Evolutionary Human Sciences (2026), **8**, e41, page 1 of 16
doi:10.1017/ehs.2026.10071



RESEARCH ARTICLE

Explaining the decline of *impal* marriage among the Karo: an epidemiological approach

Geoff Kushnick[1], Sam Passmore[2,3], Fikarwin Zuska[4], Karmila br. Karo[5] and Daniel M.T Fessler[6,7,8]

[1]School of Archaeology and Anthropology, Australian National University, Canberra, Australia; [2]Evolution of Cultural Diversity Initiative, Australian National University, Canberra, Australia; [3]School of Culture, History, and Language, Australian National University, Canberra, Australia; [4]Departemen Antropologi, Fakultas Ilmu Sosial dan Ilmu Politik, Universitas Sumatera Utara, Medan, Indonesia; [5]Balai Pelestarian Kebudayaan Wilayah II Medan, Kementerian Kebudayaan Republik Indonesia, Medan, Indonesia; [6]Department of Anthropology, University of California, Los Angeles, CA, USA; [7]UCLA Center for Behavior, Evolution, & Culture, University of California, Los Angeles, CA, USA and [8]UCLA Bedari Kindness Institute, University of California, Los Angeles, CA, USA
Corresponding author: Geoff Kushnick; Email: geoff.kushnick@anu.edu.au

Abstract
The Karo people of North Sumatra, Indonesia, have long expressed a preference for matrilateral cross-cousin (*impal*) marriage, yet the practice has declined sharply over the past century. To identify the demographic and socio-cultural factors underlying this change, we applied an epidemiological approach to cultural evolution, using a case–control design coupled with structural equation modelling. Ethnographic data from 176 married individuals across 62 villages were analysed to assess the effects of demographic, alliance, religious, cosocialisation, and modernisation variables on the likelihood of *impal* marriage. The model fit was strong (Comparative Fit Index = 0.96, Root Mean Square Error of Approximation = 0.04), revealing significant direct and indirect effects. Marrying an *impal* was positively associated with the number of marriageable *impal* and with arranged or strategically motivated unions, but negatively associated with reported religious conflict between spouses. Indicators of modernisation such as schooling and infrastructure were non-significant. These results indicate that the decline of *impal* marriage likely reflects demographic contraction and the weakening of alliance-based strategies rather than a rejection of the cultural norm itself. Framed within an epidemiological approach to cultural evolution, the findings illustrate how ecological and demographic change may contribute to the decline of culturally-prescribed social practices, even where aspects of the underlying cultural ideal persist.

Keywords: cousin marriage; Indonesia; social change; case–control study; structural equation modelling

Social media summary: Karo cousin marriage decline due to change in demographic and alliance factors, not rejection of the cultural norm.

Introduction

Marriage between relatives has long occupied a central place in anthropological research because it links individual mate choice to broader questions of kinship, alliance formation, inheritance, and social organisation (Levi-Strauss, 1949; Needham, 1986). Although many societies express preferences for particular categories of relatives as spouses, the frequency with which such marriages occur often differs markedly from the idealised patterns described in cultural norms. Understanding why

© The Author(s), 2026. Published by Cambridge University Press. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (http://creativecommons.org/licenses/by/4.0), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.

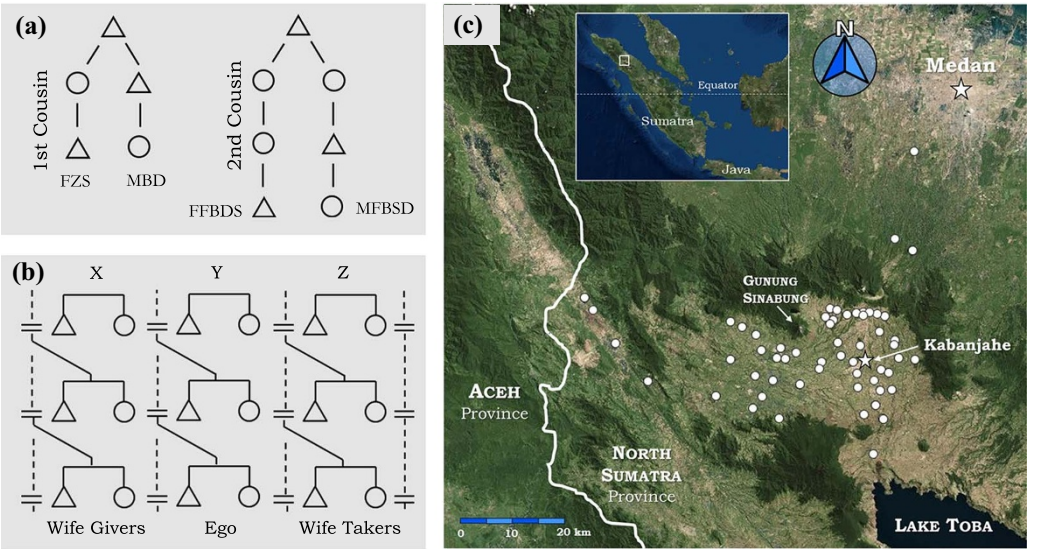


Figure 1. (a) First- and second-cousin forms of proper matrilateral cross-cousin (*impal*) marriage among the Karo; (b) the asymmetrical alliance structure fostered by *impal* marriage, in which X are wife-givers (*kalimbubu*) and Z are wife-takers (*anakberu*) of Y; and (c) the locations of the 62 Karo villages in which data were collected. In the kinship diagrams shown in Panels (a) and (b), triangles represent males, circles represent females, double lines indicate marriage, and lines indicate descent.

marriage preferences persist, weaken, or disappear therefore offers valuable insights into the relationship between cultural prescriptions and observed behaviour. Current marriage patterns within one ethnic group in Indonesia provide an especially informative case, as community members have historically expressed a strong preference for marriage to a particular type of cousin, yet the practice itself has undergone a substantial decline.

The Karo people are a *suku* (ethnic group or tribe) from North Sumatra, Indonesia, with a long-standing stated preference for matrilateral cross-cousin (*impal*) marriage (Kipp, 1993; Kushnick,2006; Kushnick & Fessler, 2011; Singarimbun, 1975; Steedly, 1993). Traditionally, 'proper' *impal* marriages encompass both first cousin (MBD-FZS) and second cousin (MFBSD-FFBDS) unions (Fig. 1a). This preference is embedded within the broader 'circulating connubium' (van Wouden, 1935) or asymmetric alliance systems described by alliance theorists (Leach, 1954; Lévi-Strauss, 1949; Needham, 1986), in which 'wife giver' (*kalimbubu*) and 'wife taker' (*anakberu*) relationships structure a patrilineal social order (Fig. 1b).

Despite its cultural importance, the practice of *impal* marriage has declined markedly over the past century. Archival and village-census data show that while 11–13% of marriages in the 1930s–1960s were proper *impal* unions, this proportion fell to just 3–5% between the 1990s and 2014 (Kushnick et al., 2016). Although marriages to genealogically defined *impal* have become less common, Karo continue to marry other categories of relatives provided clan exogamy is maintained, and spouses may be socially classified as *impal* through clan relationships even when they are not genealogically close *impal*. Since Karo customary law prohibits marrying an *impal* if one's sibling has already done so (Singarimbun, 1975), the maximum historical prevalence was always constrained by demographic realities (Kushnick & Fessler, 2011). Contemporary Karo fertility rates are around 3–4.5 children per woman (Kushnick, 2010). Such a moderate to low fertility rate would significantly limit opportunities to marry one's *impal*. Although historical fertility rates are unknown, it is likely that, as has happened throughout Indonesia, fertility has declined in the modern era, reducing the number of *impal* available as potential marriage partners.

