers are likely to contain more area and
 298 plots. Price is positively correlated with GMA, suggesting GMA areas resulted in higher bid offers.
 299 The proportion of land enrolled was negatively correlated (albeit weakly) with age, suggesting older
 300 farmers were willing to enrol proportionately less of their farms. Farm size was negatively correlated

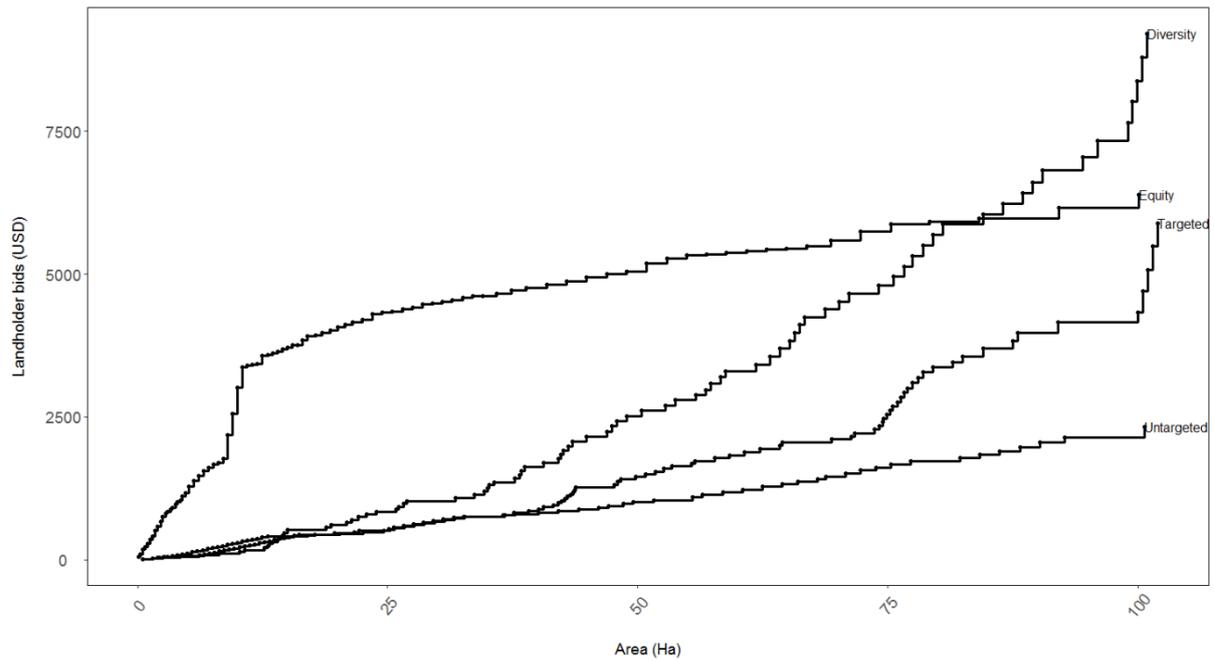
301 with GMA and ecoregion 1, as might be expected given that these areas house smaller farms. Finally,
 302 plots were positively correlated with area, suggesting as the number of plots included increases, so the
 303 area enrolled also increases.



304
 305 **Figure 3:** Correlation matrix demonstrating strength and direction of correlation for multiple
 306 explanatory variables for farmer bid offers. All populated variable cells were significant ($P < 0.05$) in
 307 the analysis. Positive correlations are displayed in red, negative in blue. Colour intensity and the size
 308 of the circle are proportional to the correlation coefficients. For a full description of the variables, see
 309 S3.

310 4.2 Site selection under multiple conservation goals

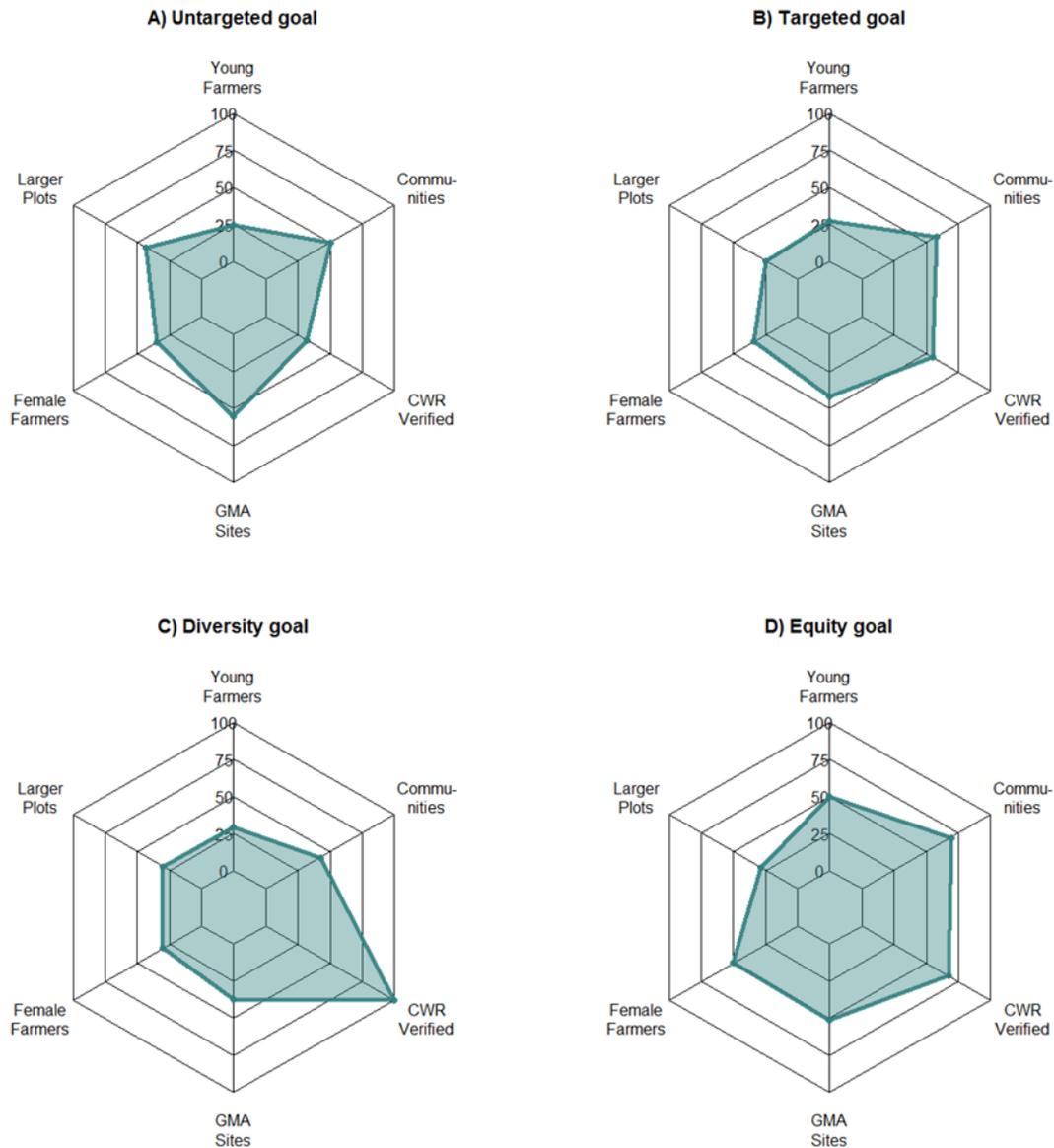
311 The construction of a supply curve allows the marginal cost for procuring an additional unit
 312 of conservation area to be estimated (Figure 4). The different model goals are shown through the
 313 varying supply curves, all of which are non-linear (i.e. price increments to procure more area vary
 314 along the curves). The supply curves show the minimum bid offer values to achieve a desired
 315 conservation area under the different selection goals. The untargeted area goal provided least-cost
 316 selection of conservation sites, followed by the targeted area and equity goals while the diversity goal
 317 was most expensive. The trade-offs between the different goals become more pronounced as selection
 318 of bid offers continues up the supply curve.



