

1 **Classification:**

2 Social Sciences: Anthropology

3 **Title:**

4 Similar social complexity and cooperation in independent pastoralist societies

5 **Short title:**

6 Cooperative herding strategies in Norway and China

7 **Authors:**

8 Juan Du^{c,d,1}, Matthew Gwynfryn Thomas^{a,b,1}, Bård-Jørgen Bårdsen^a, Ruth Mace^{c,d,2}, Marius Warg
9 Næss^{b,2}

10 ¹ These authors contributed equally

11 ² corresponding authors:

12 Ruth Mace: r.mace@ucl.ac.uk

13 Marius Warg Næss: marius.naess@niku.no

14 **Author affiliations:**

15 ^a Norwegian Institute for Nature Research (NINA), Arctic Ecology Department, Fram Centre, N-9296
16 Tromsø, Norway

17 ^b Norwegian Institute for Cultural Heritage (NIKU), High North Department, Fram Centre, N-9296
18 Tromsø, Norway

19 ^c Department of Anthropology, University College London, London WC1H 0BW, United Kingdom

20 ^d Lanzhou University, Tianshui S Rd, Chengguan Qu, Lanzhou Shi, Gansu Sheng, China

21 **ORCID iDs:**

22 MGT: 0000-0003-2288-1104

23 DJ: 0000-0001-5746-8761

24 BJB: 0000-0001-6818-5249

25 RM: 0000-0002-6137-7739

26 MWN: 0000-0002-2973-5954

27 **Author contributions:**

28 MGT, DJ, BJB, RM and MWN designed research; MGT and DJ collected data; MGT analyzed data; and

29 MGT, DJ, BJB, RM and MWN wrote the paper.

30 **Keywords:**

31 Evolution of cooperation; social networks; field experiment; social institutions

32

33

34 Significance statement

35 Cooperation in small-scale human societies is often organized around kinship. Patterns of
36 relatedness, socioecological context and subsistence strategies are known to affect the evolution of
37 social institutions promoting cooperation. Communities of reindeer herders in Norway and yak
38 herders in China utilize similar institutions to structure their cooperation: herding groups composed
39 of related and unrelated individuals. Despite vast differences between the study areas, we show that
40 these independently evolved institutions are associated with similar patterns of cooperation,
41 whereby herders prefer to cooperate with members of their own herding group rather than people
42 belonging to other groups, regardless of kinship. Similarities in social complexity might arise through
43 convergent cultural evolution due to the needs and problems arising from a pastoralist adaptation.

44 Abstract

45 Evolutionary studies of cooperation have shown how socioecological context shapes the extent to
46 which individuals help kin and non-kin. Pastoralists—people who make their living from herding
47 livestock—traditionally rely on networks of cooperating households containing relatives and others.
48 These herding groups provide examples of the independent emergence of similar social institutions
49 for organizing cooperation, despite the ecological, geographic and political differences in different
50 parts of the world. To shed light on how socioecological differences and commonalities affect these
51 social institutions, we compared cooperative decision-making using gift games for 1,404 pastoralists
52 across six sites in two countries (Saami areas in Norway and Tibetan areas in China). Members of the
53 same herding group received more gifts overall, regardless of kinship; gifts were preferentially given
54 to poorer herders, especially in Tibet. Most variance in gift-giving occurred between study sites, due
55 to differences in the effects of relatedness. Tibetan yak herders were most likely to give gifts to
56 closer relatives belonging to other, geographically distant, herding groups. This pattern was not
57 observed among Saami reindeer herders; instead, gifts went to close relatives within the same
58 herding groups. Pastoralists cooperate with kin and non-kin within and between social groups in
59 nuanced and complex ways, indicative of a multilevel structure resulting from this subsistence
60 strategy. Our results form the first large-scale comparative study of social complexity in pastoralist
61 cooperation, revealing the importance of social ties beyond the family and the centrality of herding
62 groups as a general pattern for social organization among pastoralists.

63 Introduction

64 Empirical studies of social evolution in humans have shown how cooperative interactions among kin
65 of varying degree, as well as non-kin, are shaped in part by social and ecological contexts (1–14).
66 Previous studies have found more between-group than within-group variability in cooperativeness,
67 where ‘groups’ can refer to societies in different countries (6), ethnic groups in the same country
68 (14), or villages and camps within a single ethnic group (1, 8). Researchers disagree about the extent
69 to which this variation is driven by differences in market integration and stable society-wide cultural
70 norms (6), or more localized differences in demography (8) or expectations of trust and fairness (15).
71 Studies to date have not analyzed cross-cultural variation in cooperation among populations
72 following similar subsistence strategies and social organization, but where there are vast differences
73 in country-level social, political and ecological contexts. To address this gap, we examine variation in
74 cooperative behavior within and between groups of pastoralists living in Norway and China.

75 Assortment is fundamental for cooperation to evolve, and social networks are shaped by individuals
76 clustering on a number of dimensions, including reciprocal benefits, shared genes, reputations, need,
77 or the ‘market value’ of potential social partners (16–18). Disruptions to socioecological systems can

78 have unforetold consequences on social networks, especially for smaller-scale societies whose
79 members rely on flexible cooperative interactions with others to survive and thrive: a pertinent
80 example being pastoralists. Pastoralists often find themselves socially marginalized and tend to
81 inhabit marginalized areas not well-suited to other subsistence strategies, such as farming. Many
82 herders are experiencing challenges due to climate change, pasture fragmentation, changes in land
83 tenure, globalization, and threats to their way of life. Although strategies of subsisting on herd
84 animals have existed in various forms for thousands of years (19) little is known about the patterns
85 and processes of contemporary pastoralist cooperation in different socioecological contexts.

