Coevolution of landesque capital intensive agriculture and sociopolitical hierarchy

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One of the defining trends of the Holocene has been the emergence of complex societies. Two essential features of complex societies are intensive resource use and sociopolitical hierarchy. Although it is widely agreed that these two phenomena are associated cross-culturally and have both contributed to the rise of complex societies, the causality underlying their relationship has been the subject of longstanding debate. Materialist theories of cultural evolution tend to view resource intensification as driving the development of hierarchy, but the reverse order of causation has also been advocated, along with a range of intermediate views. Phylogenetic methods have the potential to test between these different causal models. Here we report the results of a phylogenetic study that modeled the coevolution of one type of resource intensification—the development of landesque capital intensive agriculture—with political complexity and social stratification in a sample of 155 Austronesian-speaking societies. We found support for the coevolution of landesque capital with both political complexity and social stratification, but the contingent and nondeterministic nature of both of these relationships was clear. There was no indication that intensification was the "prime mover" in either relationship. Instead, the relationship between intensification and social stratification was broadly reciprocal, whereas political complexity was more of a driver than a result of intensification. These results challenge the materialist view and emphasize the importance of both material and social factors in the evolution of complex societies, as well as the complex and multifactorial nature of cultural evolution.

cultural evolution | cultural phylogenetics | sociopolitical hierarchy | intensive agriculture | landesque capital

The societies in which most human beings live today are vastly more complex than any that existed at the beginning of the Holocene (1, 2). Theories of cultural evolution seek to explain how and why this occurred. Such theories have been described as falling into two major types (3), or as occupying a spectrum between two extremes (4), based on the factors that they emphasize. According to "materialist" theories, the key drivers of cultural evolution are factors that relate directly to human survival and reproduction, such as technology and population growth. Other theories, sometimes labeled "idealist" or "cultural determinist," stress factors that are less directly related to these basic needs, such as ideology and social structure. Historically, the first type of theory has been advocated far more often than the second (3). However, most if not all scholars in the area have acknowledged that both material and more abstract factors play a role in cultural evolution, and some have stressed the importance of ideological phenomena such as norms, institutions and even supernatural beliefs (5–9).

The term "complexity," when applied to societies, refers to a cluster of highly intercorrelated social and cultural traits (10). Two such traits are intensive use of resources and sociopolitical hierarchy. Systems of resource use can be said to be intensive when they harvest more energy from a given resource than a previous or alternative system. Typically, the relevant resource is land (11). All else being equal, agriculturalists harness more energy per unit of land than foragers do, and intensive agriculturalists harness more energy than those who practice less intensive forms of agriculture (12). Hence a society that shifts from foraging to agriculture, or from a less intensive to a more intensive form of agriculture, can be said to have intensified its resource base. More intensive systems of resource use are relevant to the evolution of social complexity because they can support larger populations and produce more reliable surpluses, both of which are usually thought to allow or facilitate the emergence of more elaborate forms of social differentiation (ref. 13 and references therein). Hierarchy involves the culturally sanctioned subordination of one group or individual to another within the same social system (14). A previously egalitarian society that develops social classes, or a society of previously independent villages that appoints a supralocal chief, can be said to have become more hierarchical. Like other traits considered characteristic of complex societies, hierarchy and intensive use of resources are strongly linked cross-culturally. Some foraging societies are hierarchical, and some intensive agriculturalists are egalitarian (15), but, in general, intensive agriculturalists tend to be more hierarchical than peoples who practice less intensive forms of agriculture, who in turn tend to be more hierarchical than foragers (16).

Since subsistence is clearly more "material" than sociopolitical organization, materialists typically view intensification as a driver of rather than a response to sociopolitical hierarchy (1, 17, 18). According to one materialist model (1), population pressure drives "intensification," the logistical requirements of which lead

Significance

Over the past 10,000 years, human societies have grown vastly more complex. How and why this occurred is still debated. One major point of contention is the relationship between two characteristic features of complex societies: intensive resource use and sociopolitical hierarchy. The "materialist" view is that intensification drives hierarchy, but the reverse view and intermediate views have also been proposed. Here we report the results of a phylogenetic study on the coevolution of landesque capital intensive agriculture and sociopolitical hierarchy in the Austronesian-speaking world. We find support for a reciprocal coevolutionary relationship between the two variables, challenging the materialist view and highlighting the importance of social as well as material factors as drivers of cultural evolution.