319

320 **Figure 4:** Supply curve of farmer bid offers (USD per annum) and area (ha) procured for
 321 conservation under the different conservation goals.

322 A range of diversity and social equity parameters varied depending on the goal employed (i.e.
 323 no. of younger farmers, no. larger plots, no. of female farmers, no. of GMA sites, no. of small farms
 324 and no. of communities). The untargeted area goal includes the highest proportion of larger plots of
 325 any goal, suggesting some farms with larger plots also sell cheapest (Figure 5). The targeted area goal
 326 selects more communities, verified CWR sites and female farmers relative to the untargeted goal. The
 327 diversity goal selected the highest proportion of sites with verified CWR records though not the
 328 highest number of larger plots. The social equity goal selected a higher proportion of younger farmers,
 329 female farmers, GMA sites and communities but with less emphasis on selecting sites with verified
 330 CWR.



331

332

333 **Figure 5:** Panel of radar plots corresponding to farmer selection under the ‘untargeted area’, ‘targeted
 334 area’, ‘diversity’ and ‘equity’ goals. The 0–100 scale shows the proportion (%) of each parameter in
 335 site selection under the different goals.

336 Overall, the untargeted area goal provided least-cost procurement of conservation services
 337 (\$2.3 k), followed by targeted area (\$5.9 k), social equity (\$6.4k) and diversity (\$ 9.2k) goals (Table
 338 3). Compared to using a uniform payment rule⁸, the various model goals provided cost reductions of
 339 87%, 66%, 63% and 48% per hectare, respectively; although these cost reductions would be reduced
 340 the further along the supply curve bid offers were selected. The equity goal selected the most GMA
 341 sites (45), female farmers (44), smaller farms (45) and young farmers (44) of all the model goals. The
 342 social equity goal therefore provides a basis to improve social equity outcomes but also has the

⁸ The uniform payment was calculated as the average price per hectare across all bid offers.

343 second highest cost. Compared to the most expensive goal (diversity), social equity costs \$27/ha or
 344 \$2.8k per annum less. The diversity goal selected the largest farms and had a mean species richness of
 345 2.66 – the highest species richness of any model goal. The cost per unit species richness⁹ ranged from
 346 between \$3k (untargeted area) to \$4.4 k (targeted area) under all model goals. In terms of per unit of
 347 species richness, the diversity goal was 18% cheaper than the equity goal.

348 The targeted area goal selected the most non-GMA and ecoregion 1 sites. Non-GMA sites are
 349 associated with lower bid offers (on average) than GMA sites; hence their selection. In addition, the
 350 targeted area goal procured more plots than any other selection goal (192) and these plots were on-
 351 average 17% smaller than for the untargeted and social equity goal – reporting the highest mean plot
 352 size. The untargeted area goal was 75% cheaper on a per hectare basis than the most expensive goal
 353 (diversity). If expenditure under the targeted area goal mirrored that of the social equity goal then a
 354 further 20% of conservation area, or 17% more sites, could be procured. Similarly, trade-offs between
 355 the diversity and equity goal suggest the latter could conserve an additional 50% more conservation
 356 area or 40% more sites (with mirrored budgets) but with a 48% reduction in species richness across
 357 sites (i.e. the selected sites contained less priority CWR).

358 **Table 3:** Summary of parameters associated with individual farmer bid offer selection under different
 359 model goals

Parameter	Untargeted	Targeted	Equity	Diversity
Cost per hectare (ha)	23	58	64	91
Total GMA sites	38	40	45	27
Total non-GMA sites	31	56	43	59
Total ecoregion 1 sites	23	59	50	44
Total ecoregion 2 sites	46	37	38	42
Total farmers	69	96	88	86
Total female farmers	24	33	44	26
Total young farmers	17	26	44	25
Mean farm size (ha)	5	8	8	11
Total smaller farms (< 2 ha)	31	43	45	27
Total number of plots	156	192	166	162
Mean plot size (ha)	0.64	0.53	0.64	0.62
Total large plots (≥ 0.8 ha)	30	24	25	26
Total communities	13	15	18	12
Mean CWR species richness ¹	0.77	1.34	1.51	2.66
Cost per unit (USD) species richness	\$ 3,022	\$ 4,398	\$ 4,232	\$ 3,461

⁹ A unit cost of species richness is taken by dividing the mean species richness (i.e. mean number of priority CWR from the sub-list present at each site) by the total cost for each selection goal.

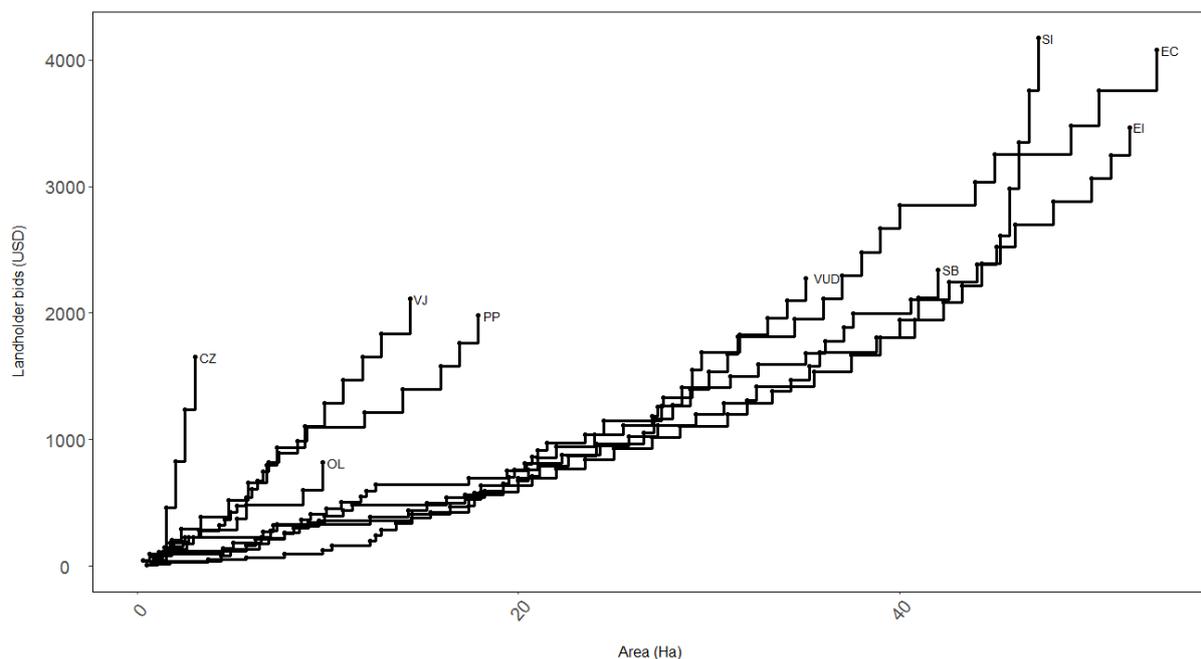
Total area (ha) ²	100	101	100	101
Total Cost (USD per annum)	\$ 2,327	\$ 5,893	\$ 6,390	\$ 9,206