86 Pastoralists around the world tend to organize their labor in cooperative herding groups (20). These
87 groups are typically formed of several related households, allowing herders to pool risk, achieve
88 economies of scale, and survive in otherwise uncertain environments, while also facilitating
89 communication, monitoring and sanctioning (20–23). Within their social networks, pastoralists rely
90 on herding group members over and above relatives (24); however, these groups often include close
91 kin, suggesting a role for inclusive fitness benefits as a byproduct of assortment regardless of direct
92 cooperative interactions. Social norms also affect cooperation among herders. Pastoralist groups in
93 eastern Africa, for example, have developed norms allowing those in need to freely borrow livestock
94 from herding partners with a surplus of animals, without obligations to repay (4); others leverage
95 their friendship networks to recruit raiding partners (25).

96 Saami herders in Norway and herders on the Qinghai-Tibetan Plateau (QTP) in China utilize similar
97 social institutions: cooperative groups—called *siida* in the Saami languages (26) and *ru skor** on the
98 QTP (27)—that collaborate on herding tasks and share pastures at certain times of year. Pastoralism
99 in Saami areas of Norway and on the QTP varies greatly in scale and extent. Reindeer herding
100 encompasses approximately 120,000 km² (> 40% of mainland Norway), with a little over 3,000
101 herders owning ~250,000 reindeer (28). There are around 5 million Tibetan herders owning 12
102 million yaks and 30 million goats and sheep, with over 1.6 million km² of rangelands (~64% of QTP in
103 China; see (29) and SI Text).

104 Organization of winter pastures in Finnmark, Norway, shifted in the late 1970s from a customary land
105 tenure system to a commons system; today, winter pastures are in the process of becoming
106 privatized or semi-privatized. Following the 1854 Reindeer Law for Finnmark, reindeer herding was
107 formally (and physically) separated into different summer districts: pasture areas that can consist of
108 several summer *siidas*, bounded by fences. In contrast, winter pastures are currently being
109 reorganized primarily through establishing fixed winter *siida* grazing boundaries and user rules (30).
110 Rangelands on the QTP were leased to households starting in the early 1990s, based on the number
111 of inhabitants and are enclosed by fences. By the end of 2003 around 70% of China’s usable
112 rangeland was leased through long- term contracts, where 68% was contracted to individual
113 households and the rest to groups of households or to villages, although estimates vary (31). In the
114 study area, winter pastures were first contracted to individual households whereas the summer
115 pastures were contracted to a maximum of three households (32). There are also households grazing
116 separately from others, both in winter and summer areas; the preference for herding alone has been
117 increasing since privatization was introduced. Given these differences, we expect that the spatial
118 constraints and shared borders in Finnmark would necessitate higher levels of between-group
119 cooperation and coordination to ameliorate issues such as mixing of herds, compared to the
120 situation on QTP.

* Spelling varies: others use *Ru Rogs* or *Ru 'Khor* (51), *Ru sKor* (52), or *repkor* (53). Note, we will also use ‘QTP’ and ‘Tibet’ interchangeably.

121 To investigate variation in cooperative herding behavior within and between countries, we analyzed
122 data from 212 reindeer herders in 33 herding groups across summer and winter districts within two
123 zones in Finnmark, northern Norway and 1,192 yak herders from 172 herding groups in four villages
124 in Maqu county, on the eastern part of QTP. We employed a gift allocation task to reveal the
125 structure of existing social relationships, as used in groups of hunter-gatherers (1, 33) and
126 pastoralists (24, 25). In these gift games, participants anonymously distributed an endowment to at
127 least one other person (see Methods). Previous studies found that herders gave gifts to social
128 partners who were members of their herding group and/or relatives, people reputed to be high-
129 quality partners, young people new to the lifestyle (24), or people who were high status in terms of
130 wealth and leadership (25).

131 Despite the ecological, social and political differences between China and Norway, there are several
132 similarities making these two pastoralist systems worthy of comparison. In both regions, pastoralists
133 face similar social dilemmas that require a balance between individual interests and collective
134 interests (34), in addition to their similarities in social organization beyond the household that we
135 explore here. The main question driving this comparative study is: What combinations of kin and
136 non-kin in the same herding group or other herding groups are important for cooperation? We
137 predict that, across all sites, members of the same herding group will be preferentially chosen as gift
138 recipients, especially when they are relatives. We also explore the similarities and differences in
139 patterns of gift-giving between sites; as in the studies cited above, we expect variation to be greater
140 between groups than within.

141 Results and Discussion

142 In total, 755 participants gave a total of 1,214 gifts (Table 1). Models of the gift networks include only
143 the gift game players as ‘egos’ (i.e. potential givers) but all herders as ‘alters’, producing 219,112
144 within-site dyads. There were 28-60 herding groups in the four Tibetan sites, 24 winter groups in one
145 Saami site and nine summer groups in the other. The mean number of people in the Tibetan groups
146 ranged from 3.98 [± 1 standard deviation (SD) = 4.26] to 12.46 (SD=18.05), and in the Saami groups
147 ranged from 5.71 (SD=3.33) to 8.33 (SD=4.72). There were no differences in mean group relatedness
148 between the sites (Table 1).

