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Resource scarcity drives lethal aggression among prehistoric hunter-gatherers in central California

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The origin of human violence and warfare is controversial, and some scholars contend that intergroup conflict was rare until the emergence of sedentary foraging and complex sociopolitical organization, whereas others assert that violence was common and of considerable antiquity among small-scale societies. Here we consider two alternative explanations for the evolution of human violence: (*i*) individuals resort to violence when benefits outweigh potential costs, which is likely in resource poor environments, or (*ii*) participation in violence increases when there is coercion from leaders in complex societies leading to group level benefits. To test these hypotheses, we evaluate the relative importance of resource scarcity vs. sociopolitical complexity by evaluating spatial variation in three macro datasets from central California: (*i*) an extensive bioarchaeological record dating from 1,530 to 230 cal BP recording rates of blunt and sharp force skeletal trauma on thousands of burials, (*ii*) quantitative scores of sociopolitical complexity recorded ethnographically, and (*iii*) mean net primary productivity (NPP) from a remotely sensed global dataset. Results reveal that sharp force trauma, the most common form of violence in the record, is better predicted by resource scarcity than relative sociopolitical complexity. Blunt force cranial trauma shows no correlation with NPP or political complexity and may reflect a different form of close contact violence. This study provides no support for the position that violence originated with the development of more complex hunter-gatherer adaptations in the fairly recent past. Instead, findings show that individuals are prone to violence in times and places of resource scarcity.

warfare | prehistoric violence | North America

Debate over the antiquity of and explanation for human violence and warfare is longstanding and highly controversial. Two basic alternatives have historically dominated: the Hobbesian notion that civilization rescued humanity from a long history of "war of all against all," and the Jean-Jacques Rousseau counter that oppression, conflict, and violence were actually caused by civilization and that less complex societies were marked by greater levels of peace and harmony (1). Notwithstanding recent anthropological studies suggesting warfare to be extremely rare among mobile hunter-gatherers (2–7), there is undeniable ethnographic and archaeological evidence for a long history of intergroup violence among mobile forager societies (8–13), as exemplified by remains from an apparent massacre of mobile foragers in Turkana during the early Holocene and the somewhat earlier Jebel Sahaba site in Jordan (11). Granting that violence and warfare were present among ancient small-scale societies (14), the reasons why remain highly debated. Current explanations for violence among hunter-gatherers focus on two hypotheses that emphasize the causal roles of either resource scarcity or political complexity.

The first hypothesis focuses on environmental variables, building on longstanding anthropological arguments about resource scarcity and competition (15, 16), but adding the central evolutionary tenant that violence should result from individual self-interest (17–22). Given the obvious costs of engaging in aggression, including the risk of immediate mortality and long-term reprisals, individuals should only take up violence when the benefits (e.g., material goods, status, and long-term alliances) outweigh those costs (18–22). The benefits are more likely to outweigh the costs when and where environmental productivity is low, resources are scarce, and individuals have relatively more to lose from theft (23). If individual evaluation of the costs and benefits of lethal aggression determines the incidence of violence, and if these evaluations vary ecologically, then (P1) we predict that rates of lethal aggression should covary negatively with environmental productivity, increasing as productivity decreases.

The second hypothesis is sociopolitical and focuses on the group benefits of violence: even when the potential benefits of lethal aggression do not outweigh its physical cost (of injury or death), individuals may nevertheless risk their lives and join other unrelated individuals in violent conflict that benefits their sociopolitical group, if members who refuse to fight suffer significant costs of social punishment (24). If sufficiently severe, community imposed sanctions that enforce participation in lethal aggression, e.g., the ostracizing of cowards (24), may encourage cooperative participation in violence at levels giving these groups advantages over groups less able to punish, thus less capable of violence (25, 26). This hypothesis implies that violence should be more common among groups with greater sociopolitical complexity, with leaders able to enforce participation through sanctioned punishment. This line of thinking can be linked to other longstanding anthropological hypotheses about the origins of warfare that propose that social power differentials allow high-status individuals and leaders to coerce low-status individuals to risk their lives to provide benefits accrued by the high power elite (27–30). If individuals are more likely to engage in lethal aggression under the

Significance

From warfare to homicide, lethal violence is an all too common aspect of the human experience, yet we still do not have a clear explanation of why individuals kill one another. We suggest the search for an answer should begin with an empirical understanding of where and when individuals are more prone to experience violence. Examining patterns of lethal trauma among hunter-gatherer populations in prehistoric central California, this study reveals that violence is explained by resource scarcity and not political organization. This finding provides a clear rationale to understand why violence may be greater in specific times or places through human history, which can help predict where and when it may arise in the future.

