Dog-Human Coevolution: Cross-Cultural Analysis of Multiple Hypotheses

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Jaime Chambers[1], Marsha B. Quinlan[1, 2], Alexis Evans[1],
and Robert J. Quinlan[1, 2*]

Abstract. Dogs' relationship with humans is pervasive and familiar, and human-dog social bonds serve multiple functions. Yet the breadth and depth of this variation is poorly understood. This study considers our coevolutionary relationship in cross-cultural context as a self-organizing system of mutual-attraction between complementary species. We analyzed Human Relations Area Files (HRAF) texts to develop three scales of dog-human relationships: dogs' utility for humans (DUH), humans' utility for dogs (HUD), and personhood of dogs (PD). Using multilevel regression analyses of data from 844 ethnographers in 144 cultures, we evaluated multiple hypotheses for dog-human coevolution, including: influence of ecological constraints (temperature and pathogen stress), subsistence systems (hunting-agriculture continuum, livestock production), resource defense (intergroup violence, crime), and gendered-relationships (dog affiliation with men and women). Ambient temperature and pathogens showed the strongest and most consistent effects on DUH, HUD, and PD. Mutual-utility and dog-personhood increased as temperature decreased. Pathogens showed non-linear effects: outcomes increased with pathogens up to moderate-high levels, then decreased at higher levels, suggesting zoonotic infection risk. DUH, HUD, and PD were positively associated with hunting and negatively associated with food production. Intergroup violence was positively associated with dog-personhood, but not mutual-utility. Affiliation with adults was positively associated with all three outcomes; however, women showed a significantly stronger effect than men on HUD and personhood. We place these quantitative results in ethnographic context. Together these data suggest dog-human coevolution was constrained by ecological factors, enhanced by cooperative hunting and resource defense, and disproportionately influenced by dogs' relationships with women.

Keywords: Human-animal bond, ethnozoology, anthrozoology, domestication, cultural ecology

Introduction

The individual [Saami in Norway] performs some of his most important activities...if not alone, then at least seldom in concert. At no time in an individual's life will he steadily be in the company of one other, be it mother, friend, mate, or child...The exceptional indelible relationship is between a person and his dog companion. (Anderson 1978: 60–61)

Texts, as above, scattered throughout the ethnographic record, offer rich data for examining dog-human coevolution. We searched the Human Relations Area Files (HRAF) ethnographic database and uncovered thousands of texts in which ethnographers mention human-dog interactions. We collected those texts into a cross-cultural-dog database. Inspired by "evolutionary ethnobiology" (Albuquerque et al. 2015), we analyze those comparative data to elucidate dog-human coevolution.

Dogs are the oldest, most widespread domesticate, present in practically every human community worldwide with varying roles across time and space. Archaeology and evolutionary genetics have made inroads in the natural history of domesticated dogs (Freedman and Wayne 2017; Larson et al. 2012; Thalmann and Perri 2018). However, hypotheses for dog-human coevolution are difficult to evaluate with archaeological and

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genetic data alone. Variation in human-dog interactions remains poorly understood, and few studies have mapped the spectrum (Cummins 2013; Gray and Young 2011). Recent research examines human-dog interaction from psychological and evolutionary perspectives (Hare and Tomasello 2005; Jung and Pörtl 2018; Nagasawa et al. 2015), and field anthropologists have begun systematic research on dog hunting utility across social-ecological contexts (Koster 2008, 2009; Lupo 2017). Here, we present cross-cultural data from subsistence-level societies to test hypotheses about the nature and culture of mutual attraction between humans and dogs. We developed quantitative scales of dog-human mutual utility and the personhood status of dogs. We used multivariate regression models to examine associations with ecological factors, subsistence practices, resource defense, and gendered aspects of dog-human interaction. We place these quantitative analyses in ethnographic context to represent the range of dog-human relations around the globe.

Theories of Dog-Human Coevolution

Theories of initial dog-human attraction tend to emphasize commensal relationships, where proto-dogs scavenge human refuse with little benefit to humans (Zeder 2012a). Common Western cognitive models of dog domestication include human-directed intervention through abducting wolf pups followed by culling or other selection for tameness (Marshall-Pescini et al. 2017; Morey 2010; Pierotti and Fogg 2017). More recent hypotheses suggest dog-human mutual attraction through shared benefits of cooperative hunting (Freedman and Wayne 2017; Morey and Jeger 2015; Pierotti and Fogg 2017; Shipman 2015; Sykes 2019). Thinking in terms of mutual attraction allows us to consider dog-human coevolution from multiple angles: (1) how do dogs help humans; (2) how do humans help dogs; and (3) is there a coevolutionary ontology in which dogs and humans

form hybrid pack-families, where humans consider dogs as persons? These questions triangulate on dog-human coevolution as the explicit cross-species cooperation of people: human-persons and dog-persons. Here, the human-dog relationship is a self-organizing system where two species' strengths and limitations enhance adaptation beyond the ability of either species alone. We investigate factors predicted to influence dog-human mutual-utility and personhood of dogs.

Ecological factors might limit coevolution. Ambient temperatures and pathogen exposure could influence dog-human mutual benefit. First, compared with humans, dogs are pound-for-pound energetically expensive; they have higher body temperature and greater resting energy expenditure, making thermoregulation a problem. Dogs' susceptibility to thermal fluctuations makes them "prone to overheating in response to exercise-induced hyperthermia" in warmer climates (Lupo 2019:2). Though dogs live in every human environment, and special breeds show some heat tolerance (Lupo 2019), we expect less dog-human mutual utility in hot environments. Second, zoonotic infection risk increases with cross-species contact and dogs can carry pathogens that infect humans (Fiorello et al. 2017; Macpherson et al. 2013; Roegner et al. 2019). Recent behavioral immunology suggests that humans under pathogen stress avoid outsiders (Hruschka et al. 2014). We extend this simple hypothesis to dog-human coevolution; where pathogen stress is high, we expect less mutual utility of human-dog interactions.

Beyond ecological constraints on coevolution, dog domestication debates center on subsistence practices. Many researchers argue for cooperative hunting as a coevolutionary driver. Hunting models often begin with wolves scavenging human hunting-occupation sites, followed by full-on cooperative hunting (Cummins 2013; Freedman and Wayne 2017; Marshall-Pescini et al.