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to "institutionalization." Other materialist theories present a subtly different view whereby intensification and hierarchy lack a direct causal link, but both result from a third variable. Usually this third variable is population pressure, which is a key component of the influential "Boserup model" (19). According to one such theory (20), population pressure drives both an increased dependence on agriculture (via the need to feed more people with the same amount of land) and increased hierarchy (as a result of intragroup competition over resources). "Cultural determinist" explanations of the relationship argue that, in at least some conditions, it is more accurate to attribute intensification to hierarchy than vice versa. Perhaps the best-known proponent of this view is Marshall Sahlins, who argued that, whereas many anthropologists (including himself at an earlier stage in his career) had assumed that leadership arose in response to economic surplus, the relationship between the two had in fact been "at least mutual, and in the functioning of primitive society . . . rather the other way around. Leadership continually generates domestic surplus" (21).

Theories of cultural evolution have traditionally been evaluated using diachronic and synchronic methods (3). Diachronic methods examine changes over time as observed in the historical or archaeological record. While studies of this nature have proven valuable in clarifying the relationship between intensification and social complexity in many parts of the world (e.g., refs. 22–24), the incompleteness of the historical and archaeological records makes synchronic methods a useful complement (2). Synchronic methods have traditionally involved examining patterns of cross-cultural variation and comparing them to the predictions made by particular theories. Cross-cultural studies of this nature made a major contribution in assessing whether or not particular theories were plausible (25), but were unable to conclusively test them due to their inability to uncover causal relationships. The problem of inferring causation from correlation is common to all correlational research, but is particularly salient in cross-cultural studies due to the nonindependence of cultural traits, labeled "Galton's Problem" (26). Given that human societies are related to differing degrees by common origins and cultural diffusion, simple correlations between cultural traits need not imply causal relationships. Although various techniques can be used to reduce the effects of nonindependence (26, 27), the problem of establishing the direction of causation remains: Different theories can and often do predict the same cross-cultural associations.

In recent years, this limitation has begun to be addressed via the use of phylogenetic methods originating in biology. These methods seek to identify independent instances of cultural change by comparing societies whose shared "cultural ancestry" can be modeled using a phylogeny (28). Some of these methods allow inferences to be made about not only whether cultural traits are causally related but also the direction of causation (29). Phylogenetic studies of cultural evolution typically model cultural ancestry using language phylogenies, targeting variation in the cultural traits of interest within a single recognized language family (30). The Austronesian language family, which extends across a vast swathe of Southeast Asia and the Pacific, is uniquely suited to this purpose, and, perhaps for this reason, a number of phylogenetic studies involving Austronesian-speaking societies have already been conducted (31–34). Firstly, with around 1,200 members, it is the largest language family in the world to be widely recognized by linguists (35). Secondly, Austronesian-speaking societies have historically been diverse in terms of social organization and subsistence. Some, like the Ilongot of the Philippines, were egalitarian and acephalous, whereas others, such as Hawaiians and Javanese, lived in centralized, hierarchical states (36). Austronesian-speaking societies also varied considerably in their economies. The great majority were subsistence horticulturalists, but, whereas most practiced shifting or "slash-and-burn" horticulture, traditionally considered the least intensive form of cultivation (19), a considerable number used intensive agricultural techniques such as irrigation (37). Hence Austronesian-speaking societies provide an ideal sample for a phylogenetic study of how resource intensification—specifically agricultural intensification—and sociopolitical hierarchy have coevolved.

The present study investigated the coevolution of intensive agriculture and hierarchy in the Austronesian-speaking world using analyses of correlated evolution. This method models the evolution of pairs of binary traits under a dependent model (in which rates of loss and gain in one trait can depend on the presence or absence of the other trait) and an independent model (in which rates of loss and gain in either trait are independent of the state of the other trait) (38). The degree to which the dependent model is favored over the independent model, as indicated by a Bayes factor, indicates support for coevolution (39). As well as evaluating evidence for coevolution, this method also provides insight into the underlying direction of causation by inferring the specific rates at which a trait is lost or gained in the presence or absence of another trait.