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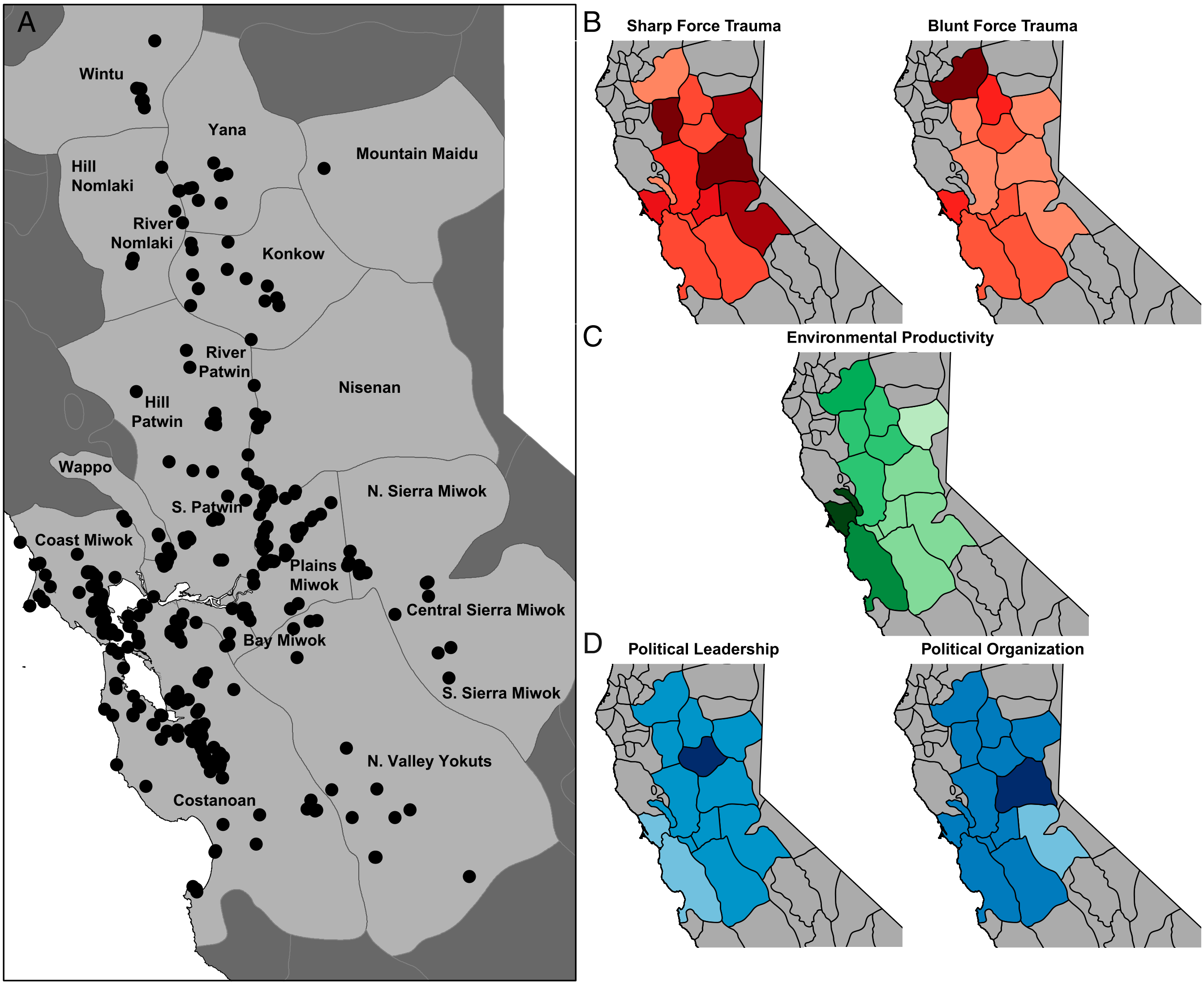

Fig. 1. Spatial distribution of (*A*) archaeological sites in the CCBD relative to contact-era ethnolinguistic boundaries, (*B*) proportion of sharp and blunt force trauma, (*C*) environmental productivity (NPP), and (*D*) political leadership and organization summarized for each ethnolinguistic group.

threat of punishment and sanction enforced by powerful leaders, then (P2) we predict that rates of lethal aggression should covary positively with sociopolitical complexity, increasing as complexity increases.