2017; Morey 2010; Morey and Jeger 2016), which elevates dogs' status with persons in some hunting populations (Morey and Jeger 2016; Perri 2016). Systematic direct observation of cooperative hunting in anthropological populations is scarce, and dogs' utility for hunting remains unclear. Among Nicaraguan subsistence hunters, dogs increased hunting return rates for agoutis (*Dasyprocta punctata*) (Koster 2008) and reduced overhunting through prey-choice for a fast-reproducing terrestrial species (Koster and Noss 2014). Among Bofi foragers of Central Africa, hunting dogs substantially influenced returns specific to prey species and hunting technologies (Lupo 2017). In sum, we predict that mutual utility and person-status of dogs are positively associated with subsistence hunting.

Food production's role in dog domestication is more difficult to evaluate. Coevolution may have occurred in stages, with an initial cooperative hunting "kick" followed by dogs' spread with agriculture (Freedman and Wayne 2017). Initial domestication occurred before the origin of agriculture; however, dogs' genetic adaptations for starch-rich diets may indicate multi-staged evolution with human agricultural refuse as a new resource for dogs (Axelsson et al. 2013). Indeed, the earliest evidence of dogs in southern Africa and Mexico coincides with agriculture's arrival (Larson et al. 2012). Coppinger and Coppinger (2001, 2016) argue that domestication arose from proto-dogs scavenging around large agricultural settlements. However, archaeological evidence from North American and Japanese dog burials suggests that the development of agriculture reduced dogs' importance (Morey and Jeger 2016; Perri 2016:1173–1174). We examine effects of agriculture and population density on dog-human mutual utility and dog-personhood.

Dog domestication occurred at least 4000 years before livestock (sheep at 11,000 yrs BP [Zeder 2012b]) and we are not aware of current theories suggesting dog domes-

tication for keeping livestock (though see Cummins 2013:53). However, dogs' role in herding and livestock guarding remains pertinent to coevolution as a multi-staged process. We examine dog-human mutual utility and dog-personhood as functions of livestock contributions to subsistence. Given relatively recent herding dog origins in Northwest Europe (Cummins 2013:73–77), our Western, Anglo-European folk models suggest that dog-human mutual utility may be greater in livestock production systems.

Resource defense may have provided an initial kick for dog-human coevolution and dogs' eventual spread with humans. Humans perhaps co-opted dogs' territorial instincts to defend human camps from carnivores (Germonpré et al. 2018; Shipman 2015) and, in some environments, dogs show substantial economic value in reducing livestock loss to predators (Ivaşcu and Biro 2020; Lescureux and Linnell 2014; Potgieter et al. 2016; Van Bommel and Johnson 2012).

Dogs' attentional and communicative "adaptations" suggest selection for cooperative resource defense. First, tone and pitch of specific dog barks might have a role in attracting human attention as alarms (Jégh-Czinege et al. 2020). Second, most domesticated animals show decreased alertness, vigilance, and arousal compared with related wild counterparts (Zeder 2012a). Dogs, however, are *more* alert, vigilant of surroundings, and relatively easily aroused from sleep compared to wolves. These findings highlight the potential importance of co-sleeping in dog-human coevolution, where humans sleep relatively deeply while vigilant dogs wake easily (Kortekaas and Kotrschal 2019).

Apex predator attacks on humans occur, but they are rare (e.g., Hill and Hurtado 1996). In the HRAF ethnography, most resource defense occurs against other humans. We hypothesize that human intergroup violence, assault, homicide, and property crime are positively associ-

ated with dog-human mutual utility and dog-personhood, reflecting dogs' value in resource defense and security.

Multiple ethnographic accounts describe women's special relationships with dogs, cross-culturally (Cummins 2013). In fact, a remarkable finding that dogs' gaze increased human oxytocin levels (Nagasawa et al. 2015) could be due to effects on women (Kekecs et al. 2016). Women might have greater influence than men in dog-human coevolution, and we may be the first to investigate gendered dog-human coevolution explicitly. We hypothesize that dogs' affiliation with women has stronger effects on mutual utility and dog-personhood than does affiliation with men.

An integrated, coevolutionary approach suggests multiple influences on dog-human mutual benefits. We now turn to the ontology of personhood with respect to dogs, the first "domesticate."

Dogs as Persons across Cultures

We argue that dog-human coevolution resulted in shared existence as hybrid pack-families. Coevolution entails biological influences among species, and reciprocal entanglements between culture and biology (Durham 1991). Interspecies relationships can strongly influence cultural perception. "[I]n their mutual attempts to live together and make sense of each other, dogs and people increasingly come to partake in a shared constellation of attributes and dispositions—a sort of shared transspecies *habitus*. Such becomings cut across nature-culture distinctions" (Kohn 2007:7). Dog-human coevolution is based on "intimate cooperation only possible through...cross-species world-making activity" (Ellen 1999:62).

Perceptual boundaries between humans and (non-human) animals as sentient actors deserve close attention (Descola 2013; Haraway 2008; Kohn 2007; Urquiza-Haas and Kotrschal 2015). In many societies, the term "person" is not necessarily equivalent to "human." Western binary oppositions of human:animal and nature:culture are not universal (Descola 2006, 2013; Ingold 1994; Lawrence 1995). Dogs' ubiquity and highly social minds make them ideal for exploring ontological notions across cultures. Ontology refers to beliefs about the nature of being and existence (Hill 2013), reflecting the diverse ways humans live in relation to others (Kohn 2015). People tend to construct ontological assumptions through self-comparison—perceiving the nature of another's being in comparison with one's own perceived being (Descola 2013).

Personhood entails perception of an organism possessing an individual identity, motives, and intent. Identity as a "person" encompasses a sense of mind, agency, mutual interaction, and "human-like subjectivity" enacted through social behavior (Brightman et al. 2012). Depending on cultural context, personhood may extend to all members of a species or only certain individuals with close, in-group relationships. Perceived degree of similarity or difference between humans and nonhumans guides cross-cultural attitudes toward and interaction with animals (Lawrence 1995). Western notions of personhood mark strict divisions between humans and animals (Chambers 2020).

Some non-Western perspectives offer a more nuanced view of the "person" boundary. "Relational ontology" describes "systems in which animals and other 'things' act as independent, sentient agents and are constituted socially, through performative interaction" (Hill 2013:120). Here, Western notions of humanity and animality translate as fluid, permeable concepts. An inner essence and consciousness, separate from the material body, constitutes "personhood" in humans and animals. Identity as a person is distinct from morphology so that "the external form of skin, fur, fins, or feathers is simply a covering, an envelope that contains a person who, under certain circumstances, may shed one for another" (Hill 2013:121).