One of the prime goals of cultural evolutionary theory is to understand what factors and causal mechanisms drive social and cultural change (Boyd & Richerson, 2024), and to explain why behaviour changes when the norms driving it remain unchanged (Boyd & Richerson, 1985; Mesoudi, 2011). Within this framework, culture is treated as a system of socially transmitted information that evolves through differential learning, imitation, and payoff-biased adoption. Hypotheses about cultural change are typically tested by examining how variation in transmission pathways, ecological conditions, or social networks alters the frequency of beliefs and behaviours across generations (Henrich & McElreath, 2003; Richerson & Boyd, 2006). Some approaches have focused on people's perceptions and representations, focusing on how ideas and values spread, mutate, and persist even when behaviour diverges from stated norms (e.g., González, 2025). Other approaches emphasise observable behaviour, drawing on methods from human behavioural ecology and demography to study actual choices, actions, and fitness outcomes (e.g., Harris et al., 2021).

Adopting the first of these two approaches, in a study conducted during the same period and at the same locations as the present research, Kushnick et al. (2016) examined Karo perceptions of *impal* marriage through a factorial vignette experiment exploring the effects of demographic and socio-cultural factors on attitudes towards marrying an *impal*. Variables included age, gender, cosocialisation with one's *impal*, availability of marriageable kin, practical alliance advantages, and church opposition. Findings revealed several unexpected patterns: cosocialisation increased both the perceived likelihood of marrying an *impal* and reduced disgust at the prospect; age influenced male and female respondents' disgust judgements in opposite directions; and female respondents placed greater weight on alliance considerations than males. Although participant cosocialization served as an indirect proxy for the early-life experiences hypothesised to underlie the Westermarck Effect, it necessarily encompassed substantial variation in childhood experience, and therefore did not constitute a direct test of the hypothesis. Nevertheless, taken together, these results suggest that the decline of *impal* marriage cannot be fully accounted for by the Westermarck Effect – where sexual aversion develops through early negative imprinting (Fessler, 2007; Kushnick & Fessler, 2011). Likewise, the relatively low levels of third parties' negative emotional reactions to *impal* marriage suggest that valuation of this prescription has not substantially eroded in recent times. Instead, the pattern appears to reflect a complex negotiation among multiple evolutionary conflicts: sexual conflict between men's and women's mating interests, parent–offspring conflict over the timing and choice of marriage partners, and sibling conflict arising when brothers and sisters have competing reproductive or alliance-related goals. Because cousin marriage involves the interests of the spouses' parents, who are siblings, it represents a unique social domain where these conflicts intersect and may be addressed simultaneously (Chagnon et al., 2017; Kushnick, 2023; Kushnick et al., 2016).

To investigate these processes beyond perceptions alone, we melded ethnographic and epidemiological approaches to study cultural change, applying methods typically used in public health to the analysis of marriage practices. Epidemiology has long recognised parallels between disease processes and culture, whether in how culture shapes disease risk (e.g., food habits, beliefs about treatments) (Dressler, 2004) or in the analogy between cultural transmission and the spread of contagion, as in Sperber's (1985) 'epidemiology of representations'. Our approach draws on a third parallel – using epidemiological research designs to study cultural practices themselves. Rather than directly examining the mechanisms through which marriage norms are transmitted across generations, we investigate the demographic and socio-cultural conditions associated with the persistence and decline of a culturally prescribed marriage practice. Our aim is therefore not to identify specific processes of social learning but to understand how changes in demographic opportunity, alliance incentives, religious influences, and other social factors are associated with changes in marriage behaviour. This complements previous work on Karo attitudes towards *impal* marriage by shifting attention from perceptions of the practice to the factors associated with its occurrence.

Specifically, we employed a case–control design, a method well suited to studying rare outcomes (Gamble, 2014; Thiese, 2014), to compare marriages involving *impal* (cases) with those that did not

(controls). In case–control studies, researchers begin with individuals who have experienced a focal outcome (cases) and a comparable group who have not (controls), then work retrospectively to identify factors associated with the outcome. A classic example first identified cigarette smoking as a risk factor for lung cancer by comparing the smoking histories of cancer patients and healthy controls (Paneth et al., 2004). This design allows efficient retrospective analysis of multiple risk factors without requiring large longitudinal samples or waiting for outcomes to emerge. Given the likely interdependence among variables, we paired the case–control approach with structural equation modelling (SEM) to disentangle direct and indirect effects within a unified framework (Amorim et al., 2010; Beran & Violato, 2010; Kline, 2016). While SEM carries strong assumptions, such as potential unmeasured confounding, its exploratory power has been demonstrated in numerous studies integrating case–control designs with complex causal modelling (Gili et al., 2013; Le et al., 2017; Lyu et al., 2016; Oliveira et al., 2019; Porru et al., 2014). Applying this combined approach enabled us to quantify the social, demographic, and cultural factors shaping the decline of *impal* marriage in Karo society.

Methods

Data collection

From March to July 2014, we conducted fieldwork in 62 randomly selected Karo villages across 19 sub-regencies in the Karo and Deli Serdang regencies of North Sumatra (Fig. 1c). (For brevity, we refer to 'we' throughout this section; a credit statement at the end of the manuscript provides more details on the specific contributions of each co-author.) In each village, the village head identified individuals ever married to an opposite-sex *impal* (currently or previously). We interviewed the available spouse (husband, wife, or both) and then randomly selected volunteers from the same village who had never married an *impal* for comparison. In total, 278 individuals were interviewed: 152 who are or were married to their *impal* and 136 who were never married to their *impal*. For analysis, we created a subsample of 176 respondents by excluding those with multiple marriages, retaining only one spouse per couple, and matching the two groups by age class and gender across all sub-regencies as shown in Table 1. This comprised 88 cases (those ever married to *impal*) and 88 controls (those never married to *impal*) (Gamble, 2014; Thiese, 2014). Interviews, conducted privately and lasting 1–1.5 hours, collected information on marriage histories, *impal* relationships, and motivations for, and familial sentiment towards, marital choices. Data were recorded using ODK Collect (v1.3) on Android devices (Hartung et al., 2010).

Probit SEM models

We are using SEM with a probit family link since the main endogenous variable – Is your marriage with a proper *impal*? (bion) – and others are binary (Kline, 2016, p. 44). Probit, like logistic (aka. logit) regression, aims to predict the likelihood of a binary outcome and is expected to give similar results for substantive effects (Aldrich & Nelson, 1984; Hoffmann, 2016). Probit regression coefficients have a different interpretation from logit regression coefficients and cannot be transformed to odds ratios, so we analyse them by indicating significance ($\alpha = 0.05$) and the sign of the effect and then produce marginal effects to aid interpretation. We used the lavaan package in R for SEM analyses, which drove the decision to use probit rather than logit models (Rosseel, 2012).

There are two types of variables in an SEM model: endogenous and exogenous (Amorim et al., 2010; Beran & Violato, 2010; Kline, 2016). An endogenous variable is any measured variable that can be treated as a response somewhere within the model. That is, any measured variable that has an arrow pointing into it. An exogenous variable is any variable that does not have an arrow pointing into it and is treated like an independent variable in a regression. SEM models often also contain unmeasured or latent variables, but we do not use them here. The advantage of SEM is that we can pool variance across the paths of the equations. Rather than treating each predictor as independent,

Table 1. Sample by gender and age class

	Male		Female		
Age class (years)	*impal*	Non-*impal*	*impal*	Non-*impal*	Total
≤30	6	6	9	9	30
31–40	13	13	14	14	54
41–50	17	17	8	8	50
51–60	3	3	8	8	22
≥61	4	4	6	6	20
Total	43	43	45	45	176

the equations are structured in such a way that variance is considered along the structural paths, providing us with better estimates for the relationships of interest.

