Latitudinal patterns and environmental determinants of recent human cultural diversity: do humans follow biogeographical rules?

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ABSTRACT

Biogeographers have noted many strong patterns in the diversity and distribution of animal and plant taxa. Human cultural diversity also exhibits strong geographical patterns. Here we analyse the global distribution of 3814 human cultures in relation to latitude and climatic parameters. The density and diversity of human cultures declines with latitude and increases with temperature and rainfall. Human cultures in tropical, wetter or warmer areas have smaller ranges and are more densely packed and differentiated. These relationships can be documented statistically in ways that parallel species diversity among other organisms. The global nature of these patterns implies ecological equilibrium independent of evolutionary history in different continents, and has implications for the interpretation of human genetic diversity, as well as for the understanding of processes of human cultural diversification and their relationship to evolutionary and ecological mechanisms.

Keywords: biogeography; human evolutionary ecology; cultural diversity; cultural density; latitudinal gradient.

INTRODUCTION

The distribution of plants and animals in space has been a topic of long standing interest to biologists. In particular there has been considerable debate concerning the global and continental patterns of variation in species diversity and richness (for reviews see Myers & Giller 1988; Rosenzweig 1995). It has been shown that the number of species occurring within a given area of land, and inversely, the area over which any one species is distributed, varies with latitude, temperature, productivity, available area and the degree of environmental perturbation that may have occurred in the past. Although there are several competing hypotheses to explain the variation that has been observed (Rosenzweig 1992; Rosenzweig & Sandlin 1997; Rohde 1998; Chown & Gaston 2000) nonetheless there is consensus that the pattern of variation is ultimately a product of historical, ecological and environmental parameters.

These biogeographical analyses stem from the way in which plants and animals are divided into species and higher taxonomic units. In contrast, humans all belong to the same species, and it may seem at first sight that such models are inappropriate. However, human populations are not entirely continuous, and have historically become subdivided by language, culture and other factors. This cultural diversity is the focus of much

anthropological study and it is reasonable to ask whether the processes by which diversification occurs, and subsequent diversity is maintained, is subject to the same ecological mechanisms that underlie biogeographical patterns in other taxa.

Mace & Pagel (1995) have shown a latitudinal gradient for North American linguistic diversity, and Nettle (1998) has also looked at linguistic diversity globally in relation to subsistence and habitat. Although there are clear and fundamental differences between species and cultures or human societies as units, a visual inspection of their global distribution (Figure 1) shows that there is considerable variation in cultural diversity from one part of the world to another. As cultural patterns reflect the formation of some form of boundary between groups, analogous to the formation of boundaries between species, then it is possible to examine the distribution of human cultures as being the product of ecological parameters.

A number of hypotheses can be proposed for the pattern of human cultural diversity. The simplest would be that it merely reflects the events of history, and that there is no relationship between patterns of cultural diversity and those of other species and populations. A second, more neutral, hypothesis would be that the historical element does not produce random patterns, but reflects the amount of time populations have been in a particular area. Diversification would in this sense be a property similar to genetic diversity, and that the greater the diversity, the greater the length of population history (Cavalli-Sforza et al. 1988). Using the analogy of human genetics, therefore, we might expect Africa, where people have been the longest (Cann *et al.* 1987; Stringer & Andrews 1988; Harpending *et al.* 1993; Lahr 1994), to have much greater diversity than South America, with a human history of less than 20,000 years (Lahr 1995; Forster *et al.* 1996). A further set of hypotheses would predict that cultural diversity would reflect the constraints and potential carrying capacity of the environment, and would thus be related to aspects of biomass, productivity, growing season, etc. (Mace & Pagel 1995; Nettle 1998).

In this paper we explore the pattern of recent human cultural diversity in relation to the environment, with a view to seeing whether historical or ecological factors play a significant role in determining the pattern of variation. Mace and Pagel (1995) in particular have argued that group boundary formation may be an active process in response to resource competition, and that language diversification follows from this. Here we extend this linguistic work by exploring the geographical pattern of recent global human cultural groups in relation to the environment, with a view to seeing whether this follows other biogeographical mechanisms, and the extent to which historical or ecological factors play a significant role.

METHODS

Human cultural diversity

The anthropological unit, 'the culture', refers to a social group that shares some set of traits such as language, dialect, belief system, political organisation, kinship system, etc., and which is distinct, either in its own view or the view of other such units. The distribution of human cultural groups shown in Figure 1 was derived from a series of forty small-scale maps in the *Atlas of World Cultures* (Price 1990). Latitude and longitude values for each of more than 3,800 cultures listed in the atlas were calculated and mapped.