Here we evaluate the relative importance of resource scarcity and sociopolitical complexity on rates of violence using an exceptionally robust archaeological database of human burials that includes remains from thousands of individuals who lived in central California between 1,530 and 230 cal BP (31). Specifically, we evaluate how two forms of violence, sharp force and blunt force craniofacial trauma, vary relative to resource scarcity and political complexity (Fig. 1 and Table S1). Because we cannot distinguish between offensive vs. defensive violence, interpersonal vs. coalitional lethal aggression, or intra- vs. intergroup violence from the archaeological record, we treat these data as a long-term record of overall violence occurring in a given area. First, we summarize the evidence of violence occurring within the boundaries of each ethnolinguistic group in central California. Then, using environmental productivity as a proxy for the relative utility of the local environment (32) and ethnographic estimates of political complexity (33), we link the data on violence to these ecological and ethnographic proxies to determine if rates of violence are driven more by resource scarcity or political complexity.

Results

As shown in Table 1 and Fig. 2*A*, the proportion of individuals suffering from sharp force trauma significantly declines with environmental productivity, confirming the first prediction (P1) that resource scarcity increases lethal aggression. Sharp force trauma also varies significantly with political complexity (Table 1), but contrary to the second prediction (P2), sharp force trauma is highest at intermediate levels of political leadership (Fig. 2*B*) and the extremes of political organization (Fig. 2*C*).

Neither environmental productivity nor political organization predicts the proportion of cases exhibiting blunt force trauma across the study area, suggesting that different causal factors may be driving this type of violence (Table 1). This interpretation is supported by significant variation between the frequency of blunt force vs. sharp force trauma that resulted in or was at least associated with mortality; a relatively low number of blunt force trauma cases were identified as definitively perimortem (23.53%; 36/153), with the remainder being antemortem or indeterminate, whereas 94.39% (286/303) of the sharp force trauma was recorded as definitively perimortem, likely causing or contributing to the death of the individual.

Controlling for the potential covariance between environmental productivity and political complexity, which could conflate the interpreted cause of these relationships, shows that the proportion of sharp force trauma varies significantly with environmental productivity alone (Table 1 and Fig. 3). This finding provides support for the first prediction (P1) that violence is driven by resource scarcity and suggests that political complexity has little influence on violence independent of environmental productivity (refuting P2). As with the bivariate models, in multivariate models, the proportion of individuals who experienced blunt force trauma does not vary significantly with any of the independent variables (Table 1).

Discussion

Comparison of environmental productivity and sociopolitical organization relative to the skeletal record of violence over the last 1,500 y of prehistory in central California shows only one statistically meaningful correlation: negative covariance between sharp force or projectile trauma (the most pervasive form of violence in the record) and net primary productivity (NPP). When accounting for environmental variation, our findings provide no indication that societies with more complex societal forms were more prone to intergroup or interpersonal violence. Although the range of variation in sociopolitical complexity is limited in this region relative to global variation, our California sample shows significant levels of, and variation in, violence and further demonstrates that violence has little or nothing to do with sociopolitical complexity but rather with environmental productivity. Sociopolitical complexity may be a sufficient, but is not a necessary cause of hunter-gatherer violence. Blunt force cranial trauma does not correlate with either environmental productivity or political organization in the central California prehistoric record. Given that the majority of incidents of blunt force trauma are not associated with lethal violence, these findings suggest that it represents a different form of close-range, interpersonal conflict occurring in different environmental and political contexts than projectile injuries.