A limitation of our SEM models is that potential confounding variables were excluded. Given the constraints of the sample size, incorporating too many parameters would have risked overfitting and estimation instability (Kline, 2016; Wolf et al., 2013). While the model prioritises theoretically central variables, the omission of additional confounders means that some residual bias cannot be ruled out (Arif & MacNeil, 2023; Greenland et al., 1999). Spatial clustering similarly cannot be ruled out, but it is unlikely to account for the observed associations as cases and controls were drawn from the same villages. The small number of marriages sampled from each village precluded a formal analysis of spatial clustering at the village level.

To assess the models' goodness of fit, we use two statistics: Comparative Fit Index (CFI) and Root Mean Square Error of Approximation (RMSEA; Schermelleh-Engel et al., 2003). The CFI is a revised form of the Normalised Fit Index, which asks whether the target model is an improvement over the independence model (i.e., an unspecified model). A good rule of thumb is a CFI value >0.9. The RMSEA is a descriptive measure of overall fit. Values closer to 0 represent a good fit, with values less than 0.5 indicative of models that have a close fit to the data (Xia & Yang, 2019). The *p*-value presented with RMSEA tests the hypothesis that it is less than or equal to 0.05 (a cut-off sometimes used for good fit) and thus should be non-significant.

Our approach to building the combined/final SEM model (i.e., with all risk factors and risk factor groups) had elements of exploration. Our original model did not include a connection between Alliance and Cosocialization, treating these groups as independent. This model returned model fit statistics below what is considered satisfactory (CFI = 0.868; RMSEA = 0.083). We added additional links using modification indices. The largest improvement indicated by modification indices was a link from Friends (nnar2) to Marriage Type (nnr1b), with a modification index of 48.644. Rule-of-thumb estimates suggest adding links of >10 if they support theoretical positions. The added link made sense in terms of the overall causal reasoning used to build the original model (i.e., there is a strong link between unarranged marriages being between people who were friends prior to getting married), and it is the only difference between the original and the one used for final inference (see Supplementary Material). Adding this link improved model fit to above the rule-of-thumb thresholds (CFI = 0.962 [>0.9]; RMSEA = 0.045 [<0.05]).

Causal model

The foundations of an SEM model are the underlying causal assumptions (Greenland et al., 1999; Kunicki et al., 2023). The assumptions of our model are illustrated in the Directed Acyclic Graph (DAG), as shown in Fig. 2. It consists of several groupings of risk factors, each with two or more interconnected variables, and one or more causal links to whether the individual had married their *impal* (bion). The specific variables used, and their connections, are justified as follows:

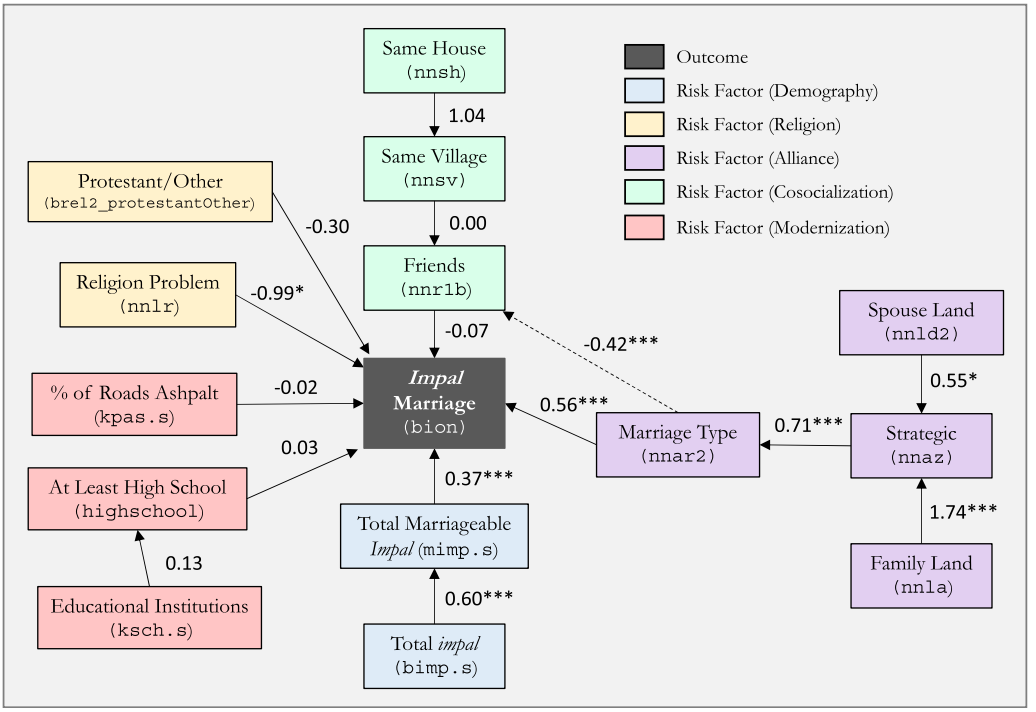


Figure 2. Directed Acyclic Graph with coefficients from the final SEM model (***$p < 0.001$, *$p < 0.05$).

- DEMOGRAPHY: Whether or not one marries their *impal* should be influenced by the total number of marriageable *impal* they have, which in turn should be influenced by the total number of opposite-sex *impal* they have regardless of age difference. This type of demographic argument has been central to explanations of cousin marriage rates (Kunstadter et al., 1963) and is relevant for Karo communities given lower fertility rates today than in the past (Kushnick, 2010).
- RELIGION: Religion can play a role in shaping whether one is able to marry a cousin. Although the religious authorities in Taneh Karo have been relatively lenient (Rae, 1994), elsewhere in Indonesia, notably among the Manggarai of Flores, religious authorities have prohibited similar practices (Hicks, 1988). The religion that one practices may shape cousin marriage rates. The Protestant and Catholic churches, for instance, have different stances on, and requirements for entering, cousin marriages. When two potential *impal* spouses have different religious practices, it can also have an effect, such as causing familial strain and strife.
- ALLIANCE: The role of marriage in creating and maintaining alliances between descent groups has been central to explaining cousin marriage (Leach, 1951; Levi-Strauss, 1949; Needham, 1986). The necessary prerequisites for alliance-based marriage – arranged marriages, inter-familial variation in landholdings, and the potential for strategically keeping land in the family, for instance – still exist in Karo society, but there may have been changes in its importance which could have driven the decline of *impal* marriage (Needham, 1978; Singarimbun, 1975). As land fragmentation, urban migration, and alternative avenues for social mobility have expanded, the instrumental value of marital alliances has weakened, potentially diminishing both the incentive and the opportunity for *impal* marriage.
- COSOCIALISATION: The variable cosocialisation reflects the potential influence of the Westermarck Effect – the hypothesis that individuals who grow up in close physical and

Table 2. Descriptive statistics for measured variables

	Impal		Non-*impal*		Total		
Category: Variable	Mean	SD	Mean	SD	Mean	SD	Missing
Demography							
Total Opposite-Sex *Impal* (bimp.s)	6.05	3.31	4.63	2.57	5.34	3.04	0
Total Marriageable *Impal* [1] (mimp.s)	2.35	1.67	1.42	1.50	1.89	1.65	0
Modernisation							
Educational Institutions (ksch)[2]	25.36	14.32	25.30	13.69	25.33	13.97	0
% of Roads Asphalt (kpas)[2]	27.73	19.09	25.15	17.36	26.43	18.23	13

[1]Defined as within 5 years of age of each other.
[2]In kecamatan (sub-regency).

emotional proximity during early childhood develop a form of sexual indifference or aversion towards one another. This could decrease the likelihood of later sexual or marital attraction between an *impal* pair (Fessler, 2007; Kushnick & Fessler, 2011). This will depend on the childhood living arrangements of the two individuals, and the sort of relationship that developed between them.