Figure 1. Distribution of human cultures by longitude and latitude: The dashed lines indicate the longitudinal bands (Americas, Africa/Europe, Oceania/South & East Asia) into which the dataset was divided for analytical purposes.
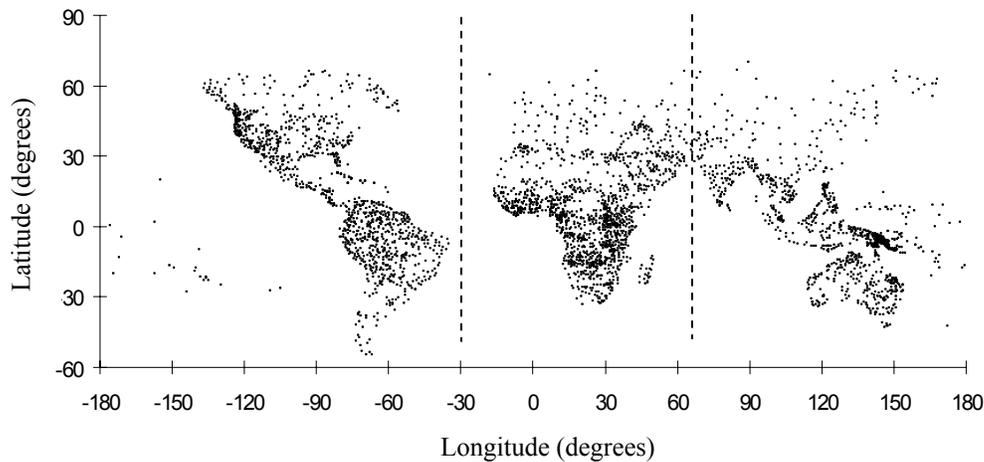
We should make it clear at the outset that we are not viewing human cultures as species, but that because they share with species distinctive traits and discrete geographical distributions they provide a basis for quantitatively analysing biogeographical patterns. This equivalence extends to the process of diversification. Since the origins of our species, and specifically during the past 40,000 years, human groups have differentiated through a process of cultural rather than biological evolution. Despite the broad social, cultural and linguistic differences between the world's populations the human species remains biologically and genetically homogenous. The major differences between human groups, on local and continental scales, are social and cultural. However, they occur geographically and against an ecological background.

Price's *Atlas of World Cultures* was established as a source of bibliographic information for anthropologists. It is limited in being based on a survey of anthropological works, rather than a full compilation based on all historical records, but is nonetheless probably the most comprehensive such survey. The data have been treated uncritically in these analyses, but a number of potential problems should perhaps be recognised.

First, the cultural unit is itself a matter of considerable debate (Barth 1969; Fried 1975). Cultures are the basic unit for much anthropology, and there is a general recognition that human social variation is broken into such units. However, these units have been subject to much controversy on the grounds that they are not isolated from each other, that they merge and split continuously, and that both people and cultural items flow across boundaries. Some cultures are defined linguistically, others socio-politically; in some cases there are clear-cut distinctions between cultural groups, while in others there may be an arbitrarily disconnected continuum. The nested lineage structure of many societies also means that they may be recognised at a number of different levels, and these may not always be systematically identified (Goody 1973). For example, the Maasai represent a distinct linguistic group, but they are also divided into relatively discrete clans, which may have an independent socio-political organisation. The level to which ethnographers have identified such groups may vary. It should thus be recognised that the

cultural database may exhibit such variations in actual cultural patterns or else in the way anthropologists have classified them. Although anthropologists have mounted many cogent criticisms of the essentialist view of culture, and would rather emphasise its fluidity, in this paper, as with other such comparative approaches, we have, for analytical purposes, taken the unit of culture to have some spatial and temporal validity.

This problem of definition may seem fatal to our approach, but it should be noted that similar problems plague the analytical use of species, sub-species and populations in biology. As many biologists have noted Mayr's (1942) Biological Species Concept is far from unproblematic. Defined by reproductive potential, populations of similar organisms are assigned to different species if they lack the potential to interbreed. However certain populations, such as wolves (*Canis lupus*) and coyotes (*Canis latrans*), are classified as different species because of their apparent choice not to interbreed, despite their ability to produce viable offspring.