Emic notions of dogs as persons vary. For example, some families in developed nations treat dogs as "flexible persons" or "emotional commodities," temporarily welcomed and then expelled from the family sphere (Grimm 2014; Shir-Vertesh 2012). Elsewhere, Nuaulu hunters, in Indonesia, do not give proper names to animals except dogs. "Dogs are made 'persons' by giving them names" (Ellen 1999:63). However, underperforming or injured dogs may be left to die of neglect, highlighting ambiguity in their status (Ellen 1999). In Northern Territory, Australia, Warlpiri communities live with dogs, call them by kinship terms, and speak of them as family (*marlpa'*) and companions (*warlalja'*) (Musharbash 2017). Although Warlpiri acknowledged dogs as not human, they place dogs on the "human," morally good end of their personhood spectrum (ranging from human—stranger—inhuman—monstrous). Foreigners from outside the community (reckoned morally ambiguous) skew farther away from the Warlpiri than do their dogs. The "non-physical characteristics of what it means to be human are attributed to dogs rather than to *Kardiya* [non-indigenous Australians]" (Musharbash 2017:109).

Case studies highlight ambiguity surrounding ontological perceptions of dogs (Bolton 2020; Chambers 2020). Similarly, archaeological interpretations of dog remains—either alone or with humans—could reflect regard for dogs as persons (Fowler 2004; Hill 2013; Larsson 1989; Losey et al. 2011; Morey 2006, 2010; Morey and Jeger 2016). Indeed, dogs are more common in burials than any other non-human species (Hill 2013; Morey 2010); however, dog grave presentations and interpretations vary (Hill 2013; Perri 2017). Distinguishing dogs' social importance versus economic value versus simple disposal of dog remains could be irresolvable. A large collection of ethnographic accounts of personhood and human-dog relationships allows us to investigate these perceptions systematically. Limited to broad brushstrokes, this study aims to explore variation in dog-human mutual utility and dog-personhood across cultures and social-ecological contexts.

Methods

HRAF Search and Coding

Cross-cultural analysis offers an empirical method of describing variation across societies to explore social-ecological contexts and specific behaviors (M. Ember 1991; Ember 2007; Ember and Ember 2009; Murdock and White 1969). The Human Relations Area Files (HRAF) are extensive collections of digitized ethnographic documents. Today, the HRAF is an important archive of human variation in traditional, subsistence-level societies. Within HRAF, the Standard Cross-Cultural Sample (SCCS) offers systematic sampling to control for historical intercultural relationships (Murdock and White 1969). Comprised of ethnographies from 186 societies with varying social organization and subsistence, the SCCS draws from culturally, economically, linguistically, and geographically diverse regions of the world. The SCCS has accumulated a large body of pre-coded data from prior studies (Divale 2004) useful in combination with newly coded data. Finally, the relatively large sample with many coded variables offers greater statistical power than do smaller probability samples. However, not all documents in the electronic-HRAF perfectly coincide with the date and place of the original SCCS observation. Therefore, we included years between the SCCS date and our coded observations as a control in multivariate analysis (see Quantitative Analysis).

We ultimately developed analyses to evaluate existing theories for dog-human coevolution; however, a grounded theory approach guided data collection from texts

(Bryant and Charmaz 2007; Glaser and Strauss 1967; Urquhart 2013:16), which may help reduce preconceived biases in domestication narratives (Pierotti and Fogg 2017). Search terms "*dog*, hound*, pup*, puppy, puppies, bitch*, canine*, mongrel*, cur, curs, mutt,* and *mutts*" yielded 15,547 paragraphs for SCCS societies in HRAF. Dog data was collected by reading every paragraph returned, followed by copying and coding pertinent narratives. As we encountered new themes or content, we discussed and created new codes as required. After we completed initial coding, co-authors recoded all data collected by other co-authors for consistency across codebooks and to improve reliability. The final dataset included 8000 paragraphs with 257 unique codes, spanning a wide spectrum of dog content for 152 of the 186 societies in the SCCS. At the time of data coding, the texts for some SCCS cultures had not been made available in the electronic-HRAF (HRAF 2020).

Quantitative Analysis

After completing coding of HRAF texts, we developed three scales characterizing aspects of dog-human coevolution: (1) dogs' utility for humans; (2) humans' utility for dogs; and (3) personhood of dogs. All items were coded as dichotomous presence-absence variables (0, 1). Items were included based on suggestions from the literature or that became apparent during HRAF coding (Chambers 2020). We used Multiple Correspondence Analysis (MCA) of binary indicators (Hjellbrekke 2019; Le Roux and Rouanet 2010) to examine item contributions to latent variables, similar to item analysis with Principal Components (Bernard 2017).

We began scale construction with personhood of dogs (PD), the focus of Chambers' (2020) research. We settled on 11 items for inclusion (Supplementary Table S1): dogs are like people, dogs are kin, dogs have souls, dogs are family members, dogs have names, dog burial and mourning, affection toward dogs, dogs allowed inside houses, dogs transform into humans, and dogs and humans sleep together. Humans talk to dogs or dogs talk to humans was initially included, but was eliminated due to its low contribution in MCA (see Results).

Dogs' utility for humans (DUH) scale includes 14 items (Supplementary Table S2): dogs used for cooperative hunting, herding, hauling/burden, tracking, guarding, alarm, dogs as human food, dogs generally valued as commodities, dog skins and teeth as commodities, dog scavenging (cleaning) human settlements, dogs and body parts used as medicine for humans, dogs as spirit mediums and protectors against evil spirits, and dogs and humans sleep together.

Humans' utility for dogs (HUD) scale includes nine items (Supplementary Table S3): feeding, care, ethnoveterinary care, dogs shown affection, dogs allowed inside human houses, dogs take shelter in outbuildings or dog houses, dogs scavenge human refuse, dog-human cooperative hunting, and dogs and humans sleep together.

We conducted three separate Multiple Correspondence Analyses, one for each coevolutionary facet, to assess dimensionality and item contributions to dimensions. A first dimension that accounted for ≥ 80% of the variance was considered unidimensional following Hjellbrekke (2019). Items with contributions substantially below the mean on the first dimension were excluded. We examined Cronbach's alpha for remaining scale items to estimate unidimensional scale reliability. The category of breastfeeding dogs was eliminated from these scales as the only gendered item in the analysis, which could confound interpretation of gendered coevolution from regression analysis (see Results). Excluding breastfeeding slightly reduced Cronbach's alpha; however, resulting scales showed useful reliability (Cronbach's alpha ≥ 0.68). Resulting scales were counts of items with

means and variances indicating overdispersion (i.e., mean < variance).