- MODERNISATION: Modernisation can reduce the rate of cousin marriage by reshaping educational and urban contexts (Shenk et al., 2024). Greater access to schooling expands social networks beyond kin, elevates individual autonomy, and promotes norms that emphasise personal choice over family obligations. Urbanisation disperses kin networks, fragmenting traditional households and opening space for non-kin interactions, reducing the structural incentives for endogamous marriage (Greenfield, 2016). Access to improved roads is a proxy measure for general mobility and access to cities. Together, these processes weaken both the supply of suitable cousins (Colleran, 2020) and the demand for kin-based unions, accelerating the decline of cousin marriage in many contexts.

Results

Descriptive statistics

Tables 2 and 3 summarise bivariate differences between *impal* and non-*impal* marriages across measured and categorical variables. Consistent with demographic expectations, individuals in *impal* marriages report higher mean numbers of both total opposite-sex *impal* and marriageable *impal* than those in non-*impal* marriages (Table 2), indicating greater exposure to eligible cross-cousin partners. In contrast, village-level modernisation indicators (school availability and road paving) show little difference between marriage types.

Clear contrasts appear in alliance-related variables (Table 3). *Impal* marriages are substantially more likely to be arranged, strategically motivated, and framed in terms of land retention, whereas non-*impal* marriages are more often described as choice-based and non-strategic. Cosocialisation measures show a mixed pattern: *impal* spouses are more likely to report close or friendly relationships prior to marriage but are not more likely to have grown up in the same village, suggesting that kin-based interaction rather than shared residence underpins early familiarity.

Religious affiliation itself differs little between marriage types, but respondents in non-*impal* marriages are considerably more likely to report religion-related problems within their marriages (Table 3). Taken together, the descriptive patterns indicate that *impal* marriage remains closely tied to demographic opportunity and alliance-based decision-making, while modernisation proxies show minimal differentiation. These bivariate associations motivate the multivariate causal modelling presented below.

Table 3. Descriptive statistics for categorical variables

		Frequency			
Category: Variable	Codes	Impal	Non	Total	Missing
Religion					
Protestant/Other (brel2_prot): Religion	0 Catholic	35	27	62	0
	1 Protest./Other	53	61	114	
Religion Problem (nnlr): Were there any problems related to religion in marrying this individual?	0 No	86	77	163	0
	1 Yes	2	11	13	
Cosocialisation					
Same Village (nnsv): Did you and your spouse grow up in the same village?	0 No	55	62	117	0
	1 Yes	33	26	59	
Same House (nnsh): Did you and your spouse grow up in the same house?	0 No	85	84	169	0
	1 Yes	3	4	7	
Friends (nnr1b): How close were you with your future spouse while growing up?	0 Not/distant	34	12	46	0
	1 Friend/Close	54	76	130	
Alliance					
Spouse Land (nnld2): How much land does your spouse's family have relative to the average member of their communities?	1 Below Av.	14	16	30	0
	2 Average	48	55	103	
	3 Above Av.	26	17	43	
Family Land (nnla): Was your marriage entered into for the purpose of keeping land in the family?	0 No	64	79	143	5
	1 Yes	22	6	28	
Strategic (nnaz): Was your marriage entered into for strategic purposes?	0 No	16	49	65	2
	1 Yes	70	39	109	
Marriage Type (nnar2): Choice or arranged marriage?	0 Choice	25	81	106	0
	1 Arranged	63	7	70	
Modernisation					
At Least High School (highschool): Did you attend senior high school?	0 No	36	39	75	0
	1 Yes	52	49	101	

SEM model

We evaluated sub-models, one for each explanatory grouping (demography, religion, cosocialisation, alliance, and modernisation) before fitting the full model, which combined all the sub-models into one amalgamated model. In the full model, we achieved model fit values exceeding the rule-of-thumb thresholds, with CFI = 0.96 and RMSEA = 0.04 ($p = 0.61$). The model results, including probit coefficient estimates and p-values, are shown in Table 4 and Fig. 2. Several effects are significant, including three of seven (43%) direct effects and five of eight (63%) indirect effects. Note that Fig. 2 includes one pipe linking two risk-factor groups – from Marriage Type (nnar2), part of the Alliance group, to Friends (nnr1b), part of the Cosocialisation group. The rationale for including this pipe is discussed in the 'Methods' section; the original DAG, without the additional between-group pipes, is included in the Supplementary Material.(Fig. 2)

Table 4. Coefficients and additional statistics for the full causal path model

							95% CI	
DV		IV	Coeff.	SE	*z*	*p*	Lower	Upper
impal Marriage (bion)	~	Protestant/Other (brel_2_prot)	0.30	0.23	−1.34	0.18	−0.75	0.14
impal Marriage (bion)	~	Religion Problem (nnlr)	−0.99	0.48	−2.06	0.04	−1.93	−0.05
impal Marriage (bion)	~	Total Marriageable *impal* (mimp.s)	0.37	0.08	4.64	0.00	0.22	0.53
impal Marriage (bion)	~	Friends (nnr1b)	−0.07	0.09	−0.83	0.41	−0.24	0.10
impal Marriage (bion)	~	Marriage Type (nnar2)	0.56	0.07	8.05	0.00	0.43	0.70
impal Marriage (bion)	~	Ar Least H.S. (highschool)	0.03	0.12	0.22	0.83	−0.20	0.25
impal Marriage (bion)	~	% of Roads Asphalt (kpas)	−0.02	0.11	− 0.21	0.84	−0.25	0.20
Total Marriageable *impal* (mimp.s)	~	Total Oposite-Sex *impal* (bimp.s)	0.60	0.07	8.32	0.00	0.46	0.74
Same Village (nnsv)	~	Same House (nnsh)	1.04	0.65	1.59	0.11	−0.24	2.32
Friends (nnr1b)	~	Same Village (nnsv)	0.00	0.14	−0.01	0.99	−0.28	0.27
Strategic (nnaz)	~	Spouse Land (nnld2)	0.55	0.23	2.45	0.01	0.11	0.99
Strategic (nnaz)	~	Family Land (nnla)	1.74	0.40	4.38	0.00	0.96	2.51
Marriage Type (nnar2)	~	Strategic (nnaz)	0.71	0.09	7.91	0.00	0.54	0.89
Friends (nnr1b)	~	Marriage Type (nnar2)	−0.42	0.07	−6.00	0.00	−0.55	−0.28
At Least High School (highschool)	~	Educational Institutions (ksch)						
phantom00.13	0.17	0.78	0.44	−0.20				
phantom00.46								

The following direct effects on *impal* Marriage (bion) are significant: a marriage is more likely to be with an *impal* if an individual has a larger number of Total Marriageable *impal* (mimp); a marriage is more likely to be with an *impal* if the Marriage Type (nnar2) is arranged; and a marriage is less likely to be with an *impal* if there was a Religion Problem (nnlr) between the married couple.