In the evolutionary arena ancestral and descendent species are defined rather by morphological differentiation than reproductive isolation (Futuyma 1986). Yet the classical typological approach to species division discounts the inclusion together of different looking forms or polymorphic types of interbreeding individuals.

Clearly the distinction of discrete biological or cultural units is not an easy one, and the validity of the unit employed will depend upon the questions asked. Here we are using observable geographical units to ask questions about the process of diversification, and in this context we consider the cultural unit to be a valid one.

Second, the database is biased towards areas without long-term state formation. This is a genuine historical process, where, for example, the expansion of states and empires in Europe and Asia has resulted in a fusion and absorption of cultural units. Some may have persisted historically for longer than others. However, the effect of these would be to reduce the visibility of any older ecological patterns (although they themselves may be following biogeographical principles) (Diamond 1997), and thus make classic biogeographical hypotheses harder to demonstrate. And third, the data is provided as latitudinal/longitudinal points, and thus may be skewed where cultures have very large ranges. These problems should be borne in mind in considering the significance of any results obtained.

In the end, many anthropologists will simply not accept that cultures can be treated analytically in this way. However, we would make two arguments in response. The first is that it is important to separate out the question of how easy it is to define any particular cultural unit from the issue of whether such units exist. The second, following on from this, is that the treatment of cultural units in this analysis is based on a simple model: that over the course of various historical time periods differentiation has occurred between human populations such that both the participants and external observers can, with a reasonable degree of agreement, identify the outcomes of such differentiation (in terms of language, political system, etc.). Number of cultures is thus a measure of *one form* of social differentiation. In this paper we are asking the question of whether ecological factors, analogous to those found in other biogeographical systems, can be said to be conditioning the rate and distribution of differentiation.

Analytical parameters

The database generated from Price was used to calculate cultural density (number of cultures per unit area) using 10° and 2° latitudinal sections, for both low and high geographical resolution analyses. We also obtained climate data that related to the same unit areas. The two degree resolution rainfall data were acquired from the Joint Institute for the Study of the Atmosphere and Ocean (1995) at http://tao.atmos.washington.edu/legates_msu/. Legates and Wilmott's 0.5-degree resolution temperature data were taken from the National Center for Atmospheric Research Data Support Section archive (1996) at ftp://www.ncardata.ucar.edu/datasets/ds236.0/.

RESULTS

Latitude

It can be seen from Figure 1 that the distribution of cultures is not random. Table 1 shows their distribution by latitude and continental landmass. From this, and Figure 2, which is based on densities of cultures, it can be seen that there are far more cultures in tropical areas than in high latitude areas, and this is true for both 'old continents' (in human evolutionary terms) such as Africa, and 'new continents' such as the Americas. Africa and the Americas show the greatest number of cultures, while Europe is relatively homogenous. This is likely to reflect both historical processes, particularly the effect of empire formation in Europe, and the relative areas of land in these continents.

Table 1. The distribution of cultures by latitude: The data shown in this table are absolute numbers, which reflects both ecological patterns and the availability of land area; for example, the small scale of Central America compared to equivalent latitudes in Africa. The cultures represented indicate those that have been identified ethnographically, and include both those in Africa and Australia known only from the recent past, and more historically deep ones for regions such as Europe and Asia. Figures in brackets represent cultural density values for each continent.

Latitude	Africa	Americas	Asia	Europe	Oceania	Totals
80 - 90 N			1			1
70 - 80 N		18	11			29
60 - 70 N		90	38	12		150
50 - 60 N		81	22	25		128
40 - 50 N		212	41	51		304
30 - 40 N	50	177	96	5		328
20 - 30 N	44	99	184			327
10 - 20 N	186	72	147		2	407
0 - 10 N	357	157	93		24	631
10 - 0 S	196	166	46		272	680
20 - 10 S	198	124	2		103	427
30 - 20 S	86	65			134	285
40 - 30 S	24	22			59	95
50 - 40 S		10			7	17
60 - 50 S		5				5
Totals	1131 (37)	1309 (31)	680 (15)	93 (8)	601 (67)	3814 (28)