360 ¹Mean species richness was calculated based on the number of verified CWR species records (from the sub-set
361 list of nine CWR species) associated with each site selected under that specific selection goal. ²The model goals
362 were constrained to select between 50 and 51 ha per ecoregion, to allow adequate flexibility to meet all other
363 constraints in the model.

364

365 4.3 CWR conservation outcomes

366 An upward sloping supply curve reveals different cost estimates for procuring conservation
367 land for each of the nine priority CWR species¹⁰ (Figure 6). While the supply curve does not consider
368 overlap in species richness, it is clear sites with higher species diversity would result in lower cost per
369 CWR. Five wild relatives have relatively comparable supply curves: *Vigna dekindtiana*, *Sorghum*
370 *bicolor*, *Eleusine indica*, *E. coracana* and *Solanum incanum*. The most abundantly conserved CWR
371 by area was *E. coracana* (54 ha) and the least conserved CWR was *Cucumis zeyheri* (3 ha). The rarer
372 CWR tend to feature in less conservation sites and are therefore conserved across less area, suggesting
373 the need for a more targeted approach to capture rare species adequately.



374

375 **Figure 6:** Supply curve revealing the cost of procuring conservation area (ha) thought to be inhabited
376 by specific CWR in the diversity goal.

377 Key: VUD (*Vigna unguiculata* subsp. *dekindtiana*), VJ (*Vigna juncea*), EC (*Eleusine coracana*), SB (*Sorghum*

¹⁰ Although 30 CWR were prioritised for conservation in Zambia, only nine priority CWR were verified to be present at our sample sites.

378 *bicolor*), SI (*Solanum incanum*), EI (*Eleusine indica*), PP (*Pennisetum purpureum*), CZ (*Cucumis zeyheri*), OL
 379 (*Oryza longistaminata*).

380 Only four priority CWR were found across both ecoregions surveyed (Table 4) suggesting the
 381 need for more wide-ranging CT surveys. The two most expensive CWR to conserve (under the
 382 diversity goal) were *C. zeyheri* (\$550 per ha) and *V. juncea* (\$148 per ha). Both *C. zeyheri* and *V.*
 383 *juncea* were also the rarest CWR in our sample. The cheapest CWR were *S. bicolor* (\$56 per ha) and
 384 *V. unguiculata* subsp. *dekindtiana* (\$65 per ha). However, these were not the most abundant CWR
 385 across our sample, suggesting other factors (beyond rarity) are also driving changes in cost.

386 The most prolifically conserved CWR for the diversity goal (by number of sites) was *E.*
 387 *indica* (43) while the most sparsely conserved was *C. zeyheri* (5). These correspond to the most, and
 388 least, prolific CWR across all farmer sites featuring in our sample, respectively. *E. indica* was
 389 conserved across more plots than any other CWR but not the highest area. *E. coracana* was conserved
 390 across the highest area (54 hectares) of any wild relative but not the most farmers or plots (this being
 391 *E. indica*). This suggests a further potential trade-off between conserving across larger geographical
 392 ranges (using farmer numbers as a proxy) and ensuring a greater extent of hectares. Decision makers
 393 should be aware of such potential trade-offs when setting conservation goals.

394 **Table 4:** Summary of conservation parameters according to each CWR for the diversity goal

CWR	No. eco- regions	No. comm- unities	No. Farmers	Total area (ha)	Total plots	Cost/ha (\$)	Total annual cost (\$)
<i>Oryza longistaminata</i>	1	1	10	10.2	17	80	817
<i>Cucumis zeyheri</i>	1	1	5	3	5	550	1,651
<i>Pennisetum purpureum</i>	1	3	24	17.9	38	111	1,981
<i>Vigna juncea</i>	1	2	16	14.3	28	148	2,109
<i>Vigna unguiculata</i> subsp. <i>dekindtiana</i>	1	3	26	35.1	59	65	2,275
<i>Sorghum bicolor</i>	2	4	28	42	63	56	2,340
<i>Eleusine indica</i>	2	5	43	52.1	85	67	3,466
<i>Eleusine coracana</i>	2	5	38	53.5	68	76	4,078
<i>Solanum incanum</i>	2	4	38	47.3	78	88	4,172

395

396 Compared to using a uniform payment rule, the diversity goal resulted in cost improvements
 397 of 120% per hectare across each CWR, excluding *C. zeyheri* where a uniform payment rule would
 398 actually result in a cost reduction of 68%. Cost improvements ranged from 18% for *V. juncea* to 213%
 399 for *S. bicolor*, although these cost reductions may be lower if the area goal was increased (i.e. as the
 400 model moves up the supply curve).

5. Discussion

5.1 Working with different types of farmer

The cost-effectiveness gains from optimised site selection reflect the heterogeneity in opportunity costs of different farmers, as revealed in bid offers (Engel, 2016). While selecting at the lower end of the supply curve may reduce cost, the advantages must be weighed against increased transaction costs associated with differentiating payments, as well as fairness and welfare implications (Börner et al., 2017).

Across our sample, farms inputting bid offers comprising greater area and plots were found to be cheaper on a price/ha basis. Male farmers input significantly higher bid offers than female farmers (both in total and on a per plot basis), possibly as a result of the fact that women are often paid less than men for undertaking similar work in rural labour markets (e.g. FAO, 2011). The proportion of land enrolled in bid offers as a percent of total land ownership was not correlated with farm size, suggesting poorer households (i.e. GMA sites) are able to participate in this PACS scheme at levels similar to those of better-off households – a finding mirrored in work by Pagiola et al. (2010).

Bid offers in GMAs were higher in absolute terms as well as per ha and per plot, suggesting poorer members of society do not necessarily “sell cheapest” (Pascual et al., 2014; Narloch et al., 2017). Importantly, these cost differences were not driven by changes in sample sizes between GMA and non-GMA sites, suggesting farmers from GMAs face higher shadow opportunity costs, possibly as a result of greater reliance on agri-production for livelihoods and survival. Additionally, these farmer groups may be aware of the financial benefits that can arise from working with conservationists. Despite the potentially higher cost of working with poorer farmers it may nonetheless be desirable to engage poorer actors in conservation activities. Working with GMA farmers may strengthen existing relationships between farmers and concurrent conservation programmes (Lindsey et al., 2014). Additionally, farmers living in the GMA may harbour pro-environmental attitudes given their proximity to protected areas (Allendorf et al., 2006) and these benefits may offset the additional cost of working with these groups.