149 Reindeer herders in Finnmark gave 74.1% of their 147 gifts to members of the same herding group,
150 while yak herders in Tibet gave 40.6% of 1,067 gifts to members of the same group (Fig. S1). In
151 Norway, the average amount received was \$10.61 purchasing power parity (PPP); the maximum
152 amount received by any one herder was \$122.13 PPP. The average amount received in China was
153 \$2.38 PPP, with the maximum amount received being \$33.18 PPP. Table S1 summarizes gifts by site.

154 *Siidas* and *ru skor* were predominately composed of at least first cousins ($r \geq 0.125$) as well as non-
155 kin (Fig. S2). In the Tibetan sites, approximately equal numbers of close kin (grandparents, parents,
156 siblings and children; $r \geq 0.25$) belonged to other herding groups, whereas few close family
157 members worked for other groups in Finnmark. Proportionally more gifts were given to non-kin on
158 the QTP (range across the four sites: 61.5% – 70.5%) and in Karasjok, Finnmark (53.5%; Fig. S3).

159 The Kautokeino site in Finnmark appears to be an outlier in terms of gift-giving behavior, with the
160 majority of gifts (77.6%) going to relatives rather than non-kin. This may be in part due to the
161 recognition of distantly related herders (r between 0.0078 and 0.0630; Fig. S2), which may have
162 occurred because of different data collection techniques in this site (see SI Methods) or due to there
163 being no upper limit on number of gift recipients (see Methods). However, the Kautokeino data

164 focused specifically on cooperation in winter *siidas*, which tend to be smaller and more family-
165 oriented groups (26).

166 Across all study sites in both regions, relatedness and herding group co-membership positively
167 predicted gift-giving, while the interaction term was negative (Fig. 1; Tables S2 and S3). Taken
168 together, the predicted probabilities of gift giving as relatedness and group membership co-vary
169 reveal similarities and differences within and between countries (Fig. 2). Across locations, members
170 of the same herding group were more likely to receive gifts compared to people belonging to other
171 groups. In the two sites in Finnmark, herders preferred to give gifts to members of their herding
172 group regardless of relatedness, although closer kin in the same *siida* were the most likely to receive
173 gifts. This pattern matches district-level evidence that kinship structures reindeer herders'
174 cooperation and productivity (21).

175 Non-kin and distant kin in the QTP sites were more likely to receive gifts if they belonged to the same
176 herding group as the giver. Yak herders were slightly more likely to give gifts to close kin belonging to
177 other herding groups (Fig. 2); *ru skor* can be spread over great distances meaning that it is difficult to
178 provision these kin. Close kin in the same herding group are geographically and psychologically close,
179 and may be considered members of the same household who might be supported by other means.

180 As in previous cross-cultural studies of cooperation (6, 8, 14), there was more variance between sites
181 than within, and in this case there was almost no variation between individuals within sites (Table 2
182 and S5). In the best-fitting model (Fig. 1), 46.4% of the variance was explained by the between-site
183 differences in the interaction between relatedness and herding group membership, while the varying
184 slopes for relatedness explained a further 24.2% (Table 2 and S5). In a null model with only varying
185 intercepts for egos nested in sites, 85.5% of the variance was explained by differences between sites
186 (Table S5). Overall, there were no systematic biases in parameter estimates or variances across sites
187 (Fig. 1).

188 Despite being given anonymously, gifts were reciprocated at higher rates than expected by chance,
189 especially among herders in the two sites in Finnmark, where 26.32 - 28.17% of gifts were
190 reciprocated (Fig. S4). There was strong assortment on gift giving within herding groups, with
191 assortativity coefficients ranging from 0.56 to 0.82 in Finnmark and from 0.26 to 0.61 in Tibet.
192 Participants did not preferentially give gifts to same-sex herders in most of the study sites, with the
193 exception of Jilehe and Tawa in Tibet; in these two villages, annual average income per household is
194 lower compared to other villages in the China sites and the sex ratio is female-biased once monks are
195 excluded, suggesting that collaboration within genders is more important in these areas. In the two
196 Saami sites, the lack of assortment on sex is likely due to male-bias as a consequence of most
197 licensed herders being males (35).

198 Modularity—a measure of how a network can be partitioned into communities (36, 37)—in the four
199 Tibetan sites was higher than expected by chance, implying a stronger community structure featuring
200 dense clusters of individuals giving gifts to one another (Fig. S4). In Karasjok, modularity was slightly
201 lower than expected by chance, with only 4.9% of the randomly generated modularity scores being
202 less than observed modularity; modularity scores in Kautokeino were indistinguishable from chance.
203 This suggests more instances of cooperation between clusters of herders in Finnmark compared to
204 Tibet, potentially resulting from increased interdependence due to larger per-capita herds operating
205 in a more spatially constrained environment.

206 Saami pastoralists kept larger herds compared to people on the QTP (Fig. S5). Inequality in herd sizes,
207 measured as Gini coefficients, are higher within the Tibetan sites (range: 0.385 – 0.454) than within
208 Finnmark (range: 0.257 – 0.292); Tibetan Gini coefficients are slightly lower (i.e. higher equality) than

209 reported by ref. (38). Across sites, herders receiving more gifts had below-average herd sizes (Fig. 3
210 and S6), indicating that gifts tended to go to poorer herders, contrary to patterns observed among
211 East African pastoralists, who gave gifts to wealthier social partners (25). This pattern was not
212 associated with age (Fig. S6 and Table S4) and it likely driven by the Tibetan herders' general
213 preference to give gifts to poorer herders, as stated during their interviews; there is no association
214 between gifts and herd size in either of the Saami sites (results not shown). Between-subject
215 differences accounted for almost all variance in predicting herd size (99.6%); there was almost no
216 variation between sites (0.4%; Fig. S7).