After settling on three outcome scales for human-dog coevolution, we conducted three separate multilevel negative-binomial regression analyses, one for each outcome. The negative-binomial link function was chosen because all three scales were counts with overdispersion. Multilevel analysis was necessary because the data were from 844 ethnographers nested within 144 cultures in six global regions (see Syme et al. 2016).

We used a collection of theoretically and empirically motivated predictor variables to explore dog-human coevolution in multiple regression. Here, all predictor variables are controlled statistically, indicating unique effects for predicted associations. In these analyses, we are primarily interested in two estimates for each predicted association. The first is β, which is interpreted as the effect of one unit of increase in the predictor variable on an outcome (DUH, HUD, or PD). If β = 0, then one unit of increase in a predictor variable is associated with 0 units of change in the outcome—there is no effect. If β = −0.25, then one unit of increase in the predictor variable is associated with a decrease of 0.25 in the outcome. If β = 0.25, then it indicates an increase in the outcome variable. The second is P, which is the p-value or significance of β. Interpreting p-values can be surprisingly complicated; however, for our purposes, we can roughly interpret P as the probability that a given β is due to chance and, hence, not a real effect. By convention, we consider results with $P \leq 0.05$ statistically significant.

Predictor variables were chosen based on their theoretical relevance and on the availability of high-quality, pre-coded variables with good SCCS coverage. In cross-cultural analyses, the pattern of missing data across multiple variables can lead to very small sample sizes, causing model overfitting that complicates interpretation. We included predictor variables with

coverage of nearly all SCCS societies and demonstrable reliability and validity from previous published reports (Divale 2004; Ember and Ember 1992; Low 1988; White et al. 1986). These predictor variables were sorted into five categories according to their theoretical or analytical importance. (See Supplementary Material for more details on predictor variables.)

Ecological Constraints

Ambient temperature entered the regression models as an 8-point scale from *Niche Temperature* (SCCS variable 854 [White et al. 1986]), reverse coded so that hotter environments had higher values. We constructed a mean-centered pathogen stress variable from the first component of a Principal Components Analysis of SCCS variables 1253–1259 (Low 1988) and this score was nearly perfectly correlated with total pathogens, SCCS 1260 ($r = 0.99$). We included squared-pathogen stress as a quadratic-term, as pathogens have shown non-linear relationships with human ecology and behavior (Quinlan 2007).

Subsistence System

We examined percent of dependence on hunting for subsistence (SCCS variable 204), dependence on agriculture (SCCS 207), dependence on animal husbandry (SCCS 206), and population-density (SCCS 64) to characterize subsistence systems. We include population-density because Coppinger and Coppinger (2001, 2016) argue for domestication from scavenging agricultural communities at high population-density. Hunting, agriculture, and population density were highly correlated, causing multi-collinearity. We created a bipolar, unidimensional scale of hunting, agriculture, and population-density using PCA (see Supplementary Table S5 for details). Cronbach's alpha = 0.85 for this scale. Hunting and low population density are at one pole and agriculture and high population density are at the other (Supplementary Table S5). This scale was reverse coded (multiplied by −1) to make hunting

the positive pole, aiding interpretation of results.

Resource Defense

We included three predictor variables for resource defense: (1) intergroup violence (SCCS variable 1648, overall warfare); (2) a theft-assault-homicide scale including three substantially correlated SCCS items (variables 1665 homicide, 1666 assault, 1667 theft; see Supplementary Table S6); and (3) trespassing (SCCS variable 1668). All of the resource defense variables demonstrate reliability (Ember and Ember 1992). The theft-assault-homicide scale showed Cronbach's alpha = 0.82.

Gendered Coevolution

We used two binary indicator variables from our coded HRAF data to indicate gendered coevolution: (1) dog affiliation with men and (2) dog affiliation with women. These variables were dichotomous, rather than counts, to more easily compare important differences in regression coefficients for men and women. We predicted that affiliation with women has greater influence on outcomes than does affiliation with men.

Nuisance Parameters

We included two control variables that are not of theoretical interest. The first is the length of the text (i.e., number of paragraphs), an important control, as rare behaviors may be more likely to be described in longer texts. Length of text is not a true exposure or offset variable common in some regression modeling (Hilbe 2014:62–66) because, unlike other exposure over units of area or time, a paragraph has no standard length. Also, including text-length as a control variable rather than as an exposure variable allows us to examine quadratic (non-linear) effects of text-length. The second variable is years since the SCCS observation, which is important because the pre-coded SCCS data we used as predictors refer to a focal time period (Ember and Ember 2009). Years since observation controls for potential decay of cultural-ecological systems over time. (See Supplementary Material for details.)

Results and Discussion

Dog-Human Coevolution Scales

Personhood of Dogs (PD) Scale

We submitted 11 personhood items (Supplementary Table S1) to MCA, which revealed unidimensional structure. The first dimension showed substantial contributions for all 11 items and accounted for 86% of the variance. For MCA, the number of dimensions extracted should account for cumulative variance of 80%, and item categories should show contributions to the dimension ≥ the mean category contribution (Hjellbrekke 2019). Figure 1 shows the item contributions and signs of the coordinates for 11 PD items. All 11 items had coordinates with the same sign and substantial contributions to the first dimension in black (86%). Affection, personhood, family, and burial showed the strongest contributions to the first dimension, at ≥ 10% for all three items (Figure 1). Co-sleeping and shape-shifter showed the weakest contributions at ≥ 5% for both (Figure 1). A second dimension, accounting for 2% of the variance, is indicated in white in Figure 1 for descriptive purposes. Co-sleeping and dogs allowed indoors largely characterized the negative pole of dimension 2, while burial, dogs have souls, and dogs given names characterized the positive pole. We interpret this dimension to indicate behavioral (co-sleeping and indoors) personhood in opposition to cognitive-symbolic personhood (burial, souls, names). Cronbach's alpha = 0.68 for the 11 personhood items and the mean and variance indicated a negative-binomial distribution (Table 1).

Dogs' Utility for Humans (DUH) Scale

We submitted 14 dog-utility items to MCA (Supplementary Table S2), which again revealed unidimensional structure. The first

Table 1. Description and associations among coevolutionary outcome variables.

