

ELEVATIONAL GRADIENT RESEMBLES LATITUDINAL GRADIENT OF GLOBAL
LANGUAGE DISTRIBUTIONS

By

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To all who nurtured my intellectual curiosity, academic interests, and sense of scholarship throughout my lifetime, making this milestone possible

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LIST OF ABBREVIATIONS

DEM	Digital elevation model
EZ	Elevation zones
LULCC	Land-use and land-cover change

Abstract of Thesis Presented to the Graduate School
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THE ELEVATIONAL GRADIENT RESEMBLES LATITUDINAL GRADIENT OF
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This research investigated biogeographic parallels of species and language distributions and determined whether human language distributions conform to the 'elevational gradient hypothesis' at global and regional scales. Language distribution patterns along elevation gradients were comprehensively addressed through three primary research questions which investigated (1) language richness along the elevational gradient, (2) 'Rapoport's rule' along the elevational gradient, and (3) global mountains areas and their importance for language diversity.

The distribution of extant languages from all latitudes were included in a global analysis, and those located on the major landmasses of Africa, Asia, Australia, Europe, North America, and South America were included in regional analyses. Significant regression models strongly support the elevational gradient hypothesis in global and regional language distributions.

Globally, language richness steadily decreased with increasing elevation, but when language richness was standardized per 1,000 km² of land area, a uni-modal hump of greatest language richness existed at intermediate elevations. Regional

analyses of Africa, Asia, and South American continents showed similar patterns as the global analysis. Australia, Europe and North American regions which represent almost half the global land surface area, but a quarter of the global languages demonstrated different patterns than expected. Language diversity increased in along the elevational gradient in Australia, Europe, and North America, but were highly variable at the regional scale. “Rapoport’s rule” was also tested along the global elevational gradient; mean language range size increased with increasing elevation. However, the predicted global pattern showed more variability at the regional scale. Finally, mountains did harbor greater language diversity than non-mountain areas at the global scale when accounting for sampling intensity in analysis. Mountain regions are important hotspots for both language and biological diversity.

Globally, language diversity distributions along the elevational gradient resemble the latitudinal gradient in human language richness and mean language range size. Cultural/language diversity may be subject to fundamental biogeographic processes and evolutionary drivers of distribution and diversification. Elevation is clearly an important explanatory variable in the pattern of language diversity distributions, and likely serves as a proxy for numerous underlying and interacting mechanistic environmental variables.

CHAPTER 1

INTRODUCTION

At least since the time of Alfred Wallace, biologists have recognized the latitudinal species richness gradient—whereby species richness decreases with increasing latitudes—as one of the fundamental patterns of life on earth (Brown and Lomolino, 1998; Gaston, 1996; Rosenzweig, 1995; Willig, 2000; MacArthur, 1972; Whittaker, 1960; Pianka, 1966; von Humboldt, 1849), albeit with few exceptions in specific taxa (Willig *et al.*, 2003). Variation in species diversity along gradients of elevation is almost as general and striking as the latitudinal variation in terrestrial species. Just as the number of species decreases from the tropics to the poles, probably due at least in part to broad-scale climatic controls (Pianka, 1966; Wallace 1876), species richness also decreases from lowland to upland elevations (Korner, 2002; Lomolino, 2001; Kapos *et al.*, 2000). The equilibrium theory of island biogeography (MacArthur, 1972) postulates that island size and distance from land determine the extinction and immigration rates of species, respectively, and predicts that islands of certain sizes and isolation should have a certain number of species. As both area decreases and the degree of isolation increases while ascending mountains, this theory may help explain the reduction in the number of species at higher elevations, just as it predicts lower diversity on smaller more isolated islands. Gradients in elevation, like latitude, act as a surrogate for an almost infinite number of underlying environmental gradients including temperature, moisture availability, and climatic variability, that interact and possibly counteract making distinct hypothesis testing of causal mechanisms difficult (Schemske, 2002).