217 An individual's position in their social network, as measured by indirect ties (e.g. friends of friends),
218 has been associated with benefits including increased reproductive success (39, 40). We quantified
219 social network position in terms of individuals' betweenness and eigenvector centrality; higher
220 betweenness scores mean that an individual acts as a bridge or broker between otherwise
221 unconnected people, while higher eigenvector centrality means that individuals are connected to
222 other well-connected people (39). These measures of indirect connections were not associated with
223 herd sizes (Table S4), suggesting that direct social bonds (i.e. gifts, in this case) are more important
224 for pastoralist cooperation than how herders are connected to third parties and beyond.

225 Despite deep social, political and ecological differences between the countries, pastoralists in
226 Norway and China follow similar subsistence strategies and have evolved similar social complexity in
227 terms of institutions that shape cooperative networks. Through analyzing the social networks that
228 emerged from allocation decisions in an economic game, we found although that most variation in
229 gift giving occurred between sites, there were comparable patterns within the same country as well
230 as broad similarities regardless of location. Pastoralists strongly depended on members of their
231 herding groups, especially close relatives. Social network structure beyond dyadic ties was not
232 associated with herd productivity, in terms of number of animals owned. Overall, herders rely on a
233 combination of kin (21) and the social institution of their herding group (20, 34, 41).

234 Future research should tie in observational measures of cooperation—especially costly forms of
235 cooperation, e.g. labor investment—as well as measures of reproductive success to produce a more
236 comprehensive evolutionary account of social behavior in pastoralist societies. Beyond pastoralism,
237 our results have relevance for the role of social institutions, population structure and the multilevel
238 organization of human communities (42) in shaping observed similarities and variation across cultural
239 groups adopting comparable adaptive lifeways.

240 Methods

241 The research in Tibet and in Karasjok, Norway, was approved in part by the University College
242 London research ethics committee. Fieldwork in Kautokeino, Norway, was undertaken in accordance
243 with the “General guidelines for research ethics” as stipulated by the Norwegian National Research
244 Ethics Committee (NNREC; <https://www.etikkom.no/en/>). Specifically, interviews were undertaken
245 in accordance with NNREC's ethical checklist by: (1) obtaining written informed consent; (2) ensuring
246 that no dependent relationship exists that could influence the subjects' decision to give consent; and
247 (3) guaranteeing anonymity and confidentiality of the informants.

248 See SI Text for descriptions of the study sites and data collection procedures.

249 Gift games

250 Participants were endowed with a fixed sum and were asked to give everything away to at least one
251 other person; they were not allowed to keep anything for themselves. Herders in QTP and Karasjok,
252 Finnmark, could give their endowment to a maximum of three people; there was no limit in

253 Kautokeino, but the median number of gifts given away was two (the maximum given by any one
254 herder was 7 gifts). In Finnmark, participants could only give gifts to licensed herders within their
255 district (*siidaandeler*; effectively heads of households). In Tibet, participants could give to anybody in
256 their village except for people living in their household. See SI Text for further discussion.

257 Participants in China were endowed with 15 yuan (\$4.33 purchasing power parity [PPP] in July 2015);
258 herders in Karasjok, Norway, were given vouchers representing 15 liters of petrol (225 Norwegian
259 kroner; \$24.92 PPP in July 2013); herders in Kautokeino, Norway, were endowed with 35 liters in
260 petrol vouchers (525 NOK; \$52.34 PPP in July 2016). PPP amounts were calculated from the OECD's
261 indicators for the relevant years and countries (43); see Table S1.

262 Statistical analyses

263 To analyze gift decisions, we fit Bayesian multilevel logistic regressions with varying intercepts for gift
264 game participants nested within study sites. This model structure allows us to estimate site-level
265 effects as well as control for the non-independence of potential gift givers in dyads (44, 45); similar
266 model structures have been used in previous studies employing gift games (1, 24). A subset of
267 models also included varying slopes for sites in order to estimate the different effects of relatedness
268 and group membership between areas (44, 46).

269 For the social network analysis of herding success, we fitted Bayesian multilevel linear regressions
270 with varying intercepts for study site to predict herd size z-scores (see Table S2 for specifications).
271 Herd sizes were standardized to mean = 0 over 1 standard deviation, grouped within sites, to allow
272 direct comparison across countries given the order of magnitude difference in livestock ownership
273 (Fig. S5).

274 All models were run for 2,000 iterations, discarding the first half as warm-up. We fitted one chain for
275 models of gift giving (due to the computational and temporal constraints of fitting such complex
276 models to a large dataset) and four chains for the social network analysis. We checked that \hat{R} scores
277 (the potential scale reduction factor, measuring convergence of chains) were close to 1.0 (they were
278 in all cases).