In this hunter-gatherer case, environmental productivity is a stronger predictor of heightened levels of lethal aggression than relative sociopolitical complexity, supporting the notion that in contexts of resource scarcity, the perceived benefits for individuals to engage in lethal aggression may have outweighed the perceived costs. There are at least two ways to interpret this finding.

On the one hand, low environmental productivity could be associated with violence simply as a result of individuals experiencing more frequent resource shortfalls. When such events occur, and possibly even when they are anticipated, individuals may find it worthwhile to take resources or territories from their neighbors. If such events are frequent enough, this could lead to increased levels of violence in low productivity regions. Individuals in low productivity environments may also be less tolerant of theft from neighbors. Given that the utility of a resource diminishes with the amount of that resource an individual possesses (23), those with more may be more tolerant of theft from others, whereas those with less should be less tolerant of theft. As such, resource claims and competitions in low productivity environments should more frequently result in episodes of violence from those intolerant of stealing. Combined, these scenarios suggest that individuals in lower productivity environments may experience a higher risk of shortfall due to the lower amounts of food available within their foraging radius; therefore, they are more likely to travel into neighboring territories in search of resources, where they encounter neighbors who are equally at risk for shortfall and intolerant of theft.

On the other hand, there are also reasons to suspect that the inverse relationship between violence and environmental productivity we report might not be due to simple resource scarcity per se, i.e., scarcity actually experienced by individuals, as intuition might suggest. If prehistoric populations distributed themselves to maximize their rate of resource acquisition, which the evidence suggests (32), then all individuals should have the same rate of energy gain regardless of environmental productivity, implying that individuals in resource-rich and resource-poor environments may be equally likely to experience per capita resource scarcity. If this is true, then the differences in violence between resource poor vs. rich environments may not result from differences in resource