Both materialist and cultural determinist theories predict that intensive agriculture and sociopolitical hierarchy will coevolve, but make different predictions as to the causality underlying the relationship. Materialist theories predict that the relationship will primarily be attributable to intensive agriculture promoting and/or sustaining hierarchy, that is, making hierarchy more likely to be gained and/or less likely to be lost. Cultural determinist theories predict the opposite: The relationship between the two should primarily be due to hierarchy promoting and/or sustaining intensive agriculture. If intensive agriculture and hierarchy were found to promote and sustain each other to a similar extent, this would suggest that neither materialist nor cultural determinist theories accurately characterize this relationship, and that a reciprocal relationship or one involving a third variable is more likely.

One hundred fifty-five Austronesian societies (Fig. 1 and Dataset S1) were coded with respect to three traits: social stratification, political complexity, and landesque capital intensive agriculture. Social stratification and political complexity were chosen to represent sociopolitical hierarchy. Originally ordinal, these variables were binarized using two different cutoff points to create four binary variables: medium-high social

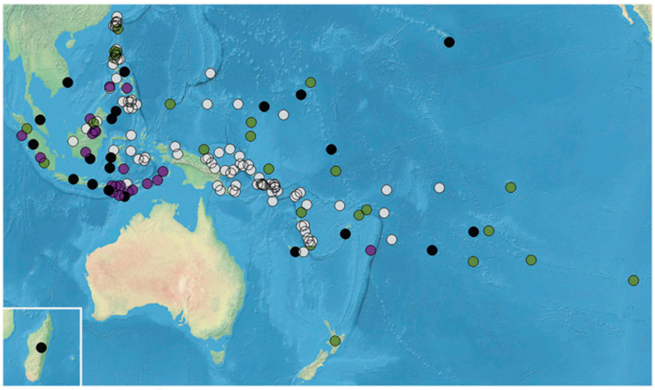

Fig. 1. Distribution of landesque capital and high social stratification in the sample. Each filled circle represents one of the 155 societies in the sample, and its color corresponds to which traits are present in that society (Dataset S1). While the sample does not include all Austronesian-speaking societies, it does represent the entire spatial extent of the Austronesian-speaking world. (Image created using map data from Natural Earth, www.naturalearthdata.com).