The relationship between cultural density and latitude is statistically significant. At the ten degree scale the correlation coefficient was $r = 0.93$, $p < 0.001$. The best fit line was a curvilinear one (Figure 3a), with average cultural diversity falling by around fifty

percent between the equator and latitude 25° i.e. the effect of latitude beyond the tropics is relatively weak. At the two degree scale the relationship was weaker, but still highly significant ($r = 0.87$, $p < 0.001$). The difference in the strength of the relationship is probably due to the fact that the highly resolved data are more likely to pick up local anomalies in environment due to patterns of relief and rainfall. Furthermore, as Figure 2 suggests, there was no difference statistically ($F = 1.47$, $t = 1.82$) between cultural diversity at comparable latitudes in the northern and southern hemispheres. This is not to say that at a micro-geographic level the pattern of human cultural diversity will be identical both north and south of the equator, not least because the availability of continental land is far greater in the northern than southern hemisphere. For example, cultures are known to exist as far north as 80° but, with the exception of Antarctica, all land in the southern hemisphere lies within 54° of the equator. It appears from these analyses, however, that where land is available the constraints on diversification of populations operate equally on either side of the equator.

Figure 2. Average cultural density at two degree intervals around the globe: Average cultural density is measured by the number of cultures per million square kilometres at two degree intervals around the globe. The highest densities occur close to the equator in each hemisphere. The distribution to the south is less extended than that of the north due to the absence of land in the southern hemisphere. High cultural densities in the higher latitudes of the southern hemisphere are the product of the islands of the southern Atlantic. Islands are outliers in these distributions as they usually have only one cultural unit regardless of the size of the land. The statistical analysis is carried out both with and without the extreme outlier (56° south, Tierra del Fuego), the results of which can be found in the Appendix.
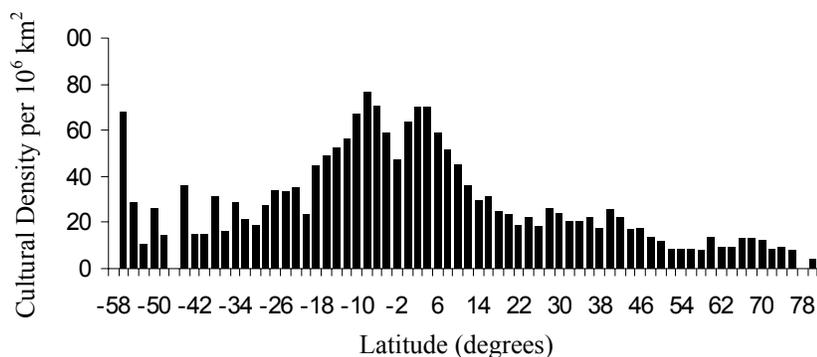
Temperature and rainfall

Latitude is obviously not a direct measure of the environmental parameters operating on populations, but is a surrogate for more immediate factors such as rainfall and temperature. As would be expected, given the strong relationship between latitude and temperature, there is a strong positive correlation at both the ten degree ($r = 0.84$, $p < 0.001$) and two degree ($r = 0.80$, $p < 0.001$) analyses (Figure 3b). Again, the relationship is stronger at the broader resolution. Once the effect of latitude is removed, however, there is no statistically significant relationship between mean annual temperature and cultural density, suggesting that while temperature is an important factor, it operates at a macro rather than micro scale.

One possibility is that this curvilinear relationship is another reflection of the Boltzmann factor (for a review see Gillooly *et al.* 2001). This proposes that increases in environmental temperature will lead to exponential increases in the rate of energy

turnover in an ecosystem. Put another way, warmer biomes will become exponentially more productive than cooler ones. If productivity in turn lies at the basis of cultural density, then it follows that more productive regions will support greater densities of cultures, following the curvilinear relationship observed in these analyses.

Cultural density also increases with mean annual rainfall (Figure 3c). This is a strong linear relationship, particularly at the ten degree scale ($r = 0.86$, $p < 0.001$). While the strength of the relationship between rainfall and cultural density is weaker at the finer resolution, it is still more marked than that of cultural density and temperature (see Appendix). This suggests that rainfall is playing a significant local role in determining cultural diversity, which the finer resolution data can pick up. As with temperature latitude and rainfall are themselves positively related; when latitudinal effects are removed, however, cultural density still increases with increasing rainfall ($p < 0.05$). This underlines the point that rainfall, which has a close relationship with primary production and biomass, especially in the tropics, is the most important determinant of cultural diversity.

Given the strong interaction between latitude (and correlated temperature) and rainfall, one approach is to use multiple regression. As expected, this produces the strongest relationships, and at the ten degree scale 91% of the variation in cultural density, and 78% at the two degree scale, is explained.