Paying farmers for environmental services provision can itself either reinforce or erode pre-existing intrinsic motivation for conservation (often termed “crowding-in” and “crowding-out”, respectively) (Narloch et al., 2013; Midler et al., 2015; Börner et al., 2017). There are many reasons for crowding-in or out, including satisfaction or demotivation with a contractual scheme (Nordén et al., 2013). Consideration regarding such potential impacts should be undertaken with a view to considering how crowding-in positive behaviours could be actively encouraged through scheme

434 design and targeting. A complimentary approach may be to reward farmers by forging public private
435 breeding initiatives to improve their crop landraces and ultimately farmer yields.

436

437 *5.2 Trade-offs in PES*

438 The cost of site selection ranged from \$23/ha to \$91/ha across all selection goals. Similar
439 work on conservation tenders for the maintenance of landraces has obtained estimates of US \$300/ha
440 to \$400/ha in Ecuador and \$835/ha in Guatemala (Drucker et al., 2017), \$1,323/ha in Bolivia
441 (conservation area of 2.8 ha) and \$3,636/ha in Peru (conservation area of 0.32 ha) (Narloch et al.,
442 2017). The lower Zambia costs may reflect the reduced opportunity costs associated with
443 conservation in field margins (as opposed to the need for active cultivation when considering
444 landraces) and lower labour costs (Rapsomanikis, 2015).

445 Using a discriminatory payment rule to select bid offers yielded cost-effectiveness
446 improvements of 87% to 48% per hectare across the various model iterations, compared to a uniform
447 payment rule. Sensitivity analysis indicates these gains in cost-effectiveness persist, albeit at a
448 somewhat reduced level, even when procuring larger conservation areas (i.e. 100 ha. per ecoregion,
449 rather than just 50 ha.) suggesting these findings are robust with regard to the area constraint imposed.
450 The different constraints employed also impact cost effectiveness. The diversity goal yielded the best
451 conservation performance (i.e. a 76% increase in mean CWR species richness, compared to the equity
452 goal) but the social equity goal resulted in 69% more female farmers, 76% more younger farmers and
453 67% more smaller farmers being selected in bid offers. These factors suggest a trade-off between
454 cost-effectiveness, diversity and other socially desirable attributes. Similar work has found
455 comparable trade-offs persist for landrace conservation (Narloch et al., 2011b) and biodiversity
456 conservation in the tropics (Calvet-Mir et al., 2015).

457 It is therefore of interest to explore the relationship between social equity and the cost-
458 effectiveness of conservation schemes. Factors such as perceived distributional fairness may influence
459 an individual's motivation to engage in conservation programmes (Vatn, 2010; Narloch et al., 2013;
460 Midler et al., 2015) and perceptions of unfairness can undermine the effectiveness of incentives
461 (Sommerville et al., 2010). Debate in the literature has raised questions regarding the appropriateness
462 of using PES programmes to tackle factors such as poverty reduction at the expense of ecological
463 outcomes (Kinzig et al., 2011; Jack et al., 2008). While there are strong arguments for including
464 equity considerations in PES (Wunder, 2007), it can be argued that allocating funds to service
465 providers that are not the most competitive may undermine conservation effort (Börner et al., 2017).

466 Our work demonstrates imposing fairness considerations would result in additional scheme
467 cost of a relatively modest 8% when compared to the targeted area goal. Although the diversity goal

468 cost an additional 44% more to procure land than the social equity, it was actually cheaper per unit of
469 species richness than the equity and targeted area goal. In other words, the diversity goal is the
470 cheapest approach to maximising species richness out of the selection goals where a minimum
471 diversity constraint is imposed. Multi-criteria approaches may be required to balance environmental
472 effectiveness and fairness considerations and there are strong arguments for not treating
473 environmental and social equity goals as fully separate objectives in PES schemes (Pascual et al.,
474 2014). Good conservation outcomes are often contingent on developing positive local attitudes
475 (Struhsaker et al., 2005) and pro-social behaviour that can improve compliance (Narloch et al., 2017).
476 Our results show it is possible to combine social equity and diversity criteria and the cost implications
477 resulted in a 15% increase. Ultimately, there is a need for such considerations to form part of the
478 establishment of a consensus around the definition of conservation goals and how trade-offs are
479 considered (Zumaran, 2018).

480

481 5.3 National scale CWR conservation

482 Establishment of national, regional and global genetic reserves has been identified as a key
483 challenge for CWR conservation (Maxted et al., 1997, 2010). Costs for establishing an on-farm
484 conservation site for CWR have been estimated by Maxted (2015, unpublished) at \$10k per ecoregion
485 per year . While the total cost of conservation under the diversity maximising goal was estimated at
486 \$9.2k per year across two ecoregions, if this estimate were extrapolated to cover all ten ecoregions in
487 Zambia (upper bound) or five ecoregions (lower bound) then the costs for establishing a national (on-
488 farm) conservation network would range from \$41,250 to \$82,500 per year¹¹. The latter is likely an
489 overestimate since Brown and Briggs (1991) and Fielder et al. (2016) note conserving each CWR at a
490 minimum of five different ecoregions should suffice. In any case we suggest this is a relatively
491 modest sum as it only amounts to between 0.5% and 0.9% of income generated by the Zambian
492 Wildlife Authority (Lindsey et al., 2014).

493 Eight of the nine priority CWR modelled in this exercise were present in existing PAs
494 (Ministry of Agriculture, 2016). Yet, many populations in PAs receive no active management
495 highlighting the need to establish their management on-farm (Maxted et al., 1997; Lawson et al.,
496 2014). While only *C. zeyheri* was not present within existing PAs, *Sorghum bicolor* and *Solanum*
497 *incanum* were found to be present in only 20% and 25% of PA sites, respectively (see S4). In
498 addition, *C. zeyheri* was not present in any *ex situ* collections while *Sol. incanum* and *S. bicolor* was
499 scarcely stored *ex situ*. This suggests rationalisation is needed and raises broader questions concerning

¹¹ Based on procuring 50 hectares per ecoregion at the mean cost of \$150/ha (this cost is based on the price/ha of individual farmer bid offers in the diversity goal). The cost estimate includes an additional 10% monitoring and management cost (as per Lindenmayer et al., 2012).

500 how best to allocate funds across integrated *in situ* and *ex situ* strategies. The high cost of conserving
501 *C. zeyheri*, suggests it may be more cost-effective to prioritise *ex situ* approaches to enable a higher
502 proportion of funds to be allocated to the *in situ* management of other CWR where the cost of
503 conserving is much lower. Alternative *in situ* strategies (e.g. protected areas designations) may also be
504 more appropriate where farmer led conservation is cost prohibitive.