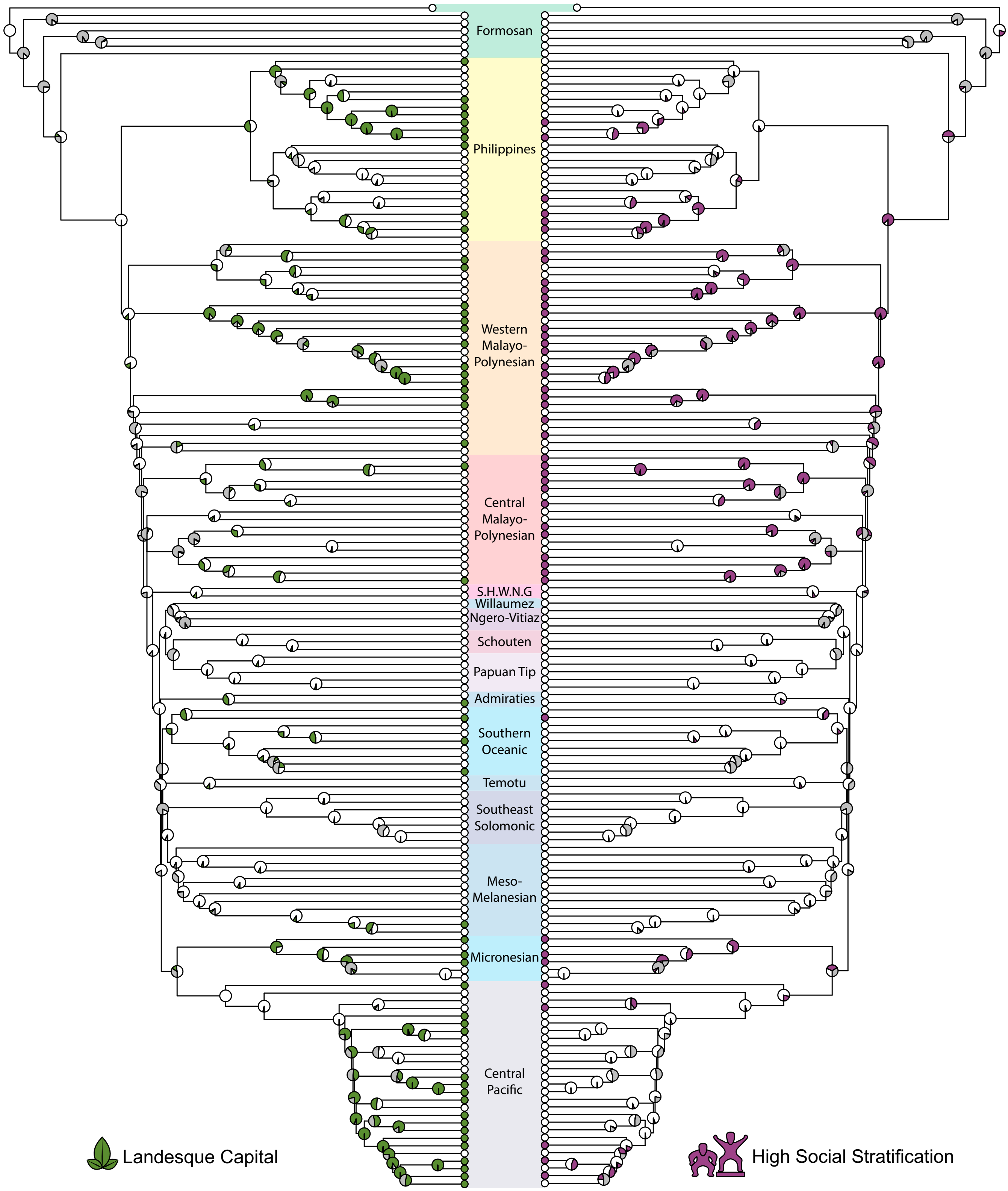

Fig. 2. Coevolution of landesque capital and high social stratification, with fossilized nodes. Shown is ancestral state reconstruction of landesque capital and high social stratification from the dependent analysis, plotted on a maximum clade credibility tree. Pie charts at the internal nodes of the tree represent the proportion of models in which the trait was inferred to be present at that node; gray represents the proportion of trees in the sample from which that particular node was absent. In this analysis, landesque capital was constrained (fossilized) to be absent at five internal nodes, including the basal node. Taxa in this figure are grouped, labeled, and color-coded following ref. 47, figure S5. See Fig. S1 for a version of this figure that includes all taxa names, and Figs. S2 and S3 for reconstructions of the two other combinations of variables for which the dependent model was favored. S.H.W.N.G., South Halmahera-West New Guinea.

stratification, high social stratification, medium-high political complexity, and high political complexity. Landesque capital intensive agriculture (henceforth "landesque capital") is a form of intensive agriculture that involves permanent changes to the landscape, such as the construction of terraces and irrigation canals (40). "Cropping cycle" intensive agriculture, by contrast, involves practices that increase the productivity of land but are not necessarily intended to change the landscape permanently (23). The decision to focus on landesque capital but not cropping cycle intensive agriculture was made for three reasons. First, landesque capital is inherently more suited to being treated as a binary trait, since it involves physical structures that can be deemed present or absent. Second, landesque capital is more likely to be identified in ethnographic sources because it is more obvious: A structure like an irrigation canal is far less likely to be overlooked than a practice like crop rotation. Third, landesque capital appeared to be the dominant mode of intensification within the sample; agricultural systems that were clearly intensive but lacked landesque capital did exist (e.g., refs. 23 and 41) but were rare and appeared to be confined to Remote Oceania.

Unlike many cultural traits, landesque capital often leaves clear archaeological evidence. Since extensive archaeological work has been carried out in the Pacific and parts of Island Southeast Asia (42, 43), two sets of analyses were conducted, one of which incorporated archaeological evidence. On the basis of this evidence, intensive agriculture was constrained ("fossilized") to be absent at five nodes of the Austronesian language phylogeny that could be linked with confidence to specific archaeological cultures (see *Methods* and Table S1). In the second set of analyses, no assumptions were made about the presence or absence of any trait at any internal node of the phylogeny.