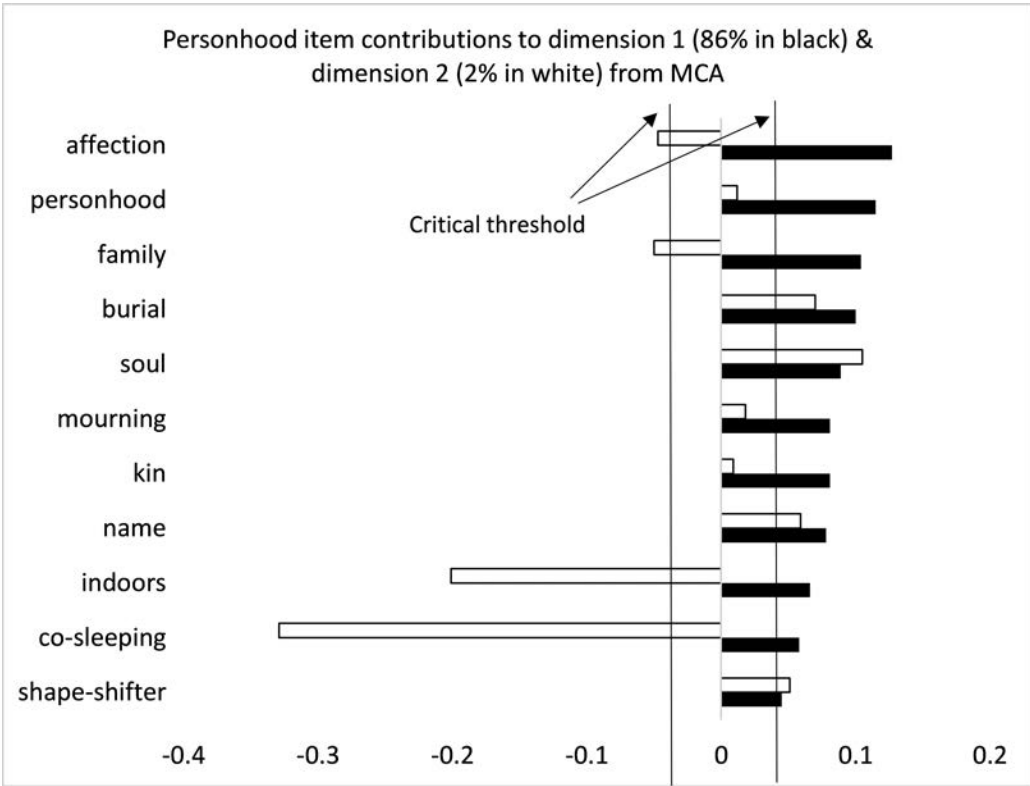|	Correlations			Descriptive	Statistics	
Outcome variables	DUH	PD	HUD	Mean (SD)	n of items	Cronbach's Alpha
Dogs' utility for humans (DUH)	1			1.5 (1.9)	14	0.69
Personhood of dogs (PD)	0.66	1		0.64 (1.3)	11	0.68
Humans' utility for dogs (HUD)	0.77	0.69	1	1.2 (1.6)	9	0.74

Figure 1. Multiple Correspondence Analysis showing unidimensional structure for personhood of dog (PD) items.

dimension showed substantial contributions from all 14 items and accounted for 83% of the variance. Figure 2 shows the item contributions and signs of the coordinates for 14 DUH items. Commodity, scavenging, spirit medium, and consumption showed the strongest contributions to dimension 1. Parts (skin and teeth), co-sleeping, and herding showed weaker contributions (Figure 2). A second bi-polar dimension accounting for 3% of the variance is shown for description. The negative pole of dimension 2 is characterized by guard, alarm, and co-sleeping while the positive pole is characterized by hauling/burden, parts (skins and teeth), and commodity. We suggest the negative pole indicates dogs' value for security, while the positive pole indicates strict economic value. Cronbach's alpha for the DUH scale = 0.69 (Table 1).

Humans' Utility for Dogs (HUD) Scale

We submitted nine HUD items (Supplementary Table S3) to MCA, which indicated one-dimension accounting for 92% of the variance (Figure 3). Care, feeding, ethnoveterinary care, and affection showed the strongest contributions at $\geq$ 10%. Scavenge, hunting, and co-sleeping showed weaker contributions at > 5% (Figure 3). Cronbach's alpha for the HUD scale = 0.74. A second dimension accounted for < 1% of the variance.

All three coevolutionary outcome scales indicated negative-binomial distributions (mean < variance for count data), and all three were substantially correlated (Table 1). Correlation among the outcome variables is obvious in that the three scales share items—cooperative hunting is good for both humans and dogs, for example. However, the scales are still substantially correlated when shared items are removed (Supplementary Table S4), indicating a latent constellation of human-dog interaction. Overdispersion of count data indicates a negative-binomial link function for multiple, multi-level regression used in the next step of the analysis.

Evaluating Multiple Hypotheses in Multilevel Regression

We conducted three multilevel negative-binomial regression analyses to explore hypothesized associations for dog-human
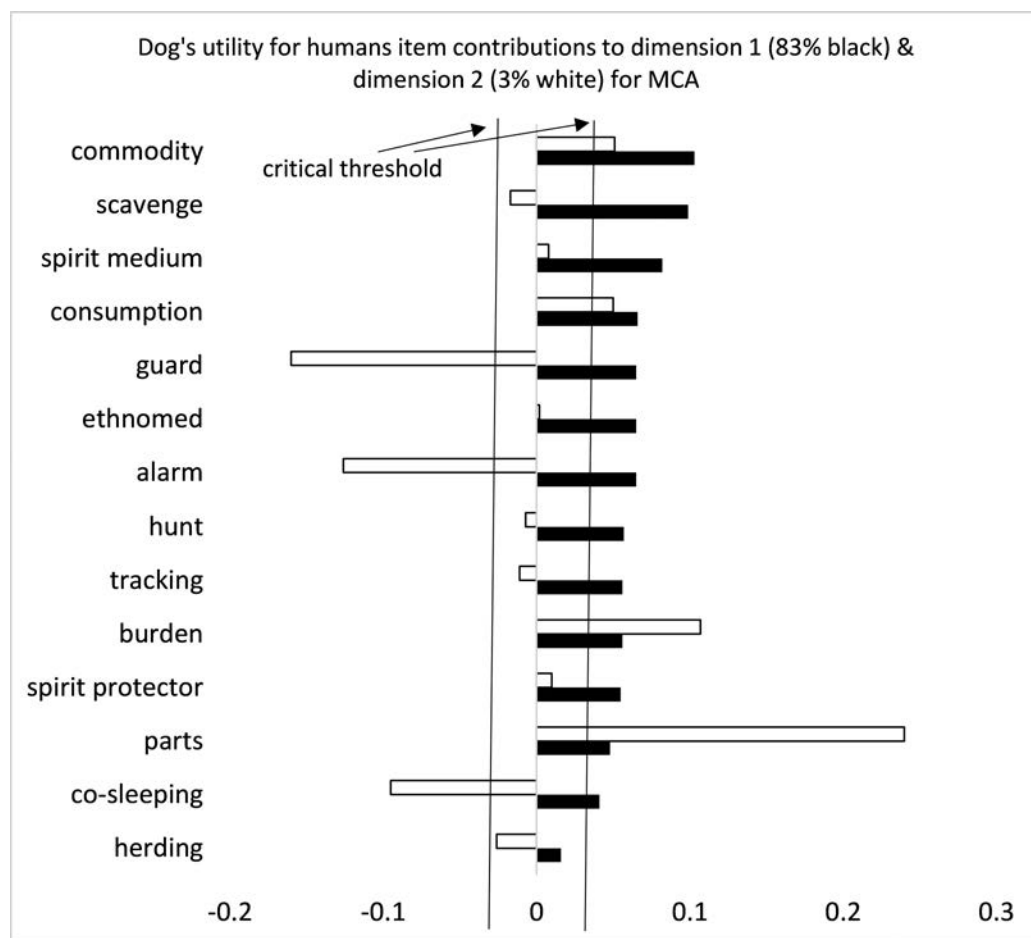