279 For model selection in both regression analyses, we compared the approximate leave-one-out cross-
280 validation information criteria (47)—an estimate of out-of-sample-predictive fit—and calculated
281 model weights by stacking posterior predictive distributions (48); in both cases, we selected the
282 model carrying most weight for analyses presented here. All models were fitted in R 3.3 (49) using
283 the packages *rstanarm* (49) and *loo* (47, 48); social network statistics were calculated with *iGraph*
284 (50). See SI Text for details of model specifications. Data are deposited in [URL; DOI] and code to
285 reproduce our analyses is available from <https://github.com/matthewgthomas/hierarchies-gifts/>

286 Acknowledgements

287 We thank the reindeer and yak herders for their help and their patience. Thanks also to our field
288 assistants in Norway (Ida Ophaug and Jon Mikkel Eira) and in China (Bai Pengpeng, Jiu Cili, Gong Bao
289 Cao and Zhou Liqong). M.W.N. and B.J.B. were financed by “HIERARCHIES”, funded by the Norwegian
290 Research Council (project number: 240280). M.W.N., B.J.B. and M.G.T. were financed by “ReiGN:
291 Reindeer Husbandry in a Globalizing North – Resilience, Adaptations and Pathways for Actions”,
292 which is a Nordforsk-funded “Nordic Centre of Excellence” (project number 76915). D.J. was funded
293 by the China Scholarship Council. D.J., M.G.T. and R.M. received funding from European Research
294 Council Advanced Grant AdG 249347. R.M. was also funded by Lanzhou University.

295 References

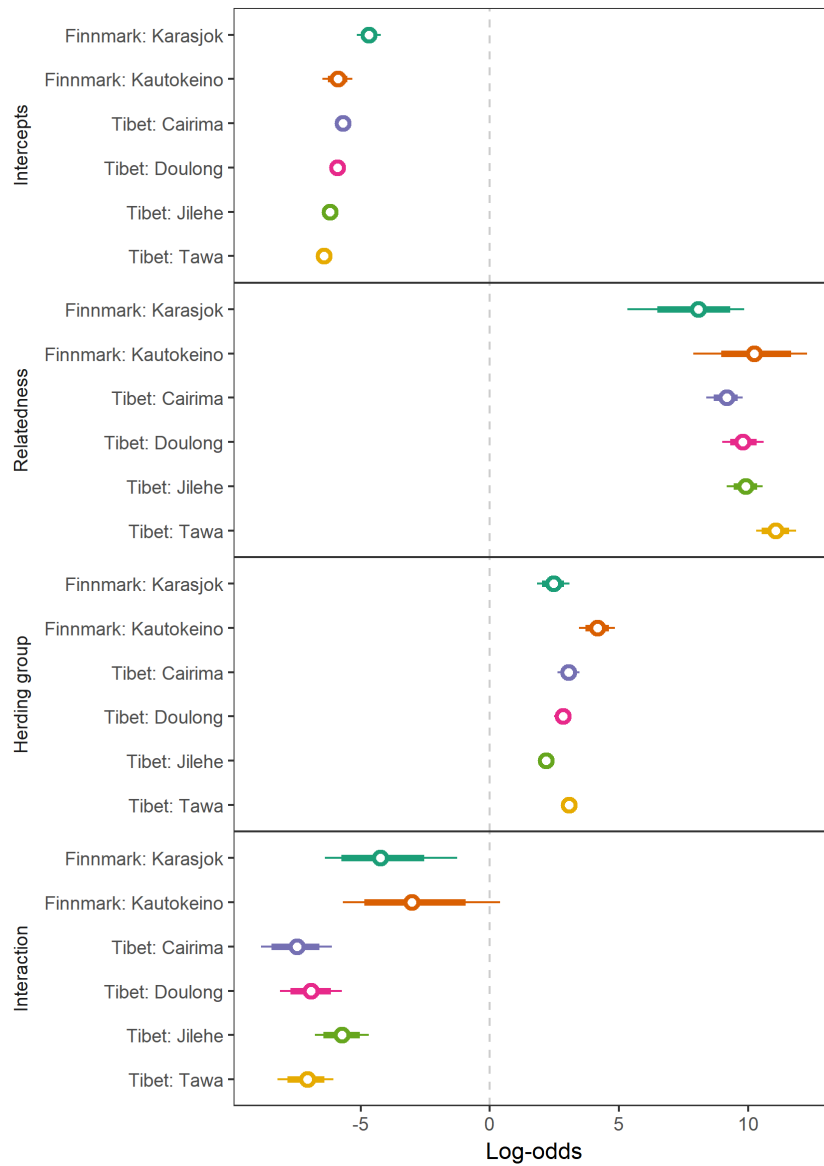
- 296 1. Apicella CL, Marlowe FW, Fowler JH, Christakis NA (2012) Social networks and cooperation in
297 hunter-gatherers. *Nature* 481(7382):497–501.
- 298 2. Balliet D, Lange PAM Van (2013) Trust, punishment, and cooperation across 18 societies: A
299 meta-analysis. *Perspect Psychol Sci* 8(4):363–379.
- 300 3. Buchan NR, et al. (2009) Globalization and human cooperation. *Proc Natl Acad Sci U S A*
301 106(11):4138–4142.
- 302 4. Cronk L (2007) The influence of cultural framing on play in the trust game: A Maasai example.
303 *Evol Hum Behav* 28(5):352–358.
- 304 5. Gerkey D (2013) Cooperation in context: Public goods games and post-Soviet collectives in
305 Kamchatka, Russia. *Curr Anthropol* 54(2):144–176.
- 306 6. Henrich J, et al. (2005) “Economic man” in cross-cultural perspective: Behavioral experiments
307 in 15 small-scale societies. *Behav Brain Sci* 28:795–855.
- 308 7. Herrmann B, Thöni C, Gächter S (2008) Antisocial punishment across societies. *Science (80-)*
309 319(5868):1362–1367.
- 310 8. Lamba S, Mace R (2011) Demography and ecology drive variation in cooperation across
311 human populations. *Proc Natl Acad Sci* 108(35):14426–14430.
- 312 9. Leibbrandt A, Gneezy U, List J a (2013) Rise and fall of competitiveness in individualistic and
313 collectivistic societies. *Proc Natl Acad Sci U S A*. doi:10.1073/pnas.1300431110.
- 314 10. Prediger S, Vollan B, Frölich M (2011) The impact of culture and ecology on cooperation in a
315 common-pool resource experiment. *Ecol Econ* 70(9):1599–1608.
- 316 11. Ruffle BJ, Sosis R (2006) Cooperation and the in-group-out-group bias: A field test on Israeli
317 kibbutz members and city residents. *J Econ Behav Organ* 60(2):147–163.
- 318 12. Silva AS, Mace R (2014) Cooperation and conflict: field experiments in Northern Ireland. *Proc*
319 *R Soc B Biol Sci* 281:20141435.
- 320 13. Smith D, et al. (2016) Camp stability predicts patterns of hunter-gatherer cooperation. *R Soc*
321 *Open Sci* 3:160131.
- 322 14. Wu J-J, Ji T, He Q-Q, Du J, Mace R (2015) Cooperation is related to dispersal patterns in Sino-
323 Tibetan populations. *Nat Commun* 6:8693.
- 324 15. Gurven M, Zanolini A, Schniter E (2008) Culture sometimes matters: Intra-cultural variation in
325 pro-social behavior among Tsimane Amerindians. *J Econ Behav Organ* 67(3–4):587–607.
- 326 16. Fletcher JA, Doebeli M (2009) A simple and general explanation for the evolution of altruism.
327 *Proc R Soc London* 276(September 2008):13–19.
- 328 17. Allen B, et al. (2017) Evolutionary dynamics on any population structure. *Nature* 544:227–230.
- 329 18. Nowak MA, May RM (1992) Evolutionary games and spatial chaos. *Nature* 359:826–829.
- 330 19. Honeychurch W, Makarewicz CA (2016) The Archaeology of Pastoral Nomadism. *Annu Rev*
331 *Anthropol* 45(1):341–359.
- 332 20. Næss MW (2012) Cooperative pastoral production: Reconceptualizing the relationship
333 between pastoral labor and production. *Am Anthropol* 114(2):309–321.