Results

Phylogenetic Signal. We used Fritz and Purvis' D statistic (44), to quantify how well the binary variables fitted our sample of trees under a standard Brownian model of trait evolution. A value of $D = 1$ represents the degree of phylogenetic signal expected in a randomly distributed trait, whereas 0 represents the amount of phylogenetic signal expected under a Brownian model. The values of D estimated for the five binary variables ranged from −0.27 (high social stratification) to 0.15 (medium-high social stratification), indicating a good fit of the data to the sample of trees. The probability of obtaining these values in the absence of phylogenetic signal was in all cases estimated to be 0.0001 or less (see *Methods* and Table S2).

Correlated Evolution. Each pair of analyses involved landesque capital and one of the four sociopolitical variables. All four pairs of analyses favored the dependent model, although one only marginally so. The weakest result was for the pair of analyses involving medium-high political complexity, which yielded a Bayes factor of 1.0, considered "not worth more than a bare mention" (39). Support for the dependent model was stronger in the pair of analyses involving high political complexity: In this case, the dependent model was favored with a Bayes factor of 5.3, considered "positive evidence." The analyses involving medium-high and high social stratification (Fig. 2) returned Bayes factors of 6.7 and 8.4, respectively, considered "strong evidence."

Examining the rates at which one trait was lost or gained in the presence or absence of the other provided further insight into the relationship (Fig. 3 and Table S3). Certain traits promoted certain other traits. Landesque capital was 6 times as likely to be gained when medium-high social stratification was present, and 4 times as likely to be gained in the presence of either high social stratification or high political complexity. High social stratification was nearly 5 times as likely to be gained, and high political complexity just under twice as likely to be gained, when landesque capital was present. Evidence that traits sustained other traits—

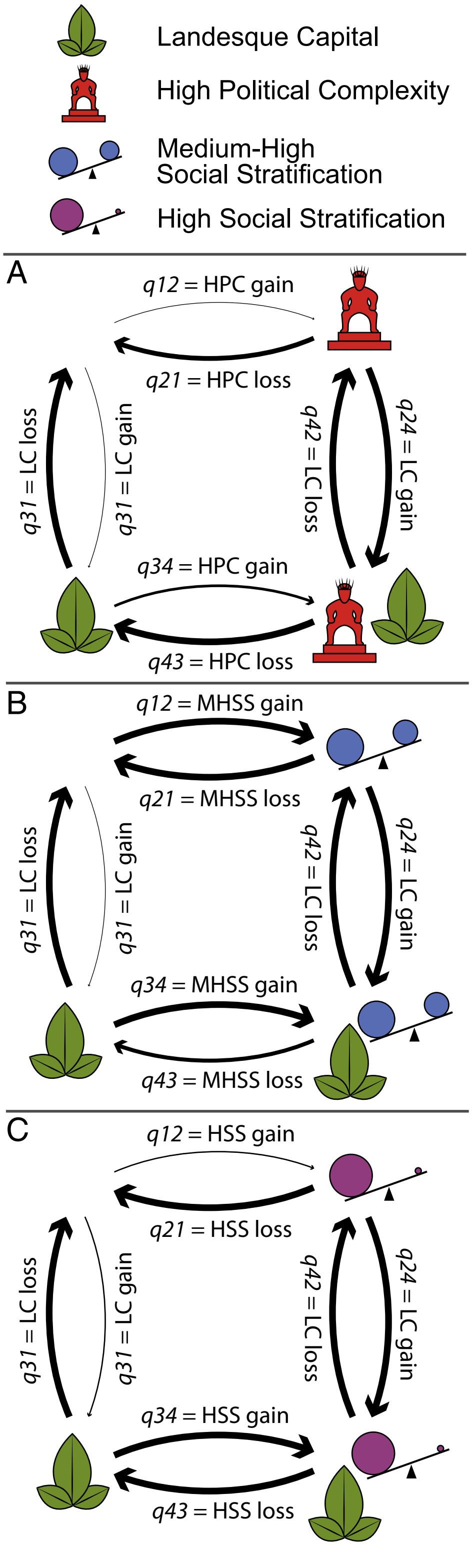

Fig. 3. Transition rate matrices for the three dependent models with fossilized nodes that were favored over the corresponding independent models. Each matrix represents the coevolution of landesque capital with one sociopolitical variable: (*A*) high political complexity, (*B*) medium-high social stratification, and (*C*) high social stratification. The analysis of landesque capital and medium-high political complexity is not depicted here as it did not favor the dependent model. Width of the arrows is proportional to rates of change between different states (see Table S3 for details).

that is, made them less likely to be lost—was very weak. The largest difference in rates of loss or gain in one trait in the presence or absence of another trait was in the opposite direction to what had been predicted: High political complexity was a little more likely to be lost in the presence of landesque capital than in its absence.