Figure 2. Multiple Correspondence Analysis showing unidimensional scale for dogs' utility for humans (DUH) items.

Human's utility for dogs item contributions to dimension 1 (92%) from MCA.
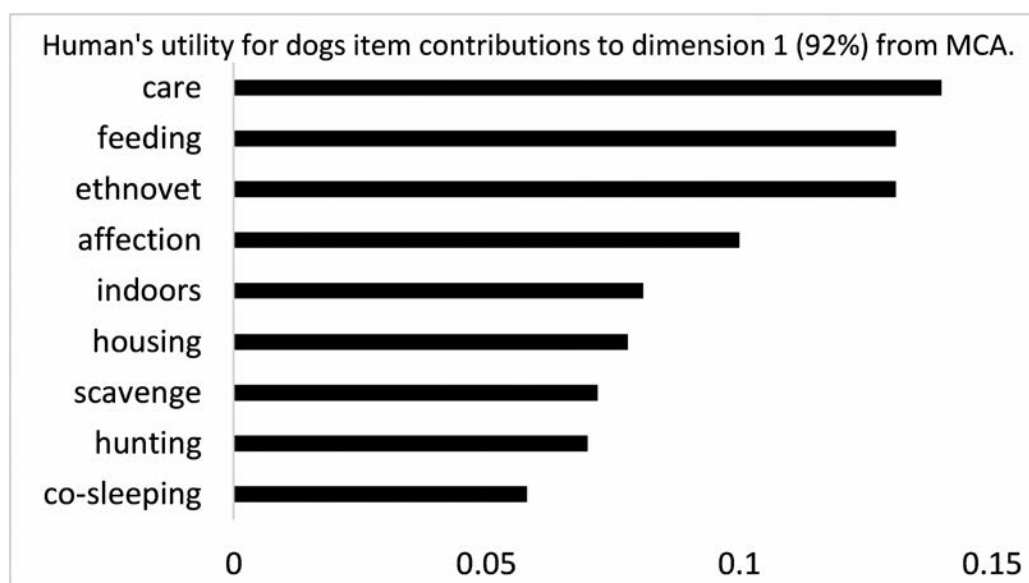

Figure 3. Multiple Correspondence Analysis showing unidimensional scale for humans' utility for dogs (HUD) items.

coevolution using STATA 16 SE. Descriptive statistics for the predictor variables are in Table 2. Supplementary Table S7 shows inter-correlations among predictor variables. We discuss the results for all three models simultaneously as the pattern across the three outcome variables—DUH, HUD, PD—is more important than individual associations.

Both ecological constraints showed strong associations across all three outcome variables (DUH, HUD, and PD). As predicted, dogs are less useful to humans, humans are less useful to dogs, and dogs are less like people in hot environments, presumably due to dogs' relatively high energy expenditure and associated narrow range of heat tolerance (see βs and Ps Table 3). This finding does not suggest that dogs are never valued in hot climates. Dogs are especially important in some Neotropical groups (e.g., Jivaro, Harner 1984; Ancient Maya, Emery et al. 2013); nevertheless, the trend holds across cultures with important local variation.

Pathogen stress, however, showed a non-linear association with all three outcome variables (Figure 4). At lower levels of pathogen stress, DUH, HUD, and PD all increased as pathogens increased, suggesting that zoonotic infection may be an acceptable cost of dog-human interaction. However, at higher levels of pathogens the trend reversed; greater pathogen stress is associated with less mutual utility and dogs are less like people. This pattern could indicate a threshold of zoonotic disease risk beyond which dog-human interactions are not worth the increased pathogen burden.

Discussion of specific zoonotic pathogens is rare in the HRAF; however, research among Turkana people is an exception. Turkana District in Kenya has the world's highest incidence of dog-tapeworm infections (hydatid disease). High tapeworm prevalence among Turkana results from human's close dog contact, and variations in morbidity may be due to regional differences in human-dog interaction (see Shell-Duncan et al. 1999:217).

Subsistence-system effects were unexpected. Livestock production showed a significant negative association across all three outcome variables (DUH, HUD, PD; Table 3). In other words, as reliance on livestock increases, dogs and humans are less useful to each other, and dogs are less

Table 2. Descriptive statistics for predictor variables.

Predictor Variables	N	Mean	SD	Min	Max
Temperature (SCCS 854*-1)	844	-2.4	2.21	-1	-8
Pathogens scale	844	0.01	1.66	-2.06	3.92
Squared Pathogens scale	844	2.75	2.91	0	15.4
Hunting-Agriculture scale	844	-0.02	1.53	-2.39	3.84
Livestock production (SCCS 206)	844	1.52	2.06	0	9
Intergroup violence (SCCS 1648)	844	11.87	14.94	0	88
Theft-assault-homicide scale	844	-0.05	1.45	-0.98	3.77
Trespassing (SCCS 1668)	844	32.64	41.63	0	99
Affiliation with men	844	0.07	0.25	0	1
Affiliation with women	844	0.11	0.31	0	1
Text length (paragraphs)	844	731	1000	1	9763
Yrs from SCCS observation	844	30	37.62	0	190