Continental patterns

A further possibility is that the global patterns observed are masking distinctive and different regional or continental patterns. To test for this the world was divided into three relatively equal sized longitudinal sections - one covering the Americas, one Africa and Europe, and one Oceania and eastern and southern Asia (see Figure 1). In effect these provide three independent latitudinal gradients, with very different cultural histories. However, all three sections showed the same trends as were found in the global dataset. The African-European section and the Americas section match each other closely. The Oceania - eastern and southern Asia section shows a much steeper decline with latitude, reflecting the very high cultural density found in New Guinea. The resulting equations are shown in the Appendix.

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Figures 3. Relationship between cultural density and latitude (a), temperature (b), and rainfall (c). Similar relationships were found at the two and ten degree scales of resolution, and when the world was divided into three continental longitudinal zones. Note the statistical analyses are carried out both excluding and including the extreme outlier (see Appendix).
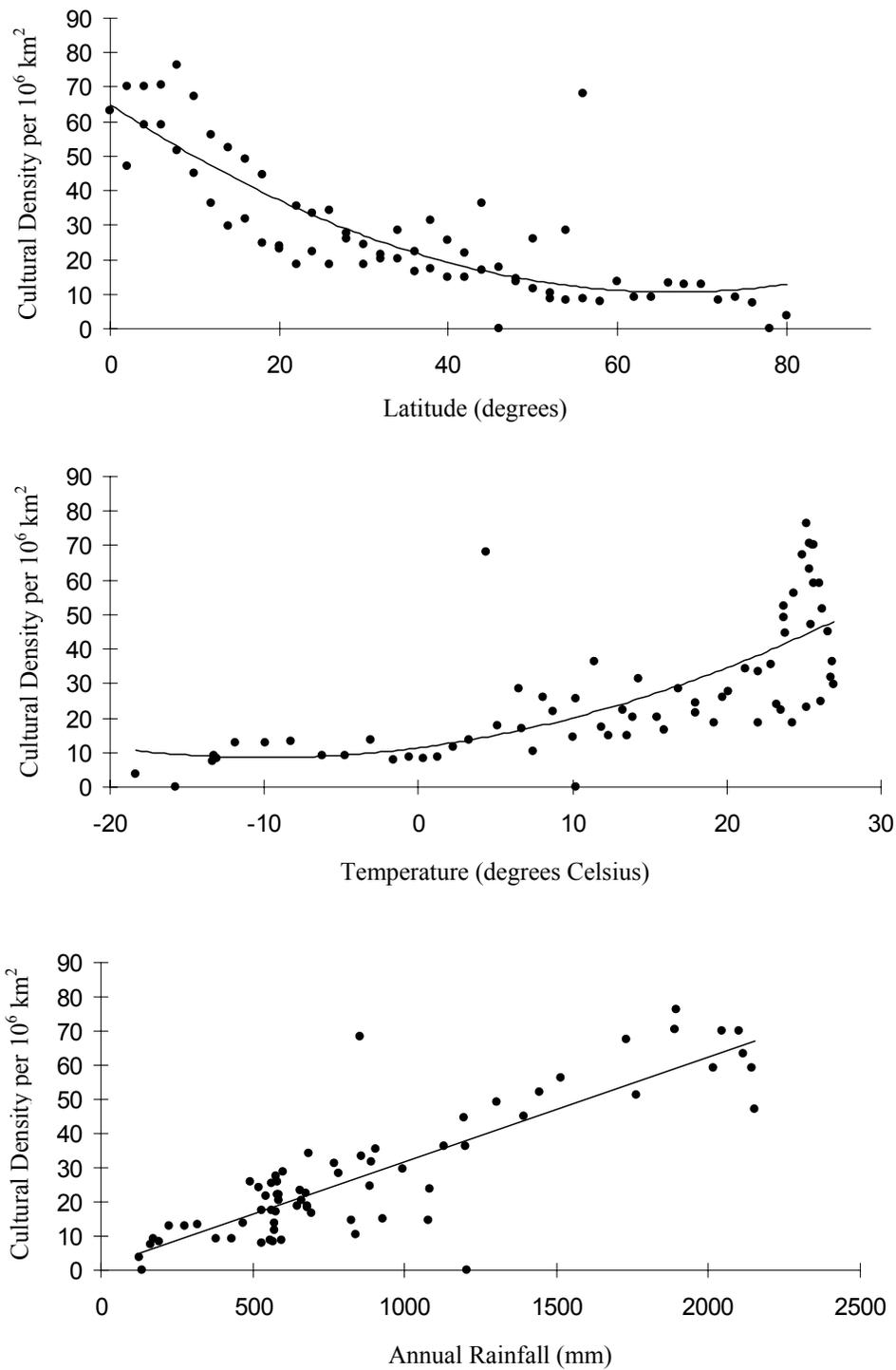
DISCUSSION