All other differences were very small, but were in the predicted direction.

The analyses that lacked fossilized nodes yielded results that were broadly similar to those already reported, but that favored coevolution more strongly. While the pair of analyses involving medium-high political complexity was also inconclusive, the remaining three pairs of analyses all returned Bayes factors corresponding to "strong" or "very strong" evidence of coevolution (Tables S5 and S6).

Discussion

The results supported the coevolution of sociopolitical hierarchy and landesque capital, but also underscored the probabilistic rather than deterministic nature of this relationship. Many societies in the sample had landesque capital but were not hierarchical, or vice versa, and ancestral state reconstructions showed that, while landesque capital and sociopolitical hierarchy tended to appear at similar points in the phylogeny, either trait could appear independently (Fig. 2 and Figs. S1–S3). Support for coevolution was strongest in the analyses involving specifically high levels of the two sociopolitical variables. This was particularly evident in the case of political complexity, only high levels of which were found to coevolve with landesque capital. Possibly, this reflects a dynamic whereby the economic and sociopolitical realms become increasingly integrated as societies become more complex.

No prediction had been made as to whether political complexity or social stratification would be more strongly linked to landesque capital. Nevertheless, the fact that support for coevolution was stronger for social stratification than for political complexity is worth noting. Explanations of the relationship between intensification and hierarchy often see leadership as either a driver (21) or a result (1) of intensification. Political complexity, by definition, involves leadership (45), whereas social stratification need not: An elite may possess economic influence but not formal political power. If leadership were the key to this coevolutionary relationship, the reverse should have been found: Coevolution should have been favored more strongly in the case of political complexity than of social stratification. This result suggests that the existence of an economic elite is more closely linked to intensification than political leadership is. Economic elites could have promoted intensification using a range of strategies, either direct (e.g., commissioning and/or financing landesque capital projects) or indirect (e.g., making demands for rent or repayment of debts that commoners could more easily meet by farming more intensively). Conversely, intensification could have facilitated the emergence of economic elites by providing larger surpluses that could be appropriated and/or redistributed. Intensification may also have allowed populations to expand to a size at which greater inequality could be sustained, and made them more sedentary and hence easier to control both politically and economically (46).

No support was found for the materialist view that intensification is primarily a driver rather than a result of hierarchy. In two of the three sets of analyses in which the dependent model was favored (those involving medium-high social stratification and high political complexity), hierarchy promoted landesque capital to a far greater extent than the reverse. In one (involving high social stratification), the effect of landesque capital on hierarchy was marginally greater than the reverse. Sahlins' observation that the relationship was "at least mutual" and often "the other way around" (21) seems apt.

Although landesque capital and hierarchy promoted each other, evidence that they sustained each other was weak. One post hoc explanation for the fact that hierarchy promoted but did not sustain landesque capital relates to the different labor requirements of cropping cycle and landesque capital intensification. Whereas cropping cycle intensification requires a sustained increase in labor for each unit of productivity gained, landesque capital may require only an initial investment of labor (23). If it is assumed that farmers avoid increasing their workloads unless under pressure to do so (Boserup's "law of least effort"), that such pressure is often applied by elites, and that maintaining a system of landesque capital is less laborious than adopting one, it seems reasonable that hierarchy would promote but not maintain this type of intensive agriculture. Further studies could test this hypothesis by assessing whether cropping cycle intensification is sustained as well as promoted by sociopolitical hierarchy. It is less clear why landesque capital promoted but did not sustain hierarchy, but a possible explanation is that the influence of intensive agriculture upon hierarchy is mediated rather than direct. Intensive agriculture could have promoted hierarchy indirectly by increasing population size. It seems reasonable to assume that hierarchy develops more easily in larger than in smaller populations (46), but it is not obvious why hierarchy would be more likely to persist in a larger than in a smaller population.