505

506 5.4 Limitations and further work

507 In this study, agricultural extension officers were used to promote the conservation tender and
508 recruit workshop participants, with bid offers ultimately being received from a wider range of
509 community members. However this approach could potentially introduce a self-selection bias that
510 lowers the bid costs we observed relative to the mean of the broader population. This tendency is
511 however potentially offset by another possible bias that can arise from the use of an open-ended
512 tender question, which in some circumstance has been shown to lead to higher WTP estimates relative
513 to a closed format. There is an extensive debate regarding the use of open versus closed formats,
514 which is arguably unresolved. In our particular context the open-ended format was considered to be
515 appropriate given the unusual nature of the conservation service contract being solicited.

516 Nevertheless, the cost figures generated are likely to reflect only a lower-bound estimate of
517 the total costs, given that a range of transaction costs have not been accounted for, falling outside of
518 the scope of this study. Such additional costs would include farmer CWR management training, as
519 well as the administration costs of the scheme and associated monitoring and verification. In other
520 studies, such transaction costs have been found to range from 6% to 87% of total costs paid to
521 landholders (Latacz-Lohmann and Schilizzi, 2005); while monitoring necessary to ensure site
522 management is maintaining or enhancing target CWR populations (Maxted et al., 1997, 2008) may be
523 differentiated based on demographic counting with costs in the range of CWR (US\$1 k per
524 monitoring event) and genetic characterisation (required every 25–30 years costing ~ \$50 k per
525 monitoring event) per ecoregion (Maxted, 2017, *personal communication*)

526 An additional constraint was our reliance on CWR records that varied in date, raising
527 questions over their reliability and the potential need for additional field surveying to establish
528 renewed population baselines. Furthermore, the limited number of CWR species used to inform the
529 site selection model may have affected outcomes under each selection goal. Further validation of the
530 results could be achieved through applying the approach developed at the national scale (with
531 associated sample sizes). Ecological metrics such as habitat connectivity and sub-populations were
532 not considered but have been shown to be important in other work (Beyer et al., 2016) and
533 incorporating such metrics into future model iterations may lead to more integrated conservation

534 approaches. Finally, the implications of climate change need to be made more explicit in decisions
535 concerning optimal site selection given range shifts that are likely to occur which threaten the
536 protection of CWR in static protected areas (Phillips et al., 2017).

537 **6. Conclusion**

538

539 Advances in genotyping technologies and plant breeding to meet yield improvement goals
540 have increased the potential for using exotic genetic material, thereby increasing the importance of
541 conserving and using CWR. In the Zambian context, we demonstrated that *in situ* conservation costs
542 ranges from \$23-\$91/ha. Including social equity goals in site selection results in a cost increase of 8%
543 relative to the targeted area goal. The diversity goal was most expensive, with an additional 42% cost
544 per ha compared to the social equity goal, but 18% cheaper per unit species richness. This implies a
545 potential trade-off between conservation area, species richness and more equitable distribution of
546 conservation funds to disadvantaged groups. Any such trade-offs should be made transparent and
547 brought to the attention of the relevant decision-makers responsible for CWR conservation strategies;
548 as should the fact that the inclusion of some rare CWR were found to disproportionately increase on
549 farm conservation costs, suggesting alternative conservation approaches (e.g. *ex situ* or *in situ* within
550 protected areas) may be more appropriate in some cases.

551 Despite data gaps, these findings reveal clear opportunities to improve the cost-effectiveness
552 of incipient conservation approaches based on existing data and the use of tender instruments that are
553 capable of identifying least-cost conservation service providers. Although this work has focused on
554 CWR conservation in Zambia, the selection model developed could be applied more widely, thereby
555 supporting national and global CWR conservation strategy design and implementation.

556

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558

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569 **References**

570

571 Allendorf, T., Swe, K.K., Oo, T., Htut, Y., Aung, M., Allendorf, K., Hayek, L.-A., Leimgruber, P., Wemmer,
572 C., 2006. Community attitudes toward three protected areas in Upper Myanmar (Burma). *Environ.*
573 *Conserv.* 33, 344–352.

574 Bertke, E., Marggraf, R., 2005. An incentive based tool for ecologically and economically efficient provision of
575 agrobiodiversity. Sustainable agricultural and natural resource management knowledge base. Available
576 from: <https://vtechworks.lib.vt.edu/handle/10919/67255>

577 Beyer, H.L., Dujardin, Y., Watts, M.E., Possingham, H.P., 2016. Solving conservation planning problems with
578 integer linear programming. *Ecol. Modell.* 328, 14–22.

579 Börner, J., Baylis, K., Corbera, E., Ezzine-de-Blas, D., Honey-Rosés, J., Persson, U.M., Wunder, S., 2017. The
580 effectiveness of payments for environmental services. *World Dev.* 96, 359–374.

581 Brooks, K., Zorya, S., Gautam, A., Goyal, A., 2013. Agriculture as a sector of opportunity for young people in
582 Africa. World Bank. Report number WPS6473.

583 Brown, A.H., Briggs, J.D., 1991. Sampling strategies for genetic variation in ex situ collections of endangered
584 plant species, in: Falk, D.A., Holsinger, K. (Eds.), *Genetics and Conservation of Rare Plants*. Oxford
585 University Press., pp. 99–119.

586 Buckland, S.T., Borchers, D.L., Johnston, A., Henrys, P.A., Marques, T.A., 2007. Line transect methods for
587 plant surveys. *Biometrics* 63, 989–998.

588 Burgess, N.D., Hales, J.D., Ricketts, T.H., Dinerstein, E., 2006. Factoring species, non-species values and
589 threats into biodiversity prioritisation across the ecoregions of Africa and its islands. *Biol. Conserv.* 127,
590 383–401.

591 Calvet-Mir, L., Corbera, E., Martin, A., Fisher, J., Gross-Camp, N., 2015. Payments for ecosystem services in
592 the tropics: a closer look at effectiveness and equity. *Curr. Opin. Environ. Sustain.* 14, 150–162.

593 Chikowo, R., 2018. Description of cropping systems, climate, and soils in Zambia [WWW Document]. URL
594 <http://www.yieldgap.org/zambia> (accessed 2.9.18).

595 Dempewolf, H., Eastwood, R.J., Guarino, L., Khoury, C.K., Müller, J. V, Toll, J., 2014. Adapting agriculture to
596 climate change: a global initiative to collect, conserve, and use crop wild relatives. *Agroecol. Sustain.*
597 *Food Syst.* 38, 369–377.

598 Dhariwal, G.K., Laroche, A., 2017. The future of genetically engineered plants to stabilize yield and improve
599 feed. *Anim. Front.* 7, 5–8.

600 Donaldson, L., Wilson, R.J., Maclean, I.M.D., 2017. Old concepts, new challenges: adapting landscape-scale
601 conservation to the twenty-first century. *Biodivers. Conserv.* 1–26.

602 Drucker, A. g., Ramirex, M., Medina, T., 2017. Incentivos costo-efectivos parala conservaciony uso in situ/en
603 finca dela agrobiodiversidad avances del programa resca en America Latina. Sirgealc, Guadalajara,
604 Mexico.

605 Engel, S., 2016. The devil in the detail: a practical guide on designing payments for environmental services. *Int.*
606 *Rev. Environ. Resour. Econ.* 9, 131–177.