Using the marginal effect of Total Marriageable *impal* (mimp.s) for the 25%, 50%, and 75% quantiles (approx. 1, 2, or 3 marriageable *impal*), the predicted probability of marrying *impal* is 0.31, 0.38, and 0.46. The other two direct effects are illustrated in Fig. 3 and described as follows: if Marriage Type (nnar2) is arranged, there is an approximately 47% chance that it is with an *impal*, but only a 29% chance if it is not arranged; and if there is a Religion Problem (nnlr) in the marriage, there is a 21% chance the marriage is to an *impal*, but if there is no Religion Problem then there is a 55% chance.

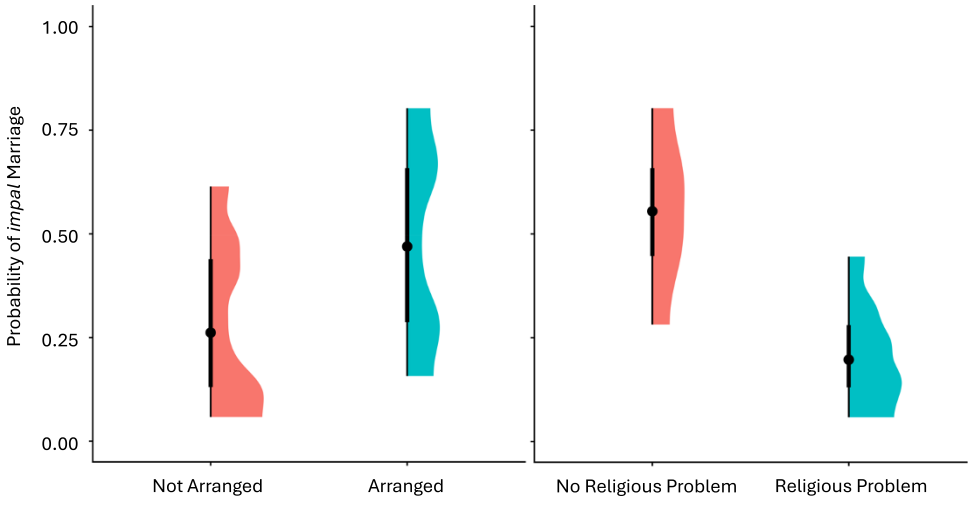


Figure 3. Marginal effects for Marriage Type (nnar2) and Religion Problem (nnlr).

The following first- and second-order indirect effects are significant: having a higher number of Total Opposite-Sex *impal* (bimp.s) means individuals are more likely to have a higher number of Total Marriageable *impal* (mimp.s); Marriage Type (nnar2) that arranged are more likely to occur between individuals who are Friends (nnr1b); marriages that were classified as Strategic (nnaz) are also likely to be of the Marriage Type (nnar2) that was arranged; and marriages that were made to retain Family Land (nnla) or gain through Spouse Land (nnld2), are also likely to be Strategic (nnaz).

Discussion

We used a case–control design combined with SEM to identify demographic, socio-cultural, and modernisation factors associated with the likelihood of *impal* (matrilateral cross-cousin) marriage in Karo communities in North Sumatra, Indonesia. The analysis revealed three key pathways: (1) a demographic chain linking the number of total *impal* to the number of marriageable *impal*, which in turn predicts the likelihood of *impal* marriage; (2) an alliance chain linking property-related motivations to strategic and arranged marriage decisions, which are strongly associated with *impal* marriage; and (3) a religion pathway, whereby the presence of religious problems between spouses is negatively associated with *impal* marriage. Indicators of modernisation, education, and infrastructural development showed no significant effects. Together, these findings suggest that the decline of *impal* marriage can be understood primarily as the product of demographic contraction and the partial erosion of alliance motives, rather than as a wholesale abandonment of the cultural norm itself.

Demographic constraints and the shrinking pool of marriageable kin

The strong positive association between the number of marriageable *impal* and the probability of marrying one's *impal* underscores the demographic basis of the practice. In traditional Karo society, moderately sized sibling sets and fertility rates, often exceeding four children per woman (Kushnick, 2010), created ample opportunities for cross-cousin unions. If fertility rates have declined, which we suspect but is undocumented, the pool of eligible *impal* would have contracted, reducing not only actual marriages but also the exposure necessary for such unions to remain culturally salient. This pattern parallels the demographic constraints mathematically modelled by Kunstadter et al. (1963), and the relatively lower fertility rates coupled with lower rates of cousin marriage in Bangladesh and India

compared to Pakistan, where both fertility and cousin marriage rates are high (Shenk et al., 2024). Demographic effects on cousin marriage extend to kinship terminology as well (Dole, 1969). From an epidemiological perspective, this represents a decline in 'exposure opportunities', the equivalent of fewer potential 'contacts' through which the practice can be transmitted.

This finding complements earlier ethnographic observations that the Karo system of asymmetric alliance, while ideologically stable, has always been demographically fragile (Needham, 1978; Singarimbun, 1975). Here, 'ideologically stable' refers to the persistence of the cultural prescription favouring *impal* marriage rather than to the frequency with which such marriages occur. Throughout the paper, we distinguish between the cultural ideal and its observed prevalence. The latter may decline because of demographic or social constraints even while the former continues to shape expectations and evaluations of appropriate marriage partners. This distinction is reflected in contemporary Karo practice, where individuals may continue to recognise and value *impal* relationships in a broader classificatory sense even as marriages to genealogically defined *impal* have become less common. The prohibition against marrying an *impal* when a sibling has already done so (Kushnick & Fessler, 2011; Singarimbun, 1975) further constrained prevalence. Our model quantifies this long-theorised demographic limitation: a reduction in total *impal* translates statistically into a reduced number of marriageable *impal*, which in turn lowers the probability of *impal* marriage. Demography, rather than changing values, thus appears to be a principal proximal driver of the decline.

Persistence and weakening of alliance motives

Despite the overall decline, alliance-related variables remain significant predictors of *impal* marriage. Marriages undertaken for strategic reasons or to retain or gain property were more likely to be arranged and, in turn, more likely to involve *impal* partners. This finding reinforces the continuing, though diminished, importance of alliance logic in Karo marriage systems. The *impal* tie has historically served as a mechanism to maintain the reciprocal flow of goods, labour, and ritual obligations between *kalimbubu* (wife-givers) and *anakberu* (wife-takers) (Leach, 1951; Levi-Strauss, 1949; Needham, 1986). Our data suggest that this structural logic persists in some contexts, particularly where property retention remains salient, but that its functional scope has narrowed.

Although most rural Karo communities engage in agriculture to some degree (Kushnick, 2010), many households are increasingly integrated into non-agricultural economies, and landholdings are fragmented by inheritance, sale, and conversion. Under these conditions, the economic incentives for arranged or alliance-oriented marriages diminish (Schaffnit et al., 2023). Yet the statistical persistence of alliance effects indicates that such motivations retain social legitimacy even as their material foundations weaken. This is consistent with cultural evolutionary theory's prediction that norms may outlive the ecological or economic conditions that originally favoured them (Boyd & Richerson, 1985; Mesoudi, 2011). The weakening of alliance motives therefore represents not the disappearance of the cultural schema but its adaptive relaxation in the face of new constraints.

