Social Sciences, Anthropology

Population Size Predicts Technological Complexity in Oceania

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Much human adaptation depends on the gradual accumulation of culturally transmitted knowledge and technology. Recent models of this process predict that large, well-connected populations will have more diverse and complex toolkits than small, isolated populations. While several examples of the loss of technology in small populations are consistent with this prediction, it found no support in the only systematic quantitative test it has faced. Here we show that in Oceania, islands with small populations had less complicated marine foraging technology. This finding suggests that optimality models used by human behavioral ecologists are incomplete because gradual cultural adaptation depends on demography. It also indicates that hominin populations with similar cognitive abilities may leave very different archaeological records, a conclusion that has important implications for our understanding of the origin of modern humans.

Humans occupy a greater diversity of habitats, use a broader range of resources, and form a wider array of social systems than any other animal species. This diversity is usually explained in terms of human cognitive ability—we are better at adapting because we are smarter than other creatures (1). However, a number of authors (2–4) have argued that culture, not raw intelligence, is the key to understanding human adaptability. Humans are much better at learning from conspecifics than any other animal, allowing them to gradually create increasingly complex technologies, knowledge, and institutions too elaborate for any one person to invent. One important corollary of this hypothesis is that larger populations will generate more complex cultural adaptations than smaller, isolated ones (5–7). Here, we test this prediction and show that in Oceania large, well-connected populations had more complicated marine foraging technology than did small, isolated populations.

Two models of cultural adaptation predict that large populations will have more diverse and more complex toolkits than small isolated populations. First, culturally transmitted information is subject to a process analogous to genetic drift (5, 6)—cultural variants are lost by chance when their practitioners are not imitated. For instance, the most knowledgeable net maker may not be copied because she is poor, unsociable, or dies unexpectedly. The rate of loss due to cultural drift will be higher in small, isolated populations than in large, connected ones. Second, social learning may be imperfect, and “pupils” may not attain the level of expertise of their “teachers;” as a result, the average level of expertise in the population will decrease. Inaccurate learning creates a “treadmill” of cultural loss, against which learners must constantly work to maintain the current level of expertise. This process is counteracted by the ability of individuals to learn selectively from expert practitioners, so that cumulative cultural adaptation happens when a rare pupil surpasses her teacher (7,8). Learners in larger populations and in populations with higher levels of external contact have access to a larger pool of experts, making such improvements more likely.
Existing empirical evidence bearing on this hypothesis is mixed. There are a number of examples of the degradation of technology in small island populations. For instance, the Tasmanian toolkit gradually became simpler after isolation from mainland Australia \((7–10)\) and other Pacific groups have apparently abandoned useful technologies such as canoes, pottery, and the bow and arrow \((11)\). The isolated Polar Inuit may also have lost kayaks and the bow and arrow \((12)\). The only systematic attempt to test this hypothesis \((13)\) found no relationship between population size and toolkit diversity or complexity. However, this analysis did not include any measure of contact and was drawn mostly from northern continental regions of the western hemisphere where intergroup contact was probably common \((14,15)\). If contact offsets the effects of small population size (as the cultural adaptation models predict) then the results from this analysis may not be robust.

Here, we examine the effects of population size and contact on the complexity of marine foraging toolkits among island populations in Oceania. Because island populations are geographically bounded, it is possible to estimate population sizes and contact rates with a reasonable degree of accuracy. Our sample is drawn from the electronic Human Relations Area Files World Cultures database \((16)\) and consists of information on indigenous marine foraging toolkits from 10 island societies (Table 1). Rates of contact are defined as high or low by the eHRAF Culture Summaries. The groups in our sample share a common cultural descent and similar marine ecosystems, minimizing the potential impact of cultural history and ecological variation on technology. In addition, we have attempted to control for variation in marine biodiversity using the number of fish genera per region as listed in Fishbase \((17)\). Similarly, for each society we used three measures to control for the amount of ethnographic effort. We tabulated two kinds of data on marine foraging tools: the total number and the complexity of tool types. Tool complexity scores ranged from one techno-unit \((18)\) (see methods for definition) (e.g., a stick used for prying shellfish from the reef) to sixteen techno-units (e.g., an untended crab trap made of a bamboo tube and baited lever). We used log-transformed population size, tool number, and tool complexity data because both the treadmill and drift models predict a concave relationship between effective population size (a function of local population size and contact rate) and technological complexity.

**Results and Discussion**

Analysis of these data support the hypothesis that gradual cultural evolution causes large populations to have a greater number of more complex cultural adaptations than small, isolated populations in three ways:

First, larger island populations have a larger repertoire of tools than smaller island populations (Figure 1). In a linear regression model, the effect of population size on the number of tools is strong and highly significant \((\beta = 0.805, p = 0.005, n = 10)\). The number of fish genera in the region was not significantly related to the number of tools produced \((\beta = 0.480, p = 0.161 n=10)\). Neither the number of publications \((\beta = 0.480, p = 0.161 n = 10)\) or any other measure of ethnographic effort significantly predicts the number of tools.
Second, both models of cultural adaptation predict that contact will be less important in larger populations. Our data provide some support for this prediction. Figure 1 shows that four of the five high contact societies have more tool-types than expected based on their population size. These five societies all fall in the intermediate range of population size. As figure 2 shows, low contact groups tended to have fewer tools than expected while high contact groups tended to have more (Mann-Whitney, $U = 5$, 1-tailed exact $p = 0.075$, $n = 5$).