607 Eroarome, A.M., 2009. Country Pasture/Forage Resource Profiles: Zambia. Rome, Italy.

608 Escobar, S.S., Odame, H.H., Tegbaru, A., 2017. 21 Gender transformative approaches in agricultural

- 609 innovation. *Sustain. Intensif. Smallhold. Agric.* 304.
- 610 FAO, 2017. *The future of food and agriculture – Trends and challenges*. Rome, Italy.
- 611 FAO, 2011. *The role of women in agriculture*. ESA Working Paper No. 11-02.
- 612 Fielder, H., Smith, C., Ford-Lloyd, B., Maxted, N., 2016. Enhancing the conservation of crop wild relatives in
613 Scotland. *J. Nat. Conserv.* 29, 51–61.
- 614 Ford-Lloyd, B. V, Schmidt, M., Armstrong, S.J., Barazani, O., Engels, J., Hadas, R., Hammer, K., Kell, S.P.,
615 Kang, D., Khoshbakht, K., 2011. Crop wild relatives—undervalued, underutilized and under threat?
616 *Bioscience* 61, 559–565.
- 617 Grogan, K., Birch-Thomsen, T., Lyimo, J., 2013. Transition of shifting cultivation and its impact on people’s
618 livelihoods in the Miombo woodlands of northern Zambia and south-western Tanzania. *Hum. Ecol.* 41,
619 77–92.
- 620 Haight, R.G., Snyder, S.A., 2009. Integer programming methods for reserve selection and design. *Spat.*
621 *Conserv. prioritization Quant. methods Comput. tools.*(A Moilanen, KA Wilson, HP Possingham, eds.).
622 Oxford Univ. Press. New York, NY 43–57.
- 623 Hajjar, R., Hodgkin, T., 2007. The use of wild relatives in crop improvement: a survey of developments over the
624 last 20 years. *Euphytica* 156, 1–13.
- 625 Jarvis, A., Lane, A., Hijmans, R.J., 2008. The effect of climate change on crop wild relatives. *Agric. Ecosyst.*
626 *Environ.* 126, 13–23.
- 627 Jarvis, S., Fielder, H., Hopkins, J., Maxted, N., Smart, S., 2015. Distribution of crop wild relatives of
628 conservation priority in the UK landscape. *Biol. Conserv.* 191, 444–451.
- 629 Kell, S.P., Maxted, N., Bilz, M., 2011. 28 European Crop Wild Relative Threat Assessment: Knowledge Gained
630 and Lessons Learnt, in: Maxted, N., Dulloo, M.E., Ford-Lloyd, B., Frese, L., Iriondo, J., Pinheiro de
631 Carvalho, M.A.. (Eds.), *Agrobiodiversity Conservation Securing the Diversity of Crop Wild Relatives and*
632 *Landraces*. CABI International, Wallingford., pp. 218–242.
- 633 Kinzig, A.P., Perrings, C., Chapin, F.S., Polasky, S., Smith, V.K., Tilman, D., Turner, B.L., 2011. Paying for
634 ecosystem services—promise and peril. *Science* (80-). 334, 603–604.
- 635 Krishna, V. V, Drucker, A.G., Pascual, U., Raghu, P.T., King, E.D.I.O., 2013. Estimating compensation
636 payments for on-farm conservation of agricultural biodiversity in developing countries. *Ecol. Econ.* 87,
637 110–123.
- 638 Latacz-Lohmann, U., Schilizzi, S., 2005. Auctions for conservation contracts: a review of the theoretical and
639 empirical literature. Rep. to Scottish Exec. Environ. Rural Aff. Dep. 15.
- 640 Lawson, C.R., Bennie, J.J., Thomas, C.D., Hodgson, J.A., Wilson, R.J., 2014. Active management of protected
641 areas enhances metapopulation expansion under climate change. *Conserv. Lett.* 7, 111–118.
- 642 Lindenmayer, D., Burgman, M., 2005. *Practical conservation biology*. Csiro Publishing.
- 643 Lindenmayer, D.B., Zammit, C., Attwood, S.J., Burns, E., Shepherd, C.L., Kay, G., Wood, J., 2012. A novel
644 and cost-effective monitoring approach for outcomes in an Australian biodiversity conservation incentive
645 program. *PLoS One* 7, e50872.
- 646 Lindsey, P.A., Nyirenda, V.R., Barnes, J.I., Becker, M.S., McRobb, R., Tambling, C.J., Taylor, W.A., Watson,
647 F.G., t’Sas-Rolfes, M., 2014. Underperformance of African protected area networks and the case for new
648 conservation models: insights from Zambia. *PLoS One* 9, e94109.
- 649 Manning, I., 2011. Wildlife conservation in Zambia and the Landsafe customary commons. *Nat. Resour. J.* 52,
650 195–214.
- 651 Mason, A.J., 2012. Opensolver-an open source add-in to solve linear and integer programmes in excel, in:
652 *Operations Research Proceedings 2011*. Springer, pp. 401–406.