like people. Inverse associations between livestock production, mutual utility, and dog-personhood are difficult to interpret. We see ethnographic ambivalence. For instance, Middle Eastern herders live with the clash between dogs' perceived pollution risk and utility. Rwala Bedouin dogs guard camels and tents against various predators and
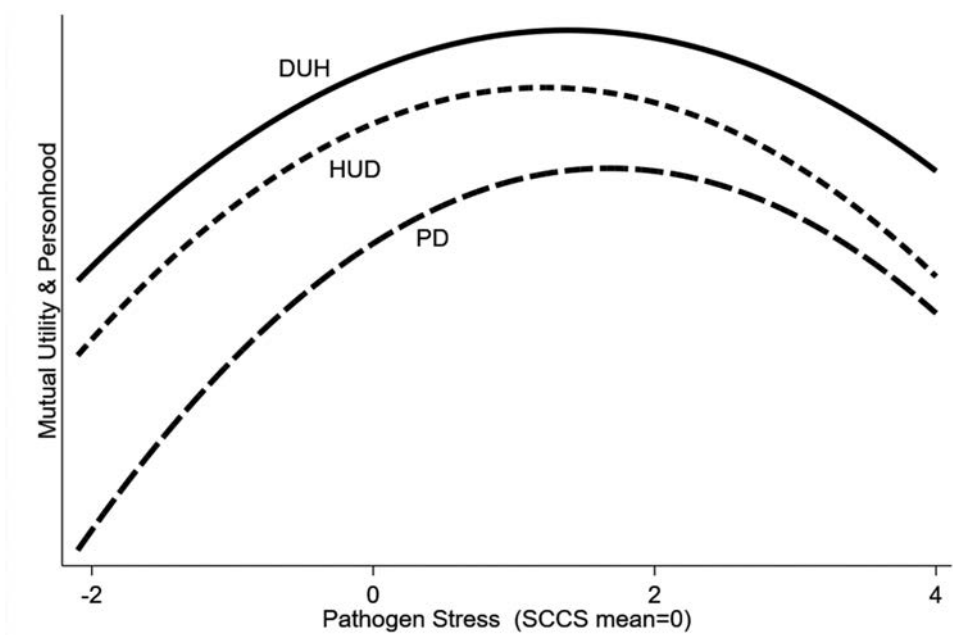

Figure 4. Mutual utility and personhood of dogs as quadratic functions of pathogen stress predicted from Table 3.

Table 3. Multilevel negative-binomial regression showing effects of predictors on dog-human mutual-utility and dogs' personhood. Note: N = 844 ethnographers in 144 cultures within 6 regions; β = slope; P = p-value; *Effect mediated for personhood by inclusion of affiliation with men and women (see text). **Compare β and 95%CI for men and women. See supplement table S10 for overdispersion and group variance and supplement figure S1 for non-linear text-length effects. DUH = Dogs' utility for humans; HUD = Humans' utility for dogs; PD = Personhood of dogs.

Theoretical relevance		DUH β	DUH P	HUD β	HUD P (95%CI)	PD β	PD P (95%CI)
Ecological constraints	**Temperature**	**−0.27**	**0.000**	**−0.24**	**0.000**	**−0.34**	**0.000**
	Pathogens scale	**0.27**	**0.002**	**0.27**	**0.003**	**0.41**	**0.000**
	Squared Pathogens	**−0.11**	**0.003**	**−0.13**	**0.001**	**−0.15**	**0.001**
	Animal husbandry	**−0.08**	**0.043**	**−0.12**	**0.006**	**−0.16**	**0.003**
Subsistence system	**Hunting-Agriculture scale***	**0.17**	**0.006**	**0.19**	**0.002**	**0.11***	**0.132**
	Intergroup violence	0.006	0.201	0.009	0.103	0.012	0.023
Resource defense, security	Theft-assault-homicide	−0.009	0.926	0.000	0.993	0.003	0.962
	Trespassing	−0.002	0.244	−0.002	0.333	v0.004	0.108
Gendered influences	*Affiliation with men*	*0.437*	*0.000*	0.314**	(.05–.58)	0.491**	(.13–.85)
	*Affiliation with women***	*0.440*	*0.000*	0.819**	(.60–1.0)	1.163**	(.86–1.5)
Nuisance parameters	Text length (paragraphs)	< 0.001	0.000	0.001	0.000	0.001	0.000
	Text length-squared	< −0.001	0.000	0.000	0.000	0.000	0.000
	Yrs between SCCS & Observation	−0.002	0.009	−0.002	0.167	−0.002	0.226
	Constant	−0.420	0.159	−0.720	0.018	−1.766	0.000

thieves who might creep into camp at night. Every household has at least one watch-dog, who sleeps near its woman, though outside the tent walls. Rwala consider dogs as unclean and prohibit dogs from eating from their food or cooking vessels. Women feed dogs by throwing them morsels or pouring sour milk onto the back of the iron bread-cooking sheet (Musil 1928).

It is possible that pastoralism constrains the utility of dogs for people where dogs' role as livestock guards removes them from close contact with humans, a prerequisite for maximizing the potential of the relationship. We welcome alternative interpretations.

Our hunting-agriculture scale was positively associated with HUD and DUH, but not PD (Table 3). Affiliation with men and women mediated the effect of hunting-agriculture on personhood (PD; Table 3). Hunting-agriculture was positively associated with personhood of dogs ($\beta = 0.19$, $p = 0.02$) when gender variables were excluded from the model (not shown). Dogs and humans have mutual utility in groups engaged in more hunting, but where agriculture is more important and population densities are higher, there is less mutual utility. Hunting is substantially inversely associated with farming and population density, which complicates interpretation of subsistence systems effects. We settled on a bipolar scale indicating intensive hunting and low population density at one pole and intensive agriculture and high-density at the other (see Supplementary Table S5 and Figure S2). We obtained the same pattern of results if we substituted either hunting (positive association) or agriculture (negative association) by itself, though p-values were slightly increased. Ethnographic examples follow.

Like most Inuit groups, Copper Inuit in Canada are extremely reliant upon dogs. Although dogs help by hauling sledges and carrying packs, their chief utility was in hunting. Trained dogs locate a seal's breathing-hole in the ice, which is their most important job, but they also join forces to hunt polar bear (*Ursus maritimus*) and musk oxen (*Ovibos moschatus*) (Damas 1972). "Inhuman as it may sound, the native hunter would sooner lose one of his own family than a dog, since a female child or an old woman represents an extra mouth to feed. But for a man to lose a dog—where would he be if he couldn't go hunting or trapping by dog team?" (De Coccola 1986:368).

Agricultural Uttar Pradia in India, however, rarely fed their dogs. "Mangy, and alive with fleas and ticks, [dogs] wander about the village lanes, stealing any unguarded food or devouring any waste which their desperate noses scent… Dirty dishes must be washed immediately or there is a crash as some dog tries to carry off a cup partly filled with milk or tea" (Wiser and Wiser 1930:90).