- 334 21. Næss MW, Bårdsen B-J, Fauchald P, Tveraa T (2010) Cooperative pastoral production - The
335 importance of kinship. *Evol Hum Behav* 31(4):246–258.
- 336 22. Mace R (1998) The coevolution of human fertility and wealth inheritance strategies. *Philos*
337 *Trans R Soc B Biol Sci* 353(1367):389–397.
- 338 23. Aktipis A, Cronk L, Aguiar R (2011) Risk-pooling and herd survival: An agent-based model of a
339 Maasai gift-giving system. *Hum Ecol* 39(2):131–140.
- 340 24. Thomas MG, Næss MW, Bårdsen B-J, Mace R (2015) Saami reindeer herders cooperate with
341 social group members and genetic kin. *Behav Ecol* 26(6):1495–1501.
- 342 25. Glowacki L, et al. (2016) Formation of raiding parties for intergroup violence is mediated by
343 social network structure. *Proc Natl Acad Sci* 113(43):12114–12119.
- 344 26. Paine R (1994) *Herds of the Tundra: A Portrait of Saami Reindeer Pastoralism* (Smithsonian
345 Institution Press, London).
- 346 27. Nietupski PK (2012) *Labrang Monastery: A Tibetan Buddhist Community on the Inner Asian*
347 *Borderlands, 1709-1958* (Lexington Books, Plymouth).
- 348 28. Anonymous (2016) *Ressursregnskap for Reindriftsnæringen (Ecological statistics of reindeer*
349 *husbandry)*.
- 350 29. Næss MW, Bårdsen B (2016) Why do Tibetan pastoralists hunt? *Land use policy* 54:116–128.
- 351 30. Næss MW (2017) Reindeer herding in a changing world—A comparative analysis. *Arcticness*
352 *and Change: Power and Voice from the North*, ed Kelman I (UCL Press, London), pp 59–75.
- 353 31. Naess MW (2013) Climate change, risk management and the end of Nomadic pastoralism. *Int*
354 *J Sustain Dev* 20(2):123–133.
- 355 32. Cao J, Yeh ET, Holden NM, Yang Y, Du G (2013) The effects of enclosures and land-use
356 contracts on rangeland degradation on the Qinghai-Tibetan plateau. *J Arid Environ* 97:3–8.
- 357 33. Chaudhary N, et al. (2015) Polygyny without wealth: Popularity in gift games predicts
358 polygyny in BaYaka Pygmies. *R Soc Open Sci* 2:150054.
- 359 34. Thomas MG, Næss MW, Bårdsen B-J, Mace R (2016) Smaller Saami herding groups cooperate
360 more in a public goods experiment. *Hum Ecol*. doi:10.1007/s10745-016-9848-3.
- 361 35. Lwi SJ, Ford BQ, Casey JJ, Miller BL, Levenson RW (2017) Poor caregiver mental health predicts
362 mortality of patients with neurodegenerative disease. doi:10.1073/pnas.1701597114.
- 363 36. Fortunato S (2010) Community detection in graphs. *Phys Rep* 486(3–5):75–174.
- 364 37. Newman MEJ (2006) Modularity and community structure in networks. *Proc Natl Acad Sci*
365 103(23):8577–8582.
- 366 38. Levine NE (2015) Transforming inequality: Eastern Tibetan pastoralists from 1955 to the
367 present. *Nomad People* 19(2):164–188.
- 368 39. Brent LNJ (2015) Friends of friends: Are indirect connections in social networks important to
369 animal behaviour? *Anim Behav* 103:211–222.
- 370 40. Page AE, et al. (2017) Hunter-gatherer social networks and reproductive success. *Sci Rep*
371 7(1):1153.
- 372 41. Dyson-Hudson R, Dyson-Hudson N (1980) Nomadic pastoralism. *Annu Rev Anthropol* 9:15–61.