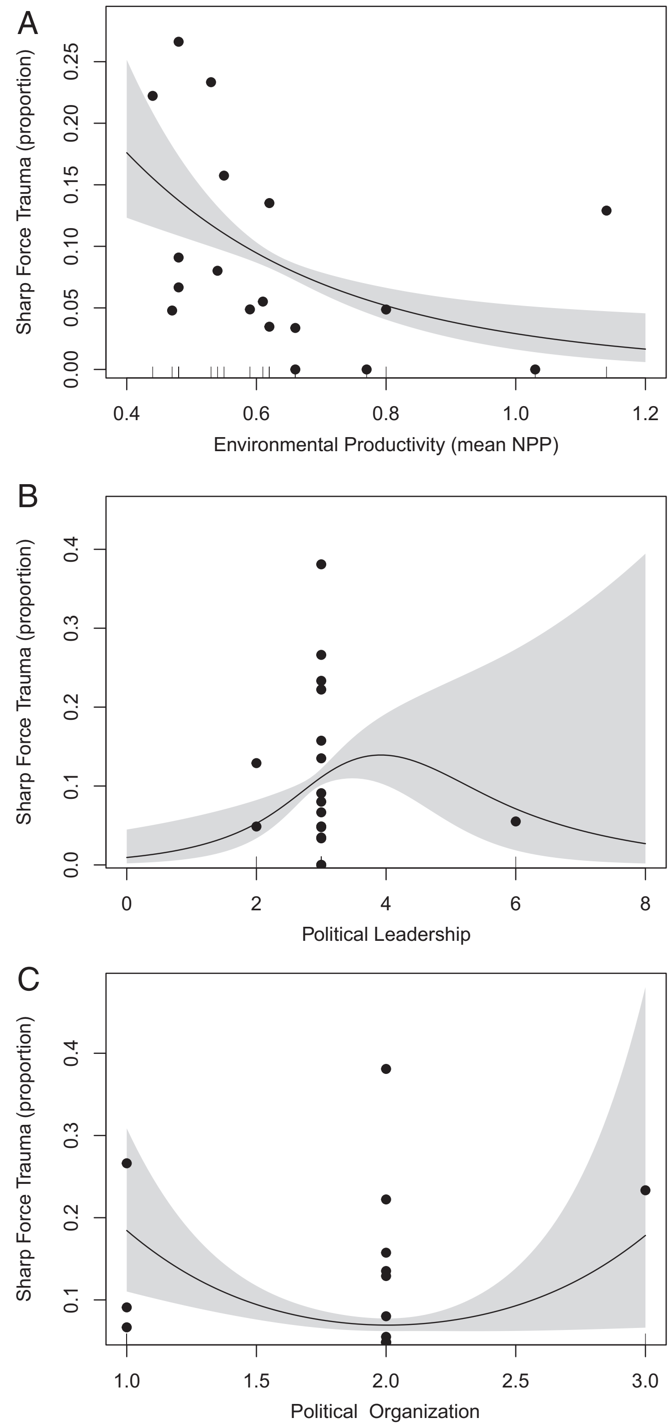

Fig. 2. Response plots illustrating significant bivariate model results: the effect of (*A*) environmental productivity, (*B*) political leadership, and (*C*) political organization on the proportion of burials exhibiting sharp force trauma.

Table 1. Summary of generalized additive model results examining the effect of EP, PL, and PO on the proportion of burials with evidence for SFT and BFT within each ethnolinguistic group

Model type	Prediction	Dependent	Independent	Estimated degrees of freedom	Proportion explained	*P*
Bivariate	P1	**SFT**	**EP**	**1.02**	**30.30**	**0.0008**
	P2a	**SFT**	**PL**	**1.83**	**31.00**	**0.0260**
	P2b	**SFT**	**PO**	**1.81**	**27.50**	**0.0078**
	P1	BFT	EP	1.31	7.81	0.4078
	P2a	BFT	PL	1.00	2.00	0.8016
	P2a	BFT	PO	1.80	22.10	0.1533
Multivariate	P1+2a	**SFT**	**EP**	**1.00**	**30.70**	**0.0091**
			PL	1.52		0.3116
	P1+2b	**SFT**	**EP**	**1.00**	**37.80**	**0.0024**
			PO	1.00		0.5892
	P1+2a	BFT	EP	1.23	9.88	0.2716
			PL	1.00		0.2871
	P1+2b	BFT	EP	1.23	37.30	0.2716
			PO	1.00		0.2871

Table shows the estimated degrees of freedom, the proportion explained, and the *P* value for each dependent and independent variable pair. Significant terms are highlighted in bold. BFT, blunt force trauma; EP, environmental productivity; PL, political leadership; PO, political organization; SFT, sharp force trauma.

scarcity, but from how those resources are distributed resulting in changes in mobility and territory size. Populations in lower productivity environments have significantly larger territories (32) and greater mobility within those territories (34). Because individuals in low productivity environments must travel widely to obtain enough resources, individuals in these environments may operate in poorly defined territorial boundaries and may have less information about their neighbor's willingness to punish poachers, both of which may cause individuals from neighboring groups to come into conflict. In this scenario, violence varies inversely with resource productivity as the result of disputes resulting from either conflicting territorial claims or misunderstandings and misinformation, where low population densities translate into widely separated groups unfamiliar with their neighbors and territorial boundaries. In these circumstances, individuals are making optimal assessments about how to acquire resources across a large and unproductive landscape on the basis of what little information they have regarding their neighbors, but this has the unintended consequence of increased violence.

Regardless of which scenario underlies the negative correlation between projectile violence and environmental productivity, these results add to a growing body of evidence suggesting that rates of violence across small scale societies are driven by individual evaluations of costs and benefits. Rather than arguing whether or not violence is an ancestral or derived characteristic of human societies, we suggest that future work should continue to examine variation in the rates of violence across populations