Mountain areas as a whole are highly diverse biologically, due to the compression of ‘life zones’ into relatively narrow geographic ranges. A 5000 m high equatorial mountain comprises nearly all the climatic zones of the world over a relatively short distance, whereas a similar series of thermal climates on flat land is spread across thousands of square kilometers (Holdridge, 1967; Körner, 2002). This compression of life zones explains why, on a 100 km grid scale, no landscape surpasses the biological richness of mountains (Barthlott *et al.*, 1996).

Though this pattern has long been recognized by ecologists and biogeographers, it has not been as well documented quantitatively as the latitudinal gradient of diversity. This is due in part to the interdependence along the elevational gradient of numerous bio-physical variables, particularly temperature and moisture availability. Albeit difficult to quantify and with some notable exceptions (Willig *et al.*, 2003; Rhode, 1992), the general decline in species diversity with decreasing temperatures and moisture availability at higher elevations is a generally accepted rule applying across a multitude of regions including the Andes (Terbough, 1977), Himalayas (Yoda, 1967), mesic tropical regions (Erwin, 1988), New Guinea (Diamond, 1972; Kikkawa and Williams, 1971), and North America (Whittaker, 1960, 1977; Sfenthourakis, 1992; Brown, 1971). Within mountains, species richness generally decreases with increasing elevation in proportion to the decrease in available land area (Körner, 2000), while endemism often increases due at least in part to geographic isolation (Gentry, 1988; Peterson *et al.*, 1993).

The negative effect of altitude on biological diversity has been broadly documented, but the pattern of decline in diversity richness has been more recently

debated, igniting much controversy as to the underlying mechanisms. Two patterns of diversity distributions along the elevational gradient have been observed in a variety of taxa (1) a linear/logarithmic decline in richness with increasing altitude, or (2) a unimodal ‘hump’ shaped relationship where intermediate elevations have the highest diversity richness. This second pattern of highest diversity richness occurring at intermediate elevations has been particularly evident when analyses were standardized by area to account for the species-area relationship (Chatzaki *et al.*, 2005; Lomolino, 2001; Rahbek, 1995). As the species-area relationship is a well established principle in ecology (Gleason, 1922; MacArthur, 1972), surprisingly few studies have accounted for area in their analysis.

Ecologists, and their predecessors, have argued for centuries about the underlying mechanisms driving these patterns along the elevational gradient. Lawton *et al.* (1987) summarized the influence of elevation on species richness being due to the following environmental trends at higher elevations (1) reduction in productivity, (2) reduction in the total area, (3) reduction in the resource diversity, and (4) the harshness and unpredictability of the environmental conditions common at higher elevations. The ‘mid-domain effect’ (Colwell & Lees, 2000) or the ‘ecotone effect’ (Lomolino, 2001) may explain the peak in species richness at mid-elevations as the increasing overlap of species ranges towards the centre of a domain, or that the transition zone between communities is likely to have the greatest species richness.

Many studies have investigated biodiversity distribution patterns in relation to environmental gradients; however few have considered fundamental biogeographic patterns in intraspecific analyses of our own human species. Although the relationship

between biological and cultural diversity has been recognized for some time (Kroeber, 1963, first published in 1939), Harmon (1996), may have opened the door to biocultural diversity research through his comprehensive review of the geographic overlaps between linguistic and biological diversity. Languages are commonly used as a reliable proxy for cultural diversity to represent the intraspecific geographic variation of the human species (Harmon and Maffi, 2002). According to Maffi (1996 pp.3) “evidence is emerging of remarkable overlaps between areas of greatest biological and greatest linguistic/cultural diversity around the world. These striking correlations require close examination and must be accounted for.” A number of authors (Chapin, 1992; Toldedo 1994; McNeely and Keeton, 1995; Poole, 1995; Wilcox and Duin, 1995; Harmon, 1996; Stepp *et al.*, 2004) have shown that cultural and biological diversity tends to be correlated. Controversially, a large number of these authors propose that indigenous social systems, which tend to concentrate in areas of high cultural and linguistic diversity, are more likely to conserve or coexist with biodiversity