Finally, both models of cultural adaptation predict that complex tools will be especially prone to loss because it is harder to learn how to make them (7) and they will be more affected by cultural drift if component parts of a tool are the units of inheritance. This prediction is supported by the data. The mean number of techno-units is significantly higher in larger populations than in smaller populations ($\beta = 0.706$, $p = 0.022$, $n = 10$). Tool complexity is not associated with number of publications ($\beta = 0.233$, $p = 0.516$, $n = 10$) or any other measures of ethnographic effort, or with the number of fish genera ($\beta = 0.495$, $p = 0.146$, $n = 10$).

There are two alternate explanations of the relationship between population size and tool complexity, but neither explains the relationship between contact and tool complexity. First, it is possible that complex technology increases the local carrying capacity, and this causes population growth. But it is not clear why rates of contact between islands would be linked to rates of population growth. Second, large populations have more domains of specialization (19), and this might lead to a more diverse toolkit. This only provides a competing explanation if increased specialization is not caused by the increase in tool complexity itself, but by some other correlate of population size. For example, economies of scale in large populations might permit higher degrees of specialization. Again, this does not explain the relationship between tool complexity and rates of contact.

Archaeologists often assume that the cognitive abilities of a hominin species can be inferred from the complexity of the artifacts that they have produced. For example, the use of ochre and other signs of modernity appear sporadically in the archaeological record of Africa during the late Middle Pleistocene. Since it seems unlikely that cognitively complex hominins evolved and then disappeared from Africa, some archaeologists have suggested that the finds are incorrectly dated or otherwise artifactual (20). However, if population size affects technological complexity, other interpretations become plausible. For example, Shennan and colleagues (21) have argued that the geographical patterning of the first emergence of markers of modern human culture, and their subsequent spatiotemporal transience, are better explained by changes in population size than by a late, species-wide cognitive revolution. Similarly, Hill et al (22) have argued that the sporadic appearance of sophisticated tools during the Late Stone Age in Africa can be understood as the result of fluctuations in population size that were induced by climate change.

These results also suggest that gradual cultural evolution plays an important role in human adaptation. Human behavioral ecologists sometimes assume that most human behavior is adaptive in contemporary environments (23). From this perspective, technological loss occurs when the tools are no longer part of the optimal kit. But our results suggest that cultural adaptation also occurs over longer time scales; when
populations are small and isolated this can lead to reduced technological diversity and complexity, so that variation may be better predicted by demography than by optimization models.

These findings are a first step in understanding the nature of cumulative cultural gains and losses. Although our sample size is small and our analysis is restricted to a limited range of tool types, our results suggest that cultural drift or the treadmill mechanism may have influenced the evolution and adaptive radiation of Homo sapiens as a cultural species.

**Materials and Methods**

We tabulated two kinds of data: the total number and the complexity of tool types. Tool types were established using the following criteria: (a) tools had different names and at least one non-overlapping function, (b) tools had different mechanical structures, or (c) tools were made through different production processes. Tool complexity was quantified by the number of “techno-units.” A techno-unit was defined by Oswalt (18) as “an integrated, physically distinct, and unique structural configuration that contributes to the form of a finished artifact (p. 38).” We include decorative elements in these counts because the production of any part of the tool may be socially learned and thus subject to the dynamics of the cultural transmission process upon which both models are based. Techno-unit counts are based on verbal descriptions, illustrations, and photographs from the eHRAF. If a given tool was present in more than one group’s toolkit, we coded each tool independently; we then used the mean of these ratings as the count for all instances, so that the same tool had the same techno-unit rating across all groups. This helped to control for coder bias and worked against our hypotheses by decreasing variation between groups.

**ACKNOWLEDGEMENTS.** This work was supported in part by UCLA Graduate Division fellowships to M.A.K. Thanks to Clark Barrett, Jeff Brantingham, Sam Boyd, Matthew Gervais, Kim Hill, Ruth Mace, Charles Perreault, Joan Silk, and John Tooby for useful comments on this research.
Table 1. Data on population size, contact, and toolkits for each population in our sample. Data were coded from the electronic Human Relations Area Files ethnographic database. Total number of tools includes artifacts for which there was no techno-unit (TU) information available; mean techno-units are based only on tools for which techno-unit information was available. The proportion of tools with techno-unit information ranged from 55% to 78% for each group, and is not significantly associated with mean techno-units (Pearson’s $r = -0.089, p = 0.404, n = 10$)

<table>
<thead>
<tr>
<th>Culture</th>
<th>Population</th>
<th>Contact</th>
<th>Total Tools</th>
<th>Mean TU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malekula</td>
<td>1100</td>
<td>low</td>
<td>13</td>
<td>3.2</td>
</tr>
<tr>
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<td>low</td>
<td>22</td>
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<tr>
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Figure 1. Number of tools as a function of population size. Larger populations have significantly more tool types than smaller populations. The trend line is based on a linear regression of the logarithm of the number of tools against the logarithm of population size ($\beta = 0.805$, $p = 0.005$, $n = 10$). Four of five low-contact groups have fewer tools than expected, while four out of five high-contact groups exceed the expected number of tools.
Figure 2. Difference between expected and actual number of tools per society. High contact groups tended to have more tools than expected while low contact groups tended to have fewer tools than expected based on population size. (Mann-Whitney, $U = 5$, $p = 0.075$, $n = 5$) Within contact conditions, groups are ordered from smallest to largest population size, from left to right.
Figure 3. Mean number of techno-units by population size. Larger populations have significantly more complex tools than smaller populations. The trend line is based on a linear regression of the logarithm of mean techno-units per tool against the logarithm of population size ($\beta = 0.706, p = 0.022, n = 10$).
References

16. World Cultures Ethnography Database. (Human Relations Area Files, Inc.; http://ehrafWorldCultures.yale.edu; 2008).