The results of this study are not consistent with materialist models wherein social and political hierarchies develop as a result of intensification, although neither are they entirely consistent with a cultural determinist model involving the reverse. Instead, they suggest that intensification and hierarchy promoted each other to a comparable extent, perhaps as a part of a feedback loop that may also have involved population growth. These results also underline two important points about human cultural evolution. First, social and political factors, far from being epiphenomenal or secondary to the process, are among its most important drivers. Second, the evolution of complex societies is itself complex. Not only are many factors involved, but the relationship between these factors is rarely deterministic.

Methods

Phylogenies. Cultural ancestry was modeled using a sample of Austronesian language phylogenies originally created by Gray et al. (47). This sample consists of 4,200 trees, each incorporating 400 Austronesian languages; 213 of the 400 languages in the sample could be matched to a society for which adequate ethnographic information was available. These societies numbered 155, of which 131 spoke only one of the languages in the phylogeny. The language that was numerically or culturally dominant was chosen to represent each of the remaining 24 societies, and the original sample was pruned so as to include only the 155 selected taxa.

Coding of Variables. Societies in the sample were coded with respect to three variables: landesque capital, political complexity, and social stratification. The first variable was coded in binary form, with 0 representing societies in which landesque capital was absent or of minor importance, and 1 representing societies in which it was present and made a major contribution to subsistence. The two sociopolitical variables, social stratification and political complexity, were originally created by Murdock and Provost (45) as ordinal variables with the same five states (0, 1, 2, 3, and 4) representing increasing levels of hierarchy. In societies in which different subgroups showed different levels of hierarchy, the level characteristic of the majority of communities within the society was coded, or, if the latter was unknown, the highest level. These two ordinal variables were subsequently binarized to make them suitable for the intended analyses of correlated evolution. The same two cutoff points ($0, 1 \rightarrow 0$ and $2, 3, 4 \rightarrow 1$; $0, 1, 2 \rightarrow 0$ and $3, 4 \rightarrow 1$) were applied to each variable, resulting in the creation of four binary variables: medium-high social stratification, high social stratification, medium-high political complexity, and high political complexity.

A range of ethnographic sources, including encyclopedias, ethnographies, and archaeological surveys, were used in the process of coding the five variables. Each coding decision was justified with citations (Dataset S1). Since many Austronesian societies underwent major cultural changes as a result of colonization, and because endogenous rather than externally imposed change was of interest in the present study, societies were coded as they were immediately before the colonial period.

Phylogenetic Signal. The strength of phylogenetic signal in the binary variables of interest was assessed by calculating Fritz and Purvis' D statistic (44), using the package "caper" (48), in the programming language R (49). A value of $D = 1$ represents the degree of phylogenetic signal expected in a randomly distributed trait, whereas 0 represents the amount of phylogenetic signal expected under a Brownian model of trait evolution. Ten thousand permutations of the test were run for each binary variable.

Correlated Evolution. Two sets of analyses of coevolution were run. The first involved fossilized nodes. On the basis of archaeological evidence (42, 43), landesque capital was constrained (fossilized) to be absent at five internal nodes of the phylogeny (Table S1), corresponding to proto-Austronesian, proto-Malayo-Polynesian, proto-Oceanic, proto-Central Pacific, and proto-Polynesian. In the second set of analyses, no nodes were fossilized. In all other respects, the two sets of analyses were identical.

Correlated evolution was investigated using a Bayesian Reversible-Jump Markov Chain Monte Carlo approach implemented in the "Discrete" component of the computer package BayesTraits (50). This method involves the testing of an independent model (in which rates are independent) against a dependent model (in which rates can covary). Each set of analyses involved four pairs of individual analyses, each pair consisting of a dependent and an independent model. Each individual analysis involved a pair of binary variables, i.e., landesque capital and one of the four binarized sociopolitical variables. Based on the results of Maximum Likelihood estimations, an exponential hyperprior with a mean of between 0 and 0.5 was chosen for all analyses. Each analysis involved running the Markov Chain for 100,000,000 iterations, with the first 10,000,000 removed as burn-in. A stepping-stone sampler with 100 stones was run for 10,000 iterations to compute a marginal likelihood for the dependent and independent models. On the basis of these marginal likelihoods, Bayes factors were calculated.

Bayes factors were interpreted following a scheme (39) according to which a Bayes factor of less than 2 is considered "not worth more than a bare mention," 2 to 6 is considered "positive," 6 to 10 is "strong," and 10 or greater is "very strong" evidence in favor of the dependent model.

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