These analyses provide intriguing insights into parallels between human cultural diversity and broader biogeographical patterns. They indicate that the patterns for language shown by Mace and Pagel (1995) for North America occur both globally and independently on other continents, and across a larger latitudinal gradient. At the ecological level it can be hypothesised that the rate at which boundaries form between human societies is directly affected by environmental factors. Nettle (1998) has suggested, on the basis of a global analysis of linguistic diversity, that where populations are subject to local food shortages that could be ameliorated by links with other groups, then language differentiation is less likely to occur. These results would indicate that broad environmental parameters influence boundary formation. Where resources are abundant but locally invariant and of relatively low quality, such as in tropical rain forests, then boundaries will develop locally, reflecting small home ranges and patchy human distributions develop, and high diversity occurs. Where resources are very widely and unevenly distributed, as at high latitudes, then range areas must be large and cultural diversity will be low. In intermediate regions a number of factors, such as seasonality and local resource distribution, will account for the variation observed. It may also be in these areas that there will be greater tendency for the formation of larger and more complex societies, dependent upon the control of resources. There is also a probable effect of population size; where groups are able to reach a critical level for reproductive and subsistence purposes, then fissioning of populations will occur. This is more likely to happen in the tropics and lower latitudes, where primary production and secondary biomass are higher. Overall these results show that social boundary formation, which in turn reflects social behaviour and interaction between residential units, is responsive to environmental and resource factors.

Another level at which these results can be considered is an evolutionary one. There is a general acceptance that patterns of human diversity have arisen in the last 100,000 years, and that most of the variation seen today is even younger. They are the product of multiple human dispersals, associated with late Pleistocene colonisations and recolonisations, and the spread of agriculture in the last 10,000 years (Lahr & Foley 1994). The results presented here can be interpreted as suggesting that such dispersals lead to an ecological equilibrium relatively quickly. The fact that the cultural diversity observable today is a rich variety of hunter-gatherers, pastoralists, agriculturalists and more complex societies, suggests that the process of cultural diversification may be independent of subsistence, although the rates of diversification will undoubtedly vary.

Future work should explore patterns of cultural diversity across time and in relation to subsistence strategies. In particular, while there are strong global patterns, it is clear that there are also major differences from one region to another. Cultural differentiation in New Guinea, for example, has occurred and been maintained at a high rate compared to other parts of the world. Smaller scale analysis is necessary to understand how local factors, especially historical events such as the rise of states in the Americas, Asia and Europe, have altered patterns of global diversity. Furthermore, given that there has been a great deal of recent work showing that genetic diversity varies very markedly on a global scale, and that this variability is the result of mating patterns among humans over the recent and not so recent past, and that mating patterns are a product of social boundaries and structures, then it may be necessary to consider these patterns of cultural diversity as a factor in interpreting genetic diversity in an evolutionary light.

CONCLUSIONS

The results presented here show that at regional and global scales there is a strong correlation between observed human cultural diversity and broad environmental parameters. We would suggest that the mechanisms by which human populations diverge ethnically and linguistically is strongly influenced by the environment, and that this occurs over relatively short time scales, such that some form of equilibrium in cultural diversity may be maintained even in the context of economic and demographic change.

This raises the question of whether the congruence in biogeographical pattern between humans and other species is the result of the same mechanisms. At one level there are clear differences, for biogeographical patterns of non-human taxa often reflect major ecological and adaptive differences, and result from sympatry among unrelated groups as much as the process of differentiation between related lineages. In contrast, all human groups share considerable adaptive similarities and needs, usually exchange mates, and overlap ecologically to a very large extent when sympatric of parapatric. What is the basis, then, for the observed congruence?

It could be argued that it is the demands of and potential for niche separation that drives large scale biodiversity as seen in species-area relationships. To some extent this may be mirrored in human cultural diversity, where, for example both hunter-gatherers and agriculturalists may occur sympatrically, exploiting different elements of the environment. However, it is also the case that a very large proportion of the cultural diversity observed is that between closely related adjacent groups, often sharing a recent common ancestral cultural group. The pattern seen in humans, therefore, is the product of a more recent process of differentiation. What this may suggest is that the competitive ecological processes that lead to fission of groups have the same effect as long term ecological niche separation. In other words, the human pattern is the microevolutionary, microecological foundations for the macroecological pattern seen in biological communities. Such a finding may also have implications for considering the relationship between ecological species-area models and the longer-term evolutionary differentiation of lineages, and that both may be underlain by the same ecological constraints.