- 653 Maxted, N., 2017. Personal Communication. Discussions concerning the appropriate scale of a CWR
654 conservation programme.
- 655 Maxted, N., 2015. Global network options for in situ conservation and on-farm management of plant genetic
656 resources. A concept note (unpublished).
- 657 Maxted, N., Ford-Lloyd, B. V., Hawkes, J.G., 1997. Complementary conservation strategies, in: Maxted, N.,
658 Ford-Lloyd, B.V., Hawkes, J.G. (Eds.), *Plant Genetic Conservation: The in Situ Approach*. Chapman &
659 Hall, London., pp. 20–55.
- 660 Maxted, N., Ford-Lloyd, B. V., Jury, S., Kell, S., Scholten, M., 2006. Towards a definition of a crop wild
661 relative. *Biodivers. Conserv.* 15, 2673–2685.
- 662 Maxted, N., Hawkes, J.G., Ford-Lloyd, B. V., Williams, J.T., 2000. A practical model for in situ genetic
663 conservation, in: *Plant Genetic Conservation*. Springer, pp. 339–367.
- 664 Maxted, N., Iriondo, J.M., De Hond, L., Dulloo, E., Lefèvre, F., Asdal, A., Kell, S.P., Guarino, L., 2008.
665 Genetic reserve management, *Plant Genetic Population Management*. CAB International, Wallingford.
- 666 Maxted, N., Kell, S., 2009. Establishment of a Global Network for the In Situ Conservation of Crop Wild
667 Relatives: Status and Needs. Rome, Italy.
- 668 Maxted, N., Kell, S., Toledo, Á., Dulloo, E., Heywood, V., Hodgkin, T., Hunter, D., Guarino, L., Jarvis, A.,
669 Ford-Lloyd, B., 2010. A global approach to crop wild relative conservation: securing the gene pool for
670 food and agriculture. *Kew Bull.* 65, 561–576.
- 671 Meilleur, B.A., Hodgkin, T., 2004. In situ conservation of crop wild relatives: status and trends. *Biodivers.*
672 *Conserv.* 13, 663–684.
- 673 Messer, K.D., 2006. The conservation benefits of cost-effective land acquisition: A case study in Maryland. *J.*
674 *Environ. Manage.* 79, 305–315.
- 675 Midler, E., Pascual, U., Drucker, A.G., Narloch, U., Soto, J.L., 2015. Unraveling the effects of payments for
676 ecosystem services on motivations for collective action. *Ecol. Econ.* 120, 394–405.
- 677 Ministry of Agriculture, 2016. National strategic action plan for the conservation and sustainable use of crop
678 wild relatives in Zambia. Lusaka, Zambia.
- 679 Ministry of Local Government and Housing., 2017. Eastern Province [WWW Document]. URL
680 http://www.mlgh.gov.zm/?page_id=666 (accessed 6.1.17).
- 681 Narloch, U., Drucker, A.G., Pascual, U., 2017. What role for cooperation in conservation tenders? Paying
682 farmer groups in the High Andes. *Land use policy* 63, 659–671.
- 683 Narloch, U., Drucker, A.G., Pascual, U., 2011a. Payments for agrobiodiversity conservation services for
684 sustained on-farm utilization of plant and animal genetic resources. *Ecol. Econ.* 70, 1837–1845.
685 <https://doi.org/10.1016/j.ecolecon.2011.05.018>
- 686 Narloch, U., Pascual, U., Drucker, A.G., 2013. How to achieve fairness in payments for ecosystem services?
687 Insights from agrobiodiversity conservation auctions. *Land use policy* 35, 107–118.
- 688 Narloch, U., Pascual, U., Drucker, A.G., 2011b. Cost-effectiveness targeting under multiple conservation goals
689 and equity considerations in the Andes. *Environ. Conserv.* 38, 417–425.
- 690 Ng’uni, D., Munkombwe, G., Mwile, G., Dulloo, E., Thormann, I., Gaisberger, H., Maxted, N., Magos Brehm,
691 J., Kell, S., 2017. Technical Background Document to the National Strategic Action Plan for the
692 Conservation and Sustainable Use of Cop Wild Relatives in Zambia.
693 <https://doi.org/doi/10.7910/DVN/VYZZFF>
- 694 Ng’uni, D., Munkombwe, G., Tembo, M., 2016. Occurrence data for priority CWR of Zambia.
695 <https://doi.org/doi/10.7910/DVN/Z5XN1F>
- 696 Nordén, A., Persson, U.M., Alpizar, F., 2013. 8 Incentives, impacts and behavioural issues in the context of

- 697 payment for ecosystem services programmes. *Glob. Dev. Rethink. Interv. Gov.* 102, 147–168.
- 698 Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G.V.N., Underwood, E.C., D’amico,
699 J.A., Itoua, I., Strand, H.E., Morrison, J.C., 2001. Terrestrial Ecoregions of the World: A New Map of Life
700 on Earth: A new global map of terrestrial ecoregions provides an innovative tool for conserving
701 biodiversity. *Bioscience* 51, 933–938.
- 702 Pachauri, R.K., Allen, M.R., Barros, V.R., Broome, J., Cramer, W., Christ, R., Church, J.A., Clarke, L., Dahe,
703 Q., Dasgupta, P., 2014. Climate change 2014: synthesis report. Contribution of Working Groups I, II and
704 III to the fifth assessment report of the Intergovernmental Panel on Climate Change. IPCC.
- 705 Pagiola, S., Rios, A.R., Arcenas, A., 2010. Poor household participation in payments for environmental
706 services: Lessons from the Silvopastoral Project in Quindío, Colombia. *Environ. Resour. Econ.* 47, 371–
707 394.
- 708 Pascual, U., Phelps, J., Garmendia, E., Brown, K., Corbera, E., Martin, A., Gomez-Baggethun, E., Muradian, R.,
709 2014. Social equity matters in payments for ecosystem services. *Bioscience* 64, 1027–1036.
- 710 Phillips, J., Brehm, J.M., van Oort, B., Asdal, Å., Rasmussen, M., Maxted, N., 2017. Climate change and
711 national crop wild relative conservation planning. *Ambio* 1–14.
- 712 PriceWaterhouseCoopers, 2013. Crop wild relatives: a valuable resource for crop development. Available
713 <http://pwc.blogs.com/files/pwc-seed-bank-analysis-for-msb-0713.pdf>
- 714 Quisumbing, A.R., Meinzen-Dick, R., Raney, T.L., Croppenstedt, A., Behrman, J.A., Peterman, A., 2014.
715 Closing the knowledge gap on gender in agriculture, in: *Gender in Agriculture*. Springer, pp. 3–27.
- 716 Rapsomanikis, G., 2015. The economic lives of smallholder farmers: an analysis based on household data from
717 nine countries. Food and Agricultural Organisation of the United Nations.
- 718 Ray, D.K., Mueller, N.D., West, P.C., Foley, J.A., 2013. Yield trends are insufficient to double global crop
719 production by 2050. *PLoS One* 8, e66428.
- 720 Rodrigues, A.S.L., Andelman, S.J., Bakarr, M.I., Boitani, L., Brooks, T.M., Cowling, R.M., Fishpool, L.D.C.,
721 da Fonseca, G.A.B., Gaston, K.J., Hoffmann, M., 2004. Effectiveness of the global protected area network
722 in representing species diversity. *Nature* 428, 640.
- 723 Seto, K.C., Ramankutty, N., 2016. Hidden linkages between urbanization and food systems. *Science* (80-.).
724 352, 943–945.
- 725 Sommerville, M., Jones, J.P.G., Rahajaharison, M., Milner-Gulland, E.J., 2010. The role of fairness and benefit
726 distribution in community-based Payment for Environmental Services interventions: A case study from
727 Menabe, Madagascar. *Ecol. Econ.* 69, 1262–1271.
- 728 Stoneham, G., Chaudhri, V., Ha, A., Strappazzon, L., 2003. Auctions for conservation contracts: an empirical
729 examination of Victoria’s BushTender trial. *Aust. J. Agric. Resour. Econ.* 47, 477–500.
730 <https://doi.org/10.1111/j.1467-8489.2003.t01-1-00224.x>
- 731 Struhsaker, T.T., Struhsaker, P.J., Siex, K.S., 2005. Conserving Africa’s rain forests: problems in protected
732 areas and possible solutions. *Biol. Conserv.* 123, 45–54.
- 733 Tester, M., Langridge, P., 2010. Breeding technologies to increase crop production in a changing world. *Science*
734 (80-.). 327, 818–822.
- 735 UN FAO, 2010. FAO Geonetwork Richness Index [WWW Document]. Available from:
736 <http://ref.data.fao.org/map?entryId=5d112b2b-9793-4484-808c-4a6172c5d4d0>
- 737 Vatn, A., 2010. An institutional analysis of payments for environmental services. *Ecol. Econ.* 69, 1245–1252.
- 738 Williams, J.C., ReVelle, C.S., Levin, S.A., 2005. Spatial attributes and reserve design models: a review.
739 *Environ. Model. Assess.* 10, 163–181.
- 740 Windle, J., Rolfe, J., 2008. Exploring the efficiencies of using competitive tenders over fixed price grants to