Religion and moral recalibration

The negative association between religious problems and *impal* marriage highlights the complex role of Christianity in reshaping marriage ideals. While the Karo Protestant and Catholic Churches have historically tolerated cousin marriage to varying degrees (Rae, 1994), Christianity may nonetheless have contributed to a moral and emotional ambivalence towards kin-based unions. Our data suggest that *impal* marriages are less likely when couples report religion-related problems. Such problems may arise through several pathways, including disapproval from clergy, kin, or the broader congregation; tensions associated with conversion between denominations; or differences in religious affiliations between spouses' parents. This pattern differs from regions in Indonesia such as Flores, where religious authorities explicitly banned cousin marriage (Hicks, 1988), but instead suggests a

gradual normative recalibration within Karo Christianity in which *impal* marriage is not forbidden but may nonetheless become socially or morally problematic.

Because our measure captured only respondents' reports of religion-related problems within the marriage, we cannot determine whether these arose during courtship, family negotiations over marriage, pressure from religious authorities, conversion between denominations, or conflicts that emerged after marriage. Nor can we determine whether the reported problems reflected temporary obstacles that were ultimately resolved, or more persistent tensions within the relationship. The present findings therefore identify religion-related conflict as an important correlate of marriage type but do not permit finer discrimination among the social processes through which religion may influence marriage decisions.

Interestingly, the direct variable for religious denomination (Protestant/other versus Catholic) was non-significant, suggesting that the observed association is unlikely to reflect denominational affiliation alone. Rather, it is the experience of religion-related conflict, regardless of source, that distinguishes *impal* from non-*impal* marriages. Religion, then, functions less as a source of top-down prohibitions and more as a cause of social friction that may subtly discourage cousin marriage by generating discord or reputational costs. It is also possible that religious affiliation serves as a basis for social cooperation and alliance formation, making religious and kinship ties partially overlapping rather than independent domains. Evaluating this possibility would require more detailed data on congregational relationships and social networks than were available in the present study.

Limited role of modernisation

The absence of significant effects for modernisation indicators (i.e., educational attainment and road infrastructure) was initially unexpected, given modernisation theory's emphasis on education and urbanisation as drivers of cultural change (Greenfield, 2016). One possible interpretation is that modernisation in the Karo highlands is now sufficiently widespread that the remaining variation among villages is too small to generate detectable differences. Alternatively, cousin marriage may have declined earlier in the modernisation process, leaving a residual norm that persists independently of current infrastructural conditions.

Another possibility is that modernisation exerts its influence indirectly through the very mechanisms already captured in the model (e.g., declining fertility, reduced land dependence, and altered alliance patterns), rendering its direct statistical effect redundant. These results, thus, caution against assuming that modernisation acts as an independent causal force. Rather, modernisation may operate through the reconfiguration of demographic and alliance systems, supporting the argument that the erosion of *impal* marriage is best understood as a downstream consequence of broader socioecological shifts. In a sense, conceptualising modernisation as a direct effect on cousin marriage, rather than as a higher-level effect that exerts its influence on the other variable blocks, is a shortcoming of our model. The effects of modernisation are unlikely to be uniform across societies, as cultural institutions, kinship systems, and local historical circumstances may shape both the form and magnitude of its influence on marriage practices. The limited effects observed in Karo communities should therefore not be taken to imply that modernisation plays a similarly constrained role in other cultural contexts.

Cultural evolutionary and methodological implications

Although we frame our study within cultural evolutionary theory, the present analyses do not directly examine the mechanisms through which marriage norms are transmitted across generations. Rather, they identify the demographic and socio-cultural conditions associated with changes in marriage practices. By focusing on these conditions, our aim is to explain why a culturally prescribed practice may become less common over time, rather than to identify the specific processes of social

learning through which culturally prescribed marriage practices are acquired, maintained, or modified. By framing cultural change in epidemiological terms, this study illuminates how demographic contraction and structural transformation can jointly reduce the 'transmissibility' of a cultural practice. The analogy to epidemiology is more than metaphorical: cultural practices, like pathogens, depend on exposure, susceptibility, and transmission pathways (Sperber, 1985). As the number of potential *impal* declines and alliance-based incentives wane, the 'reproductive number' of the practice falls below the threshold needed for its persistence. Yet, crucially, the normative preference for *impal* marriage remains widely acknowledged among the Karo (Kushnick et al., 2016). The behaviour thus declines not because the norm is rejected, but because the ecological and social conditions for its enactment have eroded, a pattern akin to a population achieving herd immunity through environmental change rather than deliberate avoidance.

In addition to cultural evolutionary theory, other perspectives may also help explain the observed decline in *impal* marriage. From a demographic perspective, the shrinking pool of marriageable *impal* may itself account for much of the decline, independent of changes in cultural prescriptions (Kunstadter et al., 1963). Likewise, developmental or life-course perspectives suggest that marriage preferences may be calibrated to prevailing social conditions during development (West-Eberhard, 2003). Such processes could contribute to differences between cohorts in marriage preferences and behaviour, potentially producing a lag between changing practices and changing cultural expectations. Indeed, results from Kushnick et al. (2016) hint at such a possibility, as, although third-party observers do not display markedly negative reactions to *impal* marriage, such reactions are more evident among young men than among middle-aged and older participants.

From a human behavioural ecological perspective, changing socioeconomic conditions may have altered the costs and benefits of alliance-based marriage, leading individuals and families to adopt different marriage strategies. Historically, cousin marriage optimised inclusive fitness by preserving resources within kin groups and reinforcing cooperative ties (Chagnon et al., 2017; Dalzero et al., 2024, 2023; Guillot et al., 2015). As market integration and migration diversify resource flows, the fitness payoffs of such marriages may diminish. Under a human behavioural ecological interpretation, individuals and families may increasingly adopt alternative strategies, and these are likely to vary by sex and other factors (Chagnon et al., 2017; Kushnick et al., 2016).

The above interpretations are not mutually exclusive, and the present findings do not permit us to adjudicate among them. Rather, they identify demographic and socio-cultural factors that any satisfactory explanation of the decline of *impal* marriage will need to accommodate.

Methodologically, this study demonstrates the utility of combining a case–control design, traditionally used in epidemiology, with SEM to explore complex causal networks relevant to cultural evolution. The case–control design efficiently addresses rare cultural outcomes such as *impal* marriage, while SEM allows simultaneous estimation of direct and indirect pathways among interdependent variables. Although this approach does not directly identify the mechanisms through which cultural practices are transmitted, it provides a framework for evaluating competing hypotheses and quantifying the demographic and socio-cultural conditions associated with their persistence or decline. Limitations include the cross-sectional nature of the data, potential recall bias in self-reports, and the exclusion of some confounders due to sample-size constraints (Kline, 2016; Wolf et al., 2013). Future research could address these limitations through longitudinal designs, demographic simulations, or agent-based models that explicitly examine how demographic, social, and cultural processes interact over time.

Conclusion

In summary, the decline of *impal* marriage among the Karo appears to stem less from ideological rejection than from demographic and structural change. The shrinking pool of marriageable kin, the weakening of alliance-based incentives, and the subtle discouragement introduced by Christianisation together reduced the opportunity and desirability of *impal* unions. By

integrating epidemiological reasoning with cultural evolutionary and human behavioural ecological perspectives, this study illustrates how social practices may decline not because they are culturally repudiated, but because their ecological and social 'hosts' have diminished. In this sense, the waning of *impal* marriage reflects the adaptive transformation of Karo kinship in response to modern demographic and economic realities. More broadly, our findings illustrate how epidemiological approaches can help identify the demographic and socio-cultural conditions associated with cultural change, providing a useful framework for investigating the persistence and decline of culturally prescribed practices.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/ehs.2026.10071.