Resource defense proxy variables were not associated with HUD or DUH, but two variables, intergroup violence and trespassing, showed relatively weak associations with personhood. Intergroup violence (SCCS variable 1648) was positively associated with personhood of dogs, and trespassing was negatively associated with personhood (Table 3). Dogs are reckoned more like people in societies with more intergroup violence, and less like people in societies where trespassing is common. Correlational analysis with unknown direction of causality complicates interpretation. Where dogs are more like people, it may be that humans are less likely to trespass because dogs are better deterrents. Where intergroup violence is relatively common, dogs may be more like people for the sense of security they provide. In no way do we suggest that dogs were commonly useful as offensive weapons. In fact, the vast majority of rare references to dogs as offensive weapons against humans are reports of European dog attacks against native peoples during the invasion of the Americas (e.g., de Sahagún's account of New Spain in the Florentine Codex ca. 1585 [Sahagún et al. 1974]).

It is possible that women had a disproportionate influence on dog-human coevolution (Cummins 2013). Dogs' affiliation with men and women entered the models as binary indicators with values of 1 or 0. This allowed us to strictly compare the regression coefficients (β) to assess differences between men and women (Table 3). Here, we are less concerned with p-values than with the magnitude of β. Affiliation with men and affiliation with women were both significant predictors of DUH, HUD, and PD. There was no difference between men and women for DUH (β = 0.44 for both). However, affiliation with women showed a significantly stronger association with HUD (β = 0.82) and PD (β = 1.16) than did affiliation with men (HUD β = 0.31; PD β = 0.49). Note that the βs for women are greater than the upper 95% confidence limits for men, and the βs for men are less than the lower 95% confidence limits for women (see underlined cells in Table 3). Women appeared to have greater influence on *humans' utility for dog* and for the *personhood of dogs*.

This intriguing gendered result echoes ethnographic accounts of close associations between women and dogs (Cummins 2013). For instance, Munduruku women (Brazilian Amazonia) treated dogs "as their own offspring; the women suckle newborn pups at their own breast and shelter them in their hammocks with the children as if they had been born of the same womb" (Tocantins 1877:15). Saami herders prefer male dogs for tending reindeer, and a bitch in heat "can cause bedlam...Only a few industrious women keep a bitch or two for reproduction purposes. It must be kept tied...much of the time, and...in heat, the dwelling is surrounded by a collection of fighting, marking, and barking dogs" (Anderson 1978:294). Saami "honorably" cull female puppies without prospect of a home. Later puppies' distribution reflects the kinship network of the woman owning the bitch.

Two nuisance variables were significant in the expected direction. *Text length* and *text length-squared* were positively associated with all three outcomes such that outcomes increased with *text length* up to about 6000 paragraphs, then leveled off (see Supplementary Figure S1). Time between SCCS observation and the ethnographer's observation was negatively associated with DUH and HUD, but not PD. Control for *time since SCCS observation* may be especially important (Ember and Ember 2009); hence, we conducted a second set of analyses including all variables in Table 3, but restricted to observations < 50 years from the SCCS date (see Supplementary Table S8). The pattern of inference remained unchanged for the restricted sample; however, time since the focal SCCS observations was not significant for DUH, HUD, or PD.

Finally, supplemental analysis limited to coevolutionary variables with overlapping items removed (Supplementary Table S4) yielded the same pattern of inferences as in Table 3 (Supplementary Table S9).

Conclusion

Text analysis and coding of HRAF's 8000 dog-paragraphs within the SCCS distilled our cross-cultural-dog database from which we developed three scales representing aspects of dog-human coevolution: *dogs' utility for humans* (DUH), *humans' utility for dogs* (HUD), and *personhood of dogs* (PD). We used these three scales to test hypotheses for dog-human coevolution in multiple regression analysis. Results indicate cross-cultural trends around which there is important local variation that must be explored in more depth and detail.

As predicted, mutual utility and the personhood of dogs decreased cross-culturally with higher ambient temperatures (Lupo 2019). This finding does not suggest that dogs are never useful in hot environments; rather, there is a global trend around which there is important local variation.

Borrowing from behavioral immunology, we hypothesized that humans

avoid outsiders and dogs (by extension) in environments with high pathogen loads (Hruschka et al. 2014). Our prediction yielded mixed support. Mutual utility and personhood of dogs increased with pathogen loads well beyond the cross-cultural mean, then outcomes decreased at very high levels of pathogens. This finding suggests that zoonotic disease may be an acceptable risk of dog-human interaction up to a point beyond which costs presumably outweigh benefits. Future studies of zoonotic disease from dogs might benefit from ethnobiological perspectives.

Predictions for subsistence-systems were complicated. Our results showed that dog-human mutual utility was greater in populations at low density engaged in more hunting. The effect of hunting on personhood of dogs was mediated by affiliation with men and women. There was no evidence suggesting salience of dogs in primarily agricultural populations. Dog-human mutual utility and personhood of dogs was reduced in agricultural groups at high population-density and in groups highly dependent on animal husbandry for subsistence. Note that effects from multiple regression are additive such that each effect is added or subtracted to others in the model to predict outcomes. Hence, dogs may be somewhat less important in some pastoralist societies; however, estimating dogs' overall importance in a particular group depends on evaluating all of the variables we discuss. We know that dogs can be economically important in livestock protection; however, our findings suggest that qualities of dog-human relationships in pastoralist groups require more detailed case studies (e.g., Ivaşcu and Biro 2020).

Resource defense predictions showed relatively weak and mixed results. Only one predictor variable, *intergroup violence*, was positively associated with one outcome, *personhood of dog*s. In contrast, where trespassing was common, dogs were less like people. Our findings shed some limited light on the role of dogs in resource

defense; dogs' status may be elevated in environments where they provide security for households. Detailed case studies should prove especially useful for disentangling nuances of dogs' roles in local resource defense and security with different sources of risk.

Finally, following ethnographic evidence (e.g., Cummins 2013). we predicted that *affiliation with women* has stronger influence on dog-human mutual-utility and *personhood of dogs* than does *affiliation with men*. This prediction was partially supported. There was no difference between the influence of men and women on dogs' utility for humans, but *affiliation with women* had a stronger effect on *humans' utility for dogs* and *personhood of dogs* than did *affiliation with men*. This intriguing finding requires in-depth ethnographic analysis from new studies.

Taken together, these results highlight the importance of environmental constraints, cooperative hunting, resource defense, and women's contributions to dog-human coevolution. Future research should include cross-cultural dynamics of cooperative hunting; specific features of woman-dog relationships cross-culturally; and better analysis of resource defense.

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