Finally, this analysis has treated the notion of human cultures as an unproblematic one. There are, however, issues involved in the definition of cultures that are even greater than those relating to the definition of species. Splitting and lumping of human societies, and the nature of the boundaries between them will be demographically, geographically and temporally very fluid. Studies such as this use a snapshot approach which shows general patterns, but further work must be done to explore the exact nature of boundary formation in human societies in order to understand the behavioural and cultural processes that lead to the observable global patterns (Lahr & Foley 1994).

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Appendix

Statistical equations on the relationship between environmental parameters and cultural diversity

Regression equations predicting cultural diversity and density, C (as the number of cultures per million square kilometres) by latitude, L (in degrees), rainfall, P (annual total in mm) and temperature, T (in degrees Celsius), for the two scales of cultural diversity data used. Section A shows global and continental relationships for the two degree dataset. Section B shows the global and continental relationships for the ten degree dataset. For global regressions the outlying value at 56º south (Tierra del Fuego) has been both included and excluded. The regressions have also been calculated with the polar zones of the northern hemisphere excluded, to allow for a more consistent comparison across the three longitudinal zones. The continental zones were created by dividing the world up into three approximately equal sections. The Americas consisted of North, Central and South America plus Greenland; the Afro-European section comprises all of Africa, Europe and Western Asia. The Oceanic-Eastern Asia zone comprises Australia, Polynesia, Melanesia, Eastern Asia and the Indian sub-continent. The dividing lines of longitude are shown on Figure 1.

A: Relationships at two degree scale

Latitude

Geographical Area	Equation	Significance	r	R^2
World	$C = 0.009 L^2 - 1.459 L + 63.781$	$p < 0.001$	0.87	0.76
World (excluding outlier)	$C = 0.009 L^2 - 1.527 L + 64.389$	$p < 0.001$	0.92	0.84
Americas	$C = -0.537 L + 46.855$	$p < 0.001$	0.71	0.50
Africa - Europe - Western Asia	$C = 0.012 L^2 - 1.802 L + 67.22$	$p < 0.001$	0.90	0.81
Oceania - Eastern and Southern Asia	$C = 0.041 L^2 - 5.147 L + 155.855$	$p < 0.002$	0.63	0.40

Rainfall

Geographical Area	Equation	Significance	r	R^2
World	$C = 0.029 P - 1.023$	$p < 0.001$	0.79	0.63
World (excluding outlier)	$C = 0.029 P - 1.423$	$p < 0.001$	0.82	0.66
Americas	$C = 0.016 P + 9.087$	$p < 0.001$	0.52	0.27
Africa - Europe - Western Asia	$C = 0.043 P - 2.625$	$p < 0.001$	0.74	0.54
Oceania - Eastern and Southern Asia	$C = 0.056 P - 13.871$	$p < 0.001$	0.63	0.40

Temperature

Geographical Area	Equation	Significance	r	R^2
World	$C = 0.017 T^2 + 0.898 T + 10.391$	$p < 0.001$	0.80	0.64
World (excluding outlier)	$C = 0.018 T^2 + 0.908 T + 9.204$	$p < 0.001$	0.84	0.69
Americas	$C = 0.722 T + 19.385$	$p < 0.001$	0.69	0.48
Africa - Europe - Western Asia	$C = 0.020 T^2 + 1.009 T + 4.974$	$p < 0.001$	0.77	0.59
Oceania - Eastern and Southern Asia	$C = 0.051 T^2 + 2.084 T + 1.477$	$p < 0.002$	0.57	0.32

Latitude (excluding poles)

Geographical Area	Equation	Significance	r	R^2
World	$C = 0.011 L^2 - 1.572 L + 64.401$	$p < 0.001$	0.83	0.68
World (excluding outlier)	$C = 0.012 L^2 - 1.660 L + 65.501$	$p < 0.001$	0.89	0.79
Americas	$C = -0.457 L + 45.003$	$p < 0.001$	0.62	0.38
Africa - Europe - Western Asia	$C = 0.014 L^2 - 1.899 L + 68.168$	$p < 0.001$	0.88	0.77
Oceania - Eastern and Southern Asia	$C = -1.955 L + 113.947$	$p < 0.001$	0.54	0.29