Data Availability Statement. For more details about the project, see https://karoimpal.wordpress.com/. The data, a variables codebook, and Supplementary Material, which provides additional methodological details and R code, are available at: https://doi.org/10.5281/zenodo.22759971.

Acknowledgements. Thanks to the Karo people who shared intimate details of their lives with us, and the research assistants who helped in the field. A version of this paper was presented at the Cultural Evolution Society 2024 Annual Conference in Durham, UK. Fieldwork permits were provided by Indonesia's Ministry of Research and Technology (RISTEK), with help from the American-Indonesian Exchange Foundation (AMINEF). Human subjects approval was granted by the Human Subjects Office at the University of Washington, Seattle (with approval to use those permissions from the Ethics Office at the Australian National University, Canberra). All participants provided informed consent before being enrolled in the study.

Author contributions. Writing was done by G.K. with help from S.P. Editing and manuscript approval were done by G.K., S.P., F.Z., K.K., and D.M.T.F. Research design was done by G.K. and D.M.T.F. Analytical design was done by G.K. and S.P. Analyses were carried out by S.P. with help from G.K. Fieldwork was done by G.K. with help from K.K. Research permits were arranged by G.K. and F.Z.

Financial support. Funding was provided by grants to G.K. from the Fulbright Scholars Progam, American Institute for Indonesian Studies (AIFIS), and ANU's Research School of Humanities and Arts, and a grant to D.F. and G.K. from UCLA's Center for Culture, Brain, and Development. S.P. was supported by the Evolution of Cultural Diversity Initiative at the ANU.

Competing interests. The authors declare no conflicts of interest.

References

Aldrich, J., & Nelson, F. (1984). *Linear Probability, Logit, and Probit Models*. SAGE Publications, Inc. https://doi.org/10.4135/9781412984744

Amorim, L. D., Fiaccone, R. L., Santos, C. A., Santos, T. N., Moraes, L. T., Oliveira, N. F., Barbosa, S. O., Santos, D. N., Santos, L. M., Matos, S. M., & Barreto, M. L. (2010). Structural equation modeling in epidemiology. *Cadernos de Saude Publica*, *26*(12), 2251–2262. https://doi.org/10.1590/s0102-311x2010001200004

Arif, S., & MacNeil, M. A. (2023). Applying the structural causal model framework for observational causal inference in ecology. *Ecological Monographs*, *93*(1), e1554. https://doi.org/10.1002/ecm.1554

Beran, T. N., & Violato, C. (2010). Structural equation modeling in medical research: A primer. *BMC Research Notes*, *3*, 267–267. https://doi.org/10.1186/1756-0500-3-267

Boyd, R., & Richerson, P. (1985). *Culture and the evolutionary process*. University of Chicago Press.

Boyd, R., & Richerson, P. J. (2024). Cultural evolution: Where we have been and where we are going (maybe). *Proceedings of the National Academy of Sciences*, *121*(48), e2322879121. https://doi.org/10.1073/pnas.2322879121

Chagnon, N., Lynch, R. F., Shenk, M. K., Hames, R., & Flinn, M. V. (2017). Cross-cousin marriage among the Yanomamö shows evidence of parent–offspring conflict and mate competition between brothers. *Proceedings of the National Academy of Science United States of America*, *114*(13), E2590–E2607. https://psycnet.apa.org/record/2017-15783-001

Colleran, H. (2020). Market integration reduces kin density in women's ego-networks in rural Poland. *Nature Communications*, *11*(1), 266. https://doi.org/10.1038/s41467-019-14158-2

Dalzero, A., Beheim, B. A., Kaplan, H., Stieglitz, J., Hooper, P. L., Ross, C. T., Gurven, M., & Lukas, D. (2024). Cross-cousin marriage among Tsimane forager-horticulturalists during demographic transition and market integration. *Evolutionary Human Sciences*, *6*, e18. https://doi.org/10.1017/ehs.2024.11

Dalzero, A., Ross, C. T., & Lukas, D. (2023). Fitness consequences of cousin marriage: A life-history assessment in two populations. *Evolutionary Human Sciences*, *5*, e3. https://doi.org/10.1017/ehs.2022.55

Dole, G. E. (1969). Generation kinship nomenclature as an adaptation to endogamy. *Southwestern Journal of Anthropology*, *25*(2), 105–123. https://doi.org/10.1086/soutjanth.25.2.3629197

Dressler, W. W. (2004). Culture and the risk of disease. *British Medical Bulletin*, *69*, 21–31. https://doi.org/10.1093/bmb/ldh020

Fessler, D. M. T. (2007). Neglected natural experiments germane to the Westermarck hypothesis: The Karo Batak and the Oneida community. *Human Nature*, *18*, 355–364. https://doi.org/10.1007/s12110-007-9021-1.

Gamble, J. M. (2014). An introduction to the fundamentals of cohort and case-control studies. *The Canadian Journal of Hospital Pharmacy*, *67*(5), 366–372. https://doi.org/10.4212/cjhp.v67i5.1391

Gili, J. A., Poletta, F. A., Campaña, H., Comas, B., Pawluk, M., Rittler, M., & López-Camelo, J. S. (2013). Is gravidity 4+ a risk factor for oral clefts? A case-control study in eight South American countries using structural equation modeling. *The Cleft Palate-craniofacial Journal: Official Publication of the American Cleft Palate-Craniofacial Association*, *50*(5), 591–596. https://doi.org/10.1597/11-320

González, R. (2025). The role of norms as promoters of social change. *Political Psychology*, *46*(2), 455–481. https://doi.org/10.1111/pops.13025

Greenfield, P. M. (2016). Social change, cultural evolution, and human development. *Current Opinion in Psychology*, *8*, 84–92. https://doi.org/10.1016/j.copsyc.2015.10.012

Greenland, S., Pearl, J., & Robins, J. M. (1999). Causal diagrams for epidemiologic research. *Epidemiology*, *10*(1), 37–48. available at: https://pubmed.ncbi.nlm.nih.gov/9888278/

Guillot, E. G., Hazelton, M. L., Karafet, T. M., Lansing, J. S., Sudoyo, H., & Cox, M. P. (2015). Relaxed observance of traditional marriage rules allows social connectivity without loss of genetic diversity. *Molecular Biology and Evolution*, *32*, 2254–2262. https://doi.org/10.1093/molbev/msv10

Harris, J. A., Boyd, R., & Wood, B. M. (2021). The role of causal knowledge in the evolution of traditional technology. *Current Biology*, *31*(8), 1798–1803.e1793. https://doi.org/10.1016/j.cub.2021.01.096

Hartung, C., Lerer, A., Anokwa, Y., Tseng, C., Brunette, W., & Borriello, G. (2010). *Open data kit: Tools to build information services for developing regions* Proceedings of the 4th ACM/IEEE International Conference on Information and Communication Technologies and Development, Association for Computing Machinery: London, United Kingdom. https://doi.org/10.1145/2369220.2369236

Henrich, J., & McElreath, R. (2003). The evolution of cultural evolution. *Evolutionary Anthropology*, *12*, 123–135. https://doi.org/10.1002/evan.10110.

Hicks, D. (1988). Change, adjustment, and persistence in generalized exchange: A case study from Indonesia. *Anthroposophy*, *83*(4/6), 395–402. http://www.jstor.org/stable/40463373

Hoffmann, J. P. (2016). *Regression models for categorical, count, and related variables: An applied approach*. University of California Press. http://www.jstor.org.virtual.anu.edu.au/stable/10.1525/j.ctv1wxrfr

Kipp, R. S. (1993). *Dissociated identities: Ethnicity, religion, and class in an Indonesian Society*. University of Michigan Press.