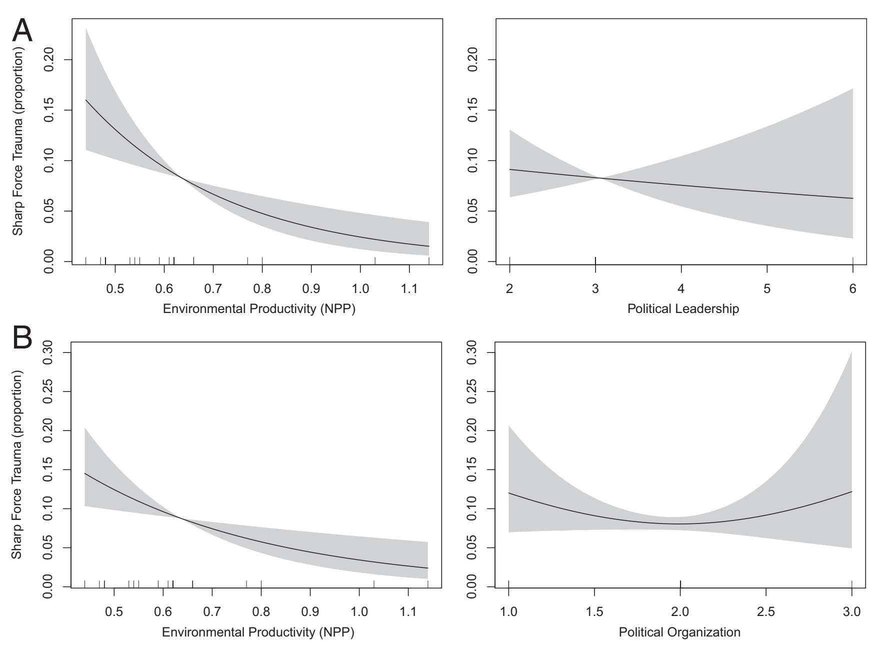

Fig. 3. Response plots illustrating results of two multivariate models. The first (*A*) examines variation in the proportion of burials exhibiting sharp force trauma as a function of the combined effect of environmental productivity and political leadership. The second (*B*) examines the proportion of burials exhibiting sharp force trauma as a function of environmental productivity and political organization. When combined, only environmental productivity remains significant (Table 1).

relative to indicators of resource scarcity to explain the underlying causes of violence throughout human history.

Methods

Data Collection.

Central California Bioarchaeological Database. The Central California Bioarchaeological Database (CCBD) was assembled by one of us (A.W.S.) over the last two decades with information gathered from 329 archaeological sites; 80% of them were excavated after 1975 because of threatened impacts from modern development (31, 35). It includes information on a total of 16,820 individual burials that date back as far as 5,000 cal BP from 19 ethnohistoric territorial delineations (31, 35). All of these groups were relatively broad-spectrum hunter-gatherers, organized into a large number of autonomous polities that are often aggregated by anthropological researchers into larger groups based on language. Three forms of violence well attested in the ethnographic record are evident in this sample: blunt force cranial trauma, sharp force trauma, and trophy taking behavior. Across the entire database, the most pervasive form of violence is sharp force or projectile trauma, found in 7.4% of 6,278 assessed burials. It was significantly more common among males (10.7%) than females (4.5%) and most common among young adult males. Indicated by cut marks, indentations, perforations on bones, and embedded projectile points, this form of trauma increased markedly in frequency during late prehistory, likely due to the introduction of the bow and arrow (31). Blunt force cranial trauma is the second most common form of injury, remaining relatively constant at ∼5% for most of prehistory for adult males and slightly less for adult females, but increasing after 500 cal BP. Trophy-taking behavior is the practice of dismembering and displaying body parts and was the least common form of violence in the CCBD, peaking 2,500–1,500 y ago, with 4.2% of males and 1% of females being subjected to removal of crania or postcranial elements. Recent research suggests that trophy-taking may represent profoundly different underlying social and political phenomena than projectile violence and blunt force trauma (36), so it is not further considered here.

For the current undertaking, we restricted our sample to burials representing only the last 1,500 y of prehistory, which are most relevant to the ethnographic record; this subsample includes 3,939 burials assessed for sharp force trauma and 3,947 burials assessed for blunt force cranial trauma from 127 sites (Table S1 and Fig. 1).

Relative sociopolitical complexity. Relative complexity of California Native hunter-gatherer societies (37, 38) was assessed for the 19 ethnolinguistic groups represented in the CCBD with reference to two variables in Jorgenson's (33) Western North American Indian database. These variables include (*i*) type and complexity of political leadership (variable VII-A-332) and (*ii*) government and territory (variable VII-B-334). Although these values are based on observations and accounts of ethnographic societies, these scores should still be representative of the general conditions experienced by individuals recorded in the CCBD given that the archaeological (39) and linguistic (40) records suggest strongly that ethnographic patterns likely emerged 1,500 y ago and that groups migrating into California had arrived in their historically observed locations by that time or only slightly thereafter.