- 741 protect biodiversity in Australian rangelands. *Land use policy* 25, 388–398.
742 <https://doi.org/10.1016/j.landusepol.2007.09.005>
- 743 World Bank, 2007. Economic and poverty impact of nature-based tourism. Lusaka, Zambia.
- 744 Wunder, S., 2007. The efficiency of payments for environmental services in tropical conservation. *Conserv.*
745 *Biol.* 21, 48–58.
- 746 Wünscher, T., Wunder, S., 2017. Conservation tenders in low-income countries: Opportunities and challenges.
747 *Land use policy* 63, 672–678.
- 748 WWF, 2004. Terrestrial Ecoregions of the World. USA. Available from:
749 <https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world>
- 750 Zamstats, 2010. Muchinga Province 2010 Census Final Population and Electoral population. Lusaka, Zambia.
- 751 Zhang, H., Mittal, N., Leamy, L.J., Barazani, O., Song, B., 2017. Back into the wild—Apply untapped genetic
752 diversity of wild relatives for crop improvement. *Evol. Appl.* 10, 5–24.
- 753 Zumarán, R., 2018. Lineamientos metodológicos para identificar la diversidad de los cultivos en riesgo de
754 erosión genética y su recuperación. Informe Final. Industrias Forestales QIRI S.A.C., Lima, Peru.

755

756 **Supplementary information**

757

- 758 **S1:** List of priority CWR used in the modelling exercise and distribution across community and
759 farmer sites.

CWR	Related crop	No. of community locations	No. of sites
<i>Cucumis zeyheri</i>	Cucumber	1	20
<i>Eleusine coracana</i>	Finger millet	5	78
<i>Eleusine indica</i>	Finger millet	5	87
<i>Oryza longistaminata</i>	Rice	1	30
<i>Pennisetum purpureum</i>	Pearl millet	4	65
<i>Solanum incanum</i>	Egg plant	4	80
<i>Sorghum bicolor</i>	Sorghum	2	50
<i>Vigna juncea</i>	Cowpea	2	20
<i>Vigna unguiculata</i> subsp. <i>dekindtiana</i>	Cowpea	3	43

760

- 761 **S2:** Information arising from focus group discussions (FGDs) with Zambian farmers concerning
762 CWR conservation and local farming practices

763

- 764 Five FGDs were undertaken across Northern and Eastern province with a total of 55
765 participants. On average, 61% of CWR from a picture list of CWR shown to participants (though to
766 inhabit the region) were identified. A range of other plant species thought to be wild relatives were

767 also mentioned by participants and a small number of species thought to be CWR but now extinct
 768 were also noted.

769 Multiple uses of CWR were identified by participants including animal feed, medicine, thatch
 770 and human food (particularly when crop harvests are poor). Wild relatives were identified as
 771 occupying a range of different habitat types including adjacent to water sources (i.e. streams and
 772 marshland); adjacent to dwellings; roadside verges; field margins; in croplands; hilly ground and near
 773 termite mounds.

774 Participants were also asked whether the CWR identified had either declined, remained
 775 stable, or increased over time. Some 35% of wild relatives were identified as declining; 54% had
 776 remained the same and 11% had increased. The decline of some CWR populations had largely been
 777 attributed to over-harvesting, human induced bush fires, weeding and increased pressure from game
 778 animals (at GMA sites). In contrast, increases of some CWR noted by communities had been driven
 779 by an increase in farm animals that resulted in greater seed dispersal. Most CWR populations were
 780 unmanaged by communities, although some were harvested if edible by farm animals or humans.
 781 Those growing on crop lands were managed as weeds unless edible.

782 Community participants identified a number of activities they believe would enhance CWR
 783 populations including wild seed harvesting; selective weeding in crop lands; increased provision of
 784 fallow lands; reduced fire burning (particularly early in agricultural season to allow plants to seed)
 785 and creating awareness as to the importance of CWR. Resources required for these activities included
 786 agricultural tools; subsidies; access to transport and training.

787 Farmers were also asked questions concerning activities required for cultivating a hectare of
 788 land and the estimated costs associated with these activities. Additionally, they were asked the
 789 estimated costs for sympathetically managing a hectare of land to not de-weed CWR. An example of
 790 the activities and associated costs mentioned are given below. These figures compare well to cost per
 791 hectare estimates derived from the tender workshops.

Activity	Estimated cost (US\$ per hectare)
Ploughing and land preparation	15 – 55
Planting	16 – 37
Weeding*	22 – 73
Harvesting	18 – 138
Sympathetic weeding (i.e. not removing weed CWR from croplands)	37 – 110
Average value of crop yield per ha**	344 – 688

792 * Usually smallholder farmers, who account for large number of farmers in the two regions, do not use
 793 herbicides in their farming activities. In most cases, it is either they use hand hoe or ox drawn implements to
 794 control weeds in their fields. However, if herbicides are used, which normally is sourced through farmer input
 795 subsidies, they normally use pre emergence herbicides before planting of their main crop such as maize. ** The
 796 average farmer yield per ha for a maize crop in Northern and Eastern Provinces ranges from 1.95 - 2.2 tons/ha
 797 (Indaba Agricultural Policy Research Institute, 2017).
 798

799 **S3:** Full description of the parameters used in the correlation matrix

Parameter	Description
Price/ha	The farmer bid offer for supplying conservation services in costs per hectare..
Ecoregion 1	Whether the conservation site was located in Ecoregion 1 or 2.
Socio-status index	The FAO Richness Index (UN FAO, 2010) represents the level of economic wellbeing associated with regions across Africa in 2010. This is measured from categories one (poorest areas) to six (wealthiest areas).
GMA	Whether the conservation site was located in a game management area.
Farm size	Total size of the farm bidding to supply conservation services.
Gender	The gender of the farmer.
Age	The age of the farmer.
Plots	The total number of plots bid in the conservation tender.
Area (ha)	The total conservation area bid in the conservation tender.
Proportion enrolled	The proportion of farmers lands bid in the conservation tender.
Bid offer (USD)	The total bid offer (per annum) for supplying conservation services.

800

801 **S4:** *In situ* and *ex situ* coverage of priority CWR in existing Zambian PAs and genebank collections.

CWR	Populations covered in PAs	% of populations covered in PAs	Accessions in national genebank	Accessions in international genebank
<i>Cucumis zeyheri</i>	0	0	0	0
<i>Eleusine coracana</i>	34	23	0	137
<i>Eleusine indica</i>	4	36	3	3
<i>Oryza longistaminata</i>	102	51	56	112
<i>Pennisetum purpureum</i>	4	50	0	5
<i>Solanum incanum</i>	1	25	0	1
<i>Sorghum bicolor</i>	1	20	0	2
<i>Vigna juncea</i>	6	19	0	13
<i>Vigna unguiculata</i> subsp. <i>dekindtiana</i>	30	32	20	86

802 Data from (Ministry of Agriculture, 2016).

803 **References:**

804 Indaba Agricultural Policy Research Institute, 2017. Zambia agriculture status report 2017. Lusaka, Zambia.

805 Ministry of Agriculture, 2016. National strategic action plan for the conservation and sustainable use of crop
806 wild relatives in Zambia. Lusaka, Zambia.

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