Kline, R. B. (2016). *Principles and practice of structural equation modeling* (4th ed). The Guilford Press.

Kunicki, Z. J., Smith, M. L., & Murray, E. J. (2023). A primer on structural equation model diagrams and directed acyclic graphs: When and how to use each in psychological and epidemiological research. *Advances in Methods and Practices in Psychological Science*, *6*(2), 25152459231156085. https://doi.org/10.1177/25152459231156085

Kunstadter, P., Buhler, R., Stephan, F. F., & Westoff, C. F. (1963). Demographic variability and preferential marriage patterns. *American Journal of Physical Anthropology*, *21*, 511–519. https://doi.org/10.1002/ajpa.1330210408.

Kushnick, G. (2006). *Parent-offspring conflict among the Karo of North Sumatra, Indonesia*. University of Washington.

Kushnick, G. (2010). Resource competition and reproduction in Karo Batak villages. *Human Nature*, *21*(1), 62–81. https://doi.org/10.1007/s12110-010-9082-4

Kushnick, G. (2023). Marriage: Parent-offspring conflict. In T. Shackelford (Ed.), *Encyclopedia of Sexual Psychology and Behaviour*. Springer Nature pp 1–5.

Kushnick, G., & Fessler, D. M. T. (2011). Karo Batak cousin marriage, cosocialization, and the Westermarck hypothesis. *Current Anthropology*, *52*(3), 443–448. https://doi.org/10.1086/659337.

Kushnick, G., Fessler, D. M. T., & Zuska, F. (2016). Disgust, gender, and social change: Testing alternative explanations for the decline of cousin marriage in Karo society. *Human Nature*, *27*(4), 533–555. https://doi.org/10.1007/s12110-016-9263-x

Le, A., Zhang, L., Liu, W., Li, X., Ren, J., & Ning, A. (2017). A case control study on the structural equation model of the mechanism of coagulation and fibrinolysis imbalance in chronic schistosomiasis. *Medicine (Baltimore)*, *96*(7), e6116. https://doi.org/10.1097/md.0000000000006116

Leach, E. R. (1951). The structural implications of matrilateral cross-cousin marriage. *The Journal of the Royal Anthropological Institute of Great Britain and Ireland*, *81*(1/2), 23–55. https://doi.org/10.2307/2844015.

Leach, E. R. (1954). *Political systems of highland Burma: A study of Kachin social structure*. G. Bell & Sons.

Levi-Strauss, C. (1949). *Les structures élémentaires de la parenté [The elementary structures of kinship]*. Presses Universitaires de France.

Lyu, J., Shi, H., Wang, S., & Zhang, J. (2016). The effect of community stress and problems on psychopathology: A structural equation modeling study. *Comprehensive Psychiatry*, *65*, 24–31. https://doi.org/10.1016/j.comppsych.2015.09.008

Mesoudi, A. (2011). *Cultural evolution: How Darwinian theory can explain human culture & synthesize the social sciences*. University of Chicago Press.

Needham, R. (1978). Classification and alliance among the Karo: An appreciation. *Bijdragen Tot de Taal-, Land- En Volkenkunde*, *134*, 116–148. https://www.jstor.org/stable/27863167.

Needham, R. (1986). Alliance. *Oceania*, *56*(3), 165–180. http://www.jstor.org/stable/40330893

Oliveira, A. A., Almeida, M. F., Silva, Z. P. D., Assunção, P. L., Silva, A. M. R., Santos, H. G. D., & Alencar, G. P. (2019). Factors associated with preterm birth: From logistic regression to structural equation modeling. *Cadernos de Saude Publica*, *35*(1), e00211917. https://doi.org/10.1590/0102-311x00211917 Fatores associados ao nascimento pré-termo: da regressão logística à modelagem com equações estruturais.

Paneth, N., Susser, E., & Susser, M. (2004). Origins and early development of the case-control study. In A. Morabia (Ed.), *A history of epidemiologic methods and concepts*(pp. 291–311). Birkhauser.

Porru, S., Pavanello, S., Carta, A., Arici, C., Simeone, C., Izzotti, A., & Mastrangelo, G. (2014). Complex relationships between occupation, environment, DNA adducts, genetic polymorphisms and bladder cancer in a case-control study using a structural equation modeling. *PLoS ONE*, *9*(4), e94566. https://doi.org/10.1371/journal.pone.0094566

Rae, S. (1994). *Breath becomes the wind: Old and new in Karo religion*. University of Otago Press.

Richerson, P., & Boyd, R. (2006). *Not by Genes Alone*.

Rosseel, Y. (2012). lavaan: An R package for structural equation modeling. *Journal of Statistical Software*, *48*(2), 1–36. https://doi.org/10.18637/jss.v048.i02

Schaffnit, S. B., Page, A. E., Lynch, R., Spake, L., Sear, R., Sosis, R., Shaver, J., Alam, N., Towner, M. C., & Shenk, M. K. (2023). The impact of market integration on arranged marriages in MATLAB, Bangladesh. *Evolutionary Human Sciences*, *5*, e5. https://doi.org/10.1017/ehs.2022.54

Schermelleh-Engel, K., Moosbrugger, H., & Müller, H. (2003). Evaluating the fit of structural equation models: Tests of significance and descriptive goodness-of-fit measures. *Methods of Psychological Research*, *8*(2), 23–74.

Shenk, M. K., Naz, S., & Chaudhry, T. (2024). Intensive kinship, development, and demography: Why Pakistan has the highest rates of cousin marriage in the world. *Population And Development Review*, *50*(4), 1045–1090. https://doi.org/10.1111/padr.12678

Singarimbun, M. (1975). *Kinship, descent, and alliance among the Karo Batak*. University of California Press.

Sperber, D. (1985). Anthropology and Psychology: Towards an Epidemiology of Representations. *Man*, *20*(1), 73–89. https://doi.org/10.2307/2802222

Steedly, M. M. (1993). *Hanging without a rope: Narrative experience in colonial and postcolonial Karoland*. Princeton University Press.

Thiese, M. S. (2014). Observational and interventional study design types: An overview. *Biochemia Medica*, *24*(2), 199–210. https://doi.org/10.11613/bm.2014.022.

van Wouden, F. (1935). *Sociale structuurtypen in de groote oost [Types of social structure in eastern Indonesia]*. (*Translated by Rodney Needham in 1968)* (R. Needham, Trans.). J. Ginsberg.

West-Eberhard, M. J. (2003). *Developmental plasticity and evolution*. Oxford University Press.

Wolf, E. J., Harrington, K. M., Clark, S. L., & Miller, M. W. (2013). Sample size requirements for structural equation models: An evaluation of power, bias, and solution propriety. *Educational and Psychological Measurement*, *73*(6), 913–934. https://doi.org/10.1177/0013164413495237

Xia, Y., & Yang, Y. (2019). RMSEA, CFI, and TLI in structural equation modeling with ordered categorical data: The story they tell depends on the estimation methods. *Behavior Research Methods*, *51*(1), 409–428. https://doi.org/10.3758/s13428-018-1055-2

Cite this article: Kushnick G., Passmore S., Zuska F., br Karo K., & Fessler D.MT. (2026). Explaining the decline of *impal* marriage among the Karo: an epidemiological approach. *Evolutionary Human Sciences*, 8, e41, 1–16. https://doi.org/10.1017/ehs.2026.10071