- 373 42. Dyble M, et al. (2016) Networks of food sharing reveal the functional significance of multilevel
374 sociality in two hunter-gatherer groups. *Curr Biol* 26:1–5.
- 375 43. OECD (2017) Purchasing power parities (PPP) (indicator). doi:10.1787/1290ee5a-en.
- 376 44. McElreath R (2016) *Statistical Rethinking: A Bayesian Course with Examples in R and Stan* (CRC
377 Press) Available at: <https://books.google.no/books?id=mDo0CwAAQBAJ>.
- 378 45. Gelman A, et al. (2013) *Bayesian Data Analysis, Third Edition* (Taylor & Francis) Available at:
379 <https://books.google.no/books?id=ZXL6AQAQBAJ>.
- 380 46. Schielzeth H, Forstmeier W (2009) Conclusions beyond support: overconfident estimates in
381 mixed models. *Behav Ecol* 20(2):416–420.
- 382 47. Vehtari A, Gelman A, Gabry J (2016) Practical Bayesian model evaluation using leave-one-out
383 cross-validation and WAIC. *Stat Comput*:1–20.
- 384 48. Yao Y, Vehtari A, Simpson D, Gelman A (2017) Using stacking to average Bayesian predictive
385 distributions. Available at: <http://arxiv.org/abs/1704.02030>.
- 386 49. R Core Team (2012) R: A Language and Environment for Statistical Computing. Available at:
387 <http://www.r-project.org/>.
- 388 50. Csardi G, Nepusz T (2006) The igraph software package for complex network research.
389 *InterJournal Complex Syst*:1695.
- 390 51. Levine NE (1995) From nomads to ranchers: Managing pasture among ethnic Tibetans in
391 Sichuan. *Development, Society and Environment in Tibet, Proceedings of the Seventh Seminar*
392 *of the International Association for Tibetan Studies, Graz*, pp 69--119.
- 393 52. Ekvall RB (1968) *Fields on the Hoof: Nexus of Tibetan Nomadic Pastoralism* (Holt, Rinehart and
394 Winston, New York).
- 395 53. Pirie F (2005) Segmentation within the state: The reconfiguration of Tibetan tribes in China's
396 reform period. *Nomad People* 9(1):83–102.
- 397
- 398
- 399
- 400

401 Figures

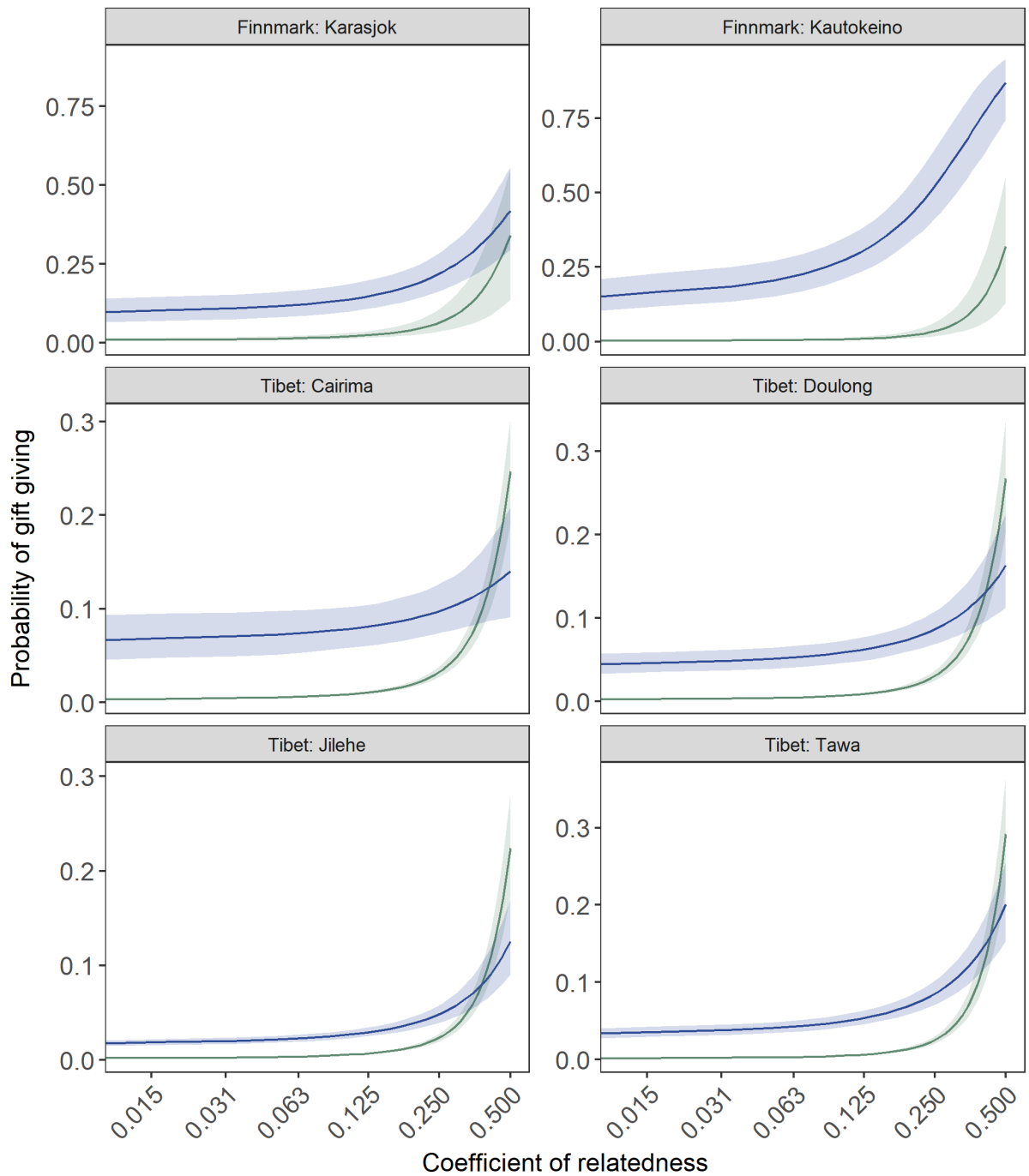
402 Fig. 1: Log-odds from the best-fitting multilevel logistic model predicting gift giving; this model
 403 contains varying intercepts and varying slopes (Table S1). Points show medians, colored by study site;
 404 thick lines are 80% credible intervals; and thin lines are 95% credible intervals. Top panel shows
 405 varying intercepts for each site (intercepts for individuals within sites not shown); remaining panels
 406 show slopes for each predictor, varying by site. Grey dotted line represents no effect; each
 407 parameter estimate was statistically distinguishable from log-odds = 0. Parameter estimates and
 408 variances are shown in Table S3; Fig. 2 shows predictions from this model.