Rainfall (excluding poles)

Geographical Area	Equation	Significance	r	R^2
World	$C = 0.031\,P + 0.867$	$p < 0.001$	0.86	0.74
World (excluding outlier)	$C = 0.031\,P + 0.240$	$p < 0.001$	0.89	0.79
Americas	$C = 0.013\,P + 15.655$	$p < 0.001$	0.49	0.24
Africa - Europe - Western Asia	$C = 0.042\,P + 0.012$	$p < 0.001$	0.73	0.53
Oceania - Eastern and Southern Asia	$C = 0.057\,P - 15.406$	$p < 0.001$	0.60	0.37

Temperature (excluding poles)

Geographical Area	Equation	Significance	r	R^2
World	$C = 0.026\,T^2 + 0.642\,T + 11.336$	$p < 0.001$	0.73	0.51
World (excluding outlier)	$C = 0.032\,T^2 + 0.595\,T + 9.232$	$p < 0.001$	0.78	0.60
Americas	$C = 0.709\,T + 20.203$	$p < 0.001$	0.59	0.34
Africa - Europe - Western Asia	$C = 1.593\,T + 2.401$	$p < 0.001$	0.71	0.50
Oceania - Eastern and Southern Asia	$C = 2.734\,T + 11.969$	$p < 0.001$	0.49	0.24

B: Relationships at ten degree scale

Latitude

Geographical Area	Equation	Significance	r	R^2
World	$C = 0.009\,L^2 - 1.560\,L + 66.420$	$p < 0.001$	0.93	0.87
Americas	$C = 0.520\,L + 46.456$	$p < 0.001$	0.79	0.62
Africa - Europe - Western Asia	$C = 0.011\,L^2 - 1.668\,L + 65.986$	$p < 0.01$	0.96	0.91
Oceania - Eastern and Southern Asia	$C = 0.035\,L^2 - 4.371\,L + 130.438$	$p < 0.003$	0.88	0.78

Rainfall

Geographical Area	Equation	Significance	r	R^2
World	$C = 0.034\,P - 3.274$	$p < 0.001$	0.93	0.86
Americas	$C = 0.018\,P + 7.101$	$p < 0.006$	0.64	0.41
Africa - Europe - Western Asia	$C = 0.044\,P - 3.746$	$p < 0.002$	0.76	0.58
Oceania - Eastern and Southern Asia	$C = 0.046\,P - 10.508$	$p < 0.001$	0.86	0.74

Temperature

Geographical Area	Equation	Significance	r	R^2
World	$C = 0.016\,T^2 + 0.881\,T + 12.259$	$p < 0.001$	0.84	0.71
Americas	$C = 0.728\,T + 19.485$	$p < 0.001$	0.78	0.61
Africa - Europe - Western Asia	$C = 0.020\,T^2 + 0.988\,T + 5.692$	$p < 0.001$	0.71	0.50
Oceania - Eastern and Southern Asia	$C = 0.037\,T^2 + 1.549\,T + 5.695$	$p < 0.001$	0.71	0.50

Latitude (excluding poles)

Geographical Area	Equation	Significance	r	R^2
Americas	$C = -0.438\,L + 44.752$	$p < 0.005$	0.70	0.49
Africa - Europe - Western Asia	$C = -0.843\,L + 55.519$	$p < 0.001$	0.91	0.82
Oceania - Eastern and Southern Asia	$C = 0.038\,L^2 - 4.580\,L + 132.752$	$p < 0.008$	0.87	0.76

Rainfall (excluding poles)

Geographical Area	Equation	Significance	r	R^2
Americas	$C = 0.015\,P + 13.276$	$p < 0.02$	0.61	0.37
Africa - Europe - Western Asia	$C = 0.043\,P + 0.036$	$p < 0.004$	0.78	0.61
Oceania - Eastern and Southern Asia	$C = 0.046\,P - 10.433$	$p < 0.001$	0.84	0.71

<u>Temperature (excluding poles)</u>

Geographical Area	Equation	Significance	r	R^2
Americas	C = 0.721 T + 20.303	$p < 0.005$	0.69	0.48
Africa - Europe - Western Asia	C = 1.617 T + 2.024	$p < 0.004$	0.78	0.62
Oceania - Eastern and Southern Asia	C = 1.967 T + 14.103	$p < 0.02$	0.65	0.43