Variation in political leadership was mainly between groups with a single leader (or headman) advised by an informal council of elders and groups with a single leader with one or more assistants and/or a formal council. Jorgenson's variable VII-A-332 is formally titled "Type and Complexity of Political Leadership in the Focal Local Community" and has 10 possible ordinal estimates for each of the ethnographic groups, but the ethnographic groups here represent only 3 of these: a score of 2 represents a single leader with at most a council of elders as additional political offices; a score of 3 represents a single leader or headman with one or more functional assistants and/or a formal council or assembly, but without an elaborate or hierarchical organization. The majority of the ethnolinguistic groups are split fairly evenly between scores of 2 and 3. A score of 6 represents "theocratic, authority being vested not in secular officials, but in a priesthood, a secret society, or other religious functionaries" (33, p. 610). This latter form of organization was found only among the Konkow Maidu.

Variation in political organization was mainly between social formations consisting of just one kin group (e.g., patrilineal bands) and formations consisting of multiple kin groups; the units are known in California as tribelets. Jorgenson variable VII-B-334 is formally titled, "Government and Territory," with up to 13 possible ordinal scores. The ethnolinguistic sample used here again only represents three of these possibilities. A score of 1 indicates a local society that has no territorial organization larger than the residential kin group. True political organization is lacking; a 2 is assigned where succession of the office of headman is through appointment by a higher political authority. This score is the vast majority of the cases in our sample. A score of 3 is assigned where the local society is composed of several residential kin groups that are formally united into villages or bands, and these political units are in turn combined with others to form a tribe or district (33, p. 611). In our sample, this is found only among the Nisenan, and even there it is on the basis of somewhat circumstantial evidence (41).

Environmental productivity. Environmental productivity values were taken from Codding and Jones (32). In some cases, data on lethal aggression are assigned more fine-grained territories than were available for the NPP data; in such cases, average NPP values are repeated for each ethnographic group. Mean NPP was calculated for each ethnolinguistic group from a global raster of remotely sensed data from the MODIS instrumentation on NASA's Terra satellite, processed and provided by the Numerical Terradynamics Simulation Group at the University of Montana (42, 43). NPP is an approximation of photosynthesis, measuring the amount of energy that is turned into mass and thereby approximating the amount of new growth biomass available to consumers. Although a crude measure of environmental variation, it does predict variation in hunter-gatherer demography and settlement patterns (32), suggesting that it is a reliable proxy of habitat quality and resource abundance. Additionally, although modern data are used here to represent the last 1,500 y, the use of modern NPP is an appropriate proxy for past resource abundance given the scale of our analysis and dominance of a single, specifically Mediterranean (dry summer, wet winter) climatic pattern during the period of interest; this is in contrast to other areas (e.g., the southern Great Basin) whose climatic history shows major shifts between quite different (e.g., dry summer Mediterranean vs. wet summer monsoonal) climatic regimes, therefore preventing simple extrapolation from present to past resource abundance. Mean NPP for our central California study area has certainly varied, but the relative ranking of each ethnographic group should have remained the same. Table S1 also reports data on territory size and population density from Codding and Jones (32), with updated territory size estimates for subdivided Miwok and Patwin linguistic regions following Kroeber (44, 45).

Analytical Methods. To determine whether each of the independent variables (environmental productivity, political complexity, and territorial organization) predicts variation in the dependent variables (the proportion of burials exhibiting sharp or blunt force trauma), we rely on generalized additive models (GAMs) (46–48). Because these relationships may be nonlinear, GAMs allow for the underlying trends within the data to emerge without any major assumptions by the investigator. All models use a binomial distribution and log link appropriate to proportional data and follow a quasi-likelihood estimation to reduce the chances of overdispersion. To maximize parsimony, we minimize the degrees of freedom (or knots) to the minimum possible ($k = 3$). In addition to bivariate models, we also construct multivariate models to control for the interaction between each of the independent variables. To account for variation in sample size, all models weight each data point by the total number of observations (burials) from which the proportion is calculated. Model results report the estimated degrees of freedom of the smooth term, the proportion of deviance explained by the inclusion of the independent variable (also known as the likelihood r^2, or R^2_L), and the α or P value associated with each independent variable.

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