409

410

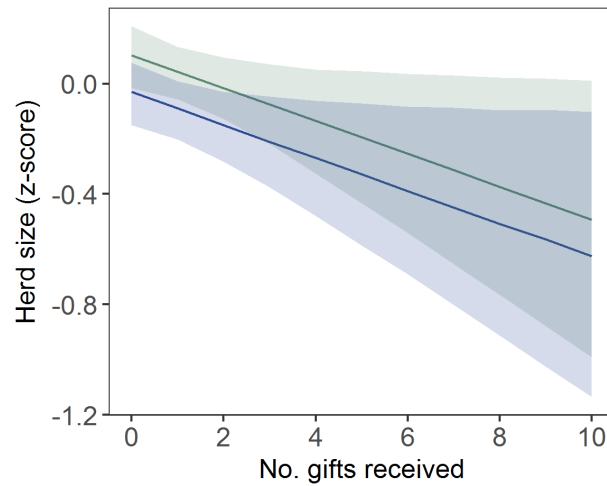
411 Fig. 2: Predicted probabilities of gift giving by coefficient of relatedness (x axis) and whether a dyad
 412 belongs to the same herding group (blue) or not (green). Lines represent median probabilities from
 413 the best-fitting multilevel model (Fig. 1 and Table S2); shaded areas are 95% credible intervals. Note
 414 that the y-axis ranges differ for Finnmark, Norway and Tibet, China; x-axes are plotted on a log scale.



415

416

417 Fig. 3: Predicted herd size (standardized) from number of gifts received (in-degree in the gift
418 network) for males (green) and females (blue). The model was fitted on the subset of 1,071 herders
419 for whom we had information about age, sex, and herd size. See Methods for model specification
420 and Table S4 for the candidate set of models. Lines show parameter estimate medians and shaded
421 ribbons are 95% credible intervals. See Table 1 for standard deviations in herd size to ease
422 interpretation of these z-scores.



423
424
425

426 Tables

427 Table 1: Descriptive statistics of the samples in each site. ‘Mean r in groups’ refers to the grand mean
 428 coefficient of relatedness within each herding group within study sites.

Study site	N	No. givers	No. gifts	No. groups	Mean (SD) N in groups	Mean r in groups	Mean (SD) herd size
Finmark: Karasjok	75	30	71	9	8.33 (4.72)	0.19	438.67 (185.38)
Finmark: Kautokeino	137	30	76	24	5.71 (3.33)	0.07	431.03 (195.27)
Tibet: Cairima	239	138	212	60	3.98 (4.26)	0.17	49.24 (42.92)
Tibet: Doulong	256	147	212	50	5.12 (5.57)	0.17	52.79 (39.38)
Tibet: Jilehe	349	213	342	28	12.46 (18.05)	0.09	75.26 (54.66)
Tibet: Tawa	348	197	301	34	10.24 (11.69)	0.15	60.24 (45.66)
Totals	1,404	755	1,214	205	—	—	—

429

430 Table 2: Estimated variances and variance partition coefficients (VPCs) for varying intercepts and
 431 slopes in the best-fitting multilevel model (Table S2). Parentheses show standard deviations of the
 432 variance estimates; note that this was not calculated for the population average intercept, as this
 433 was a logistic regression without an error term.

Variance component	Variance	VPC
Population-average intercept	0.133	1.80 %
Egos nested in sites intercepts	0.002 (0.05)	0.03 %
Study site intercepts	0.679 (0.82)	9.22 %
Relatedness slopes	1.78 (1.33)	24.16 %
Herding group membership slopes	1.358 (1.17)	18.44 %
Relatedness × herding group slopes	3.414 (1.85)	46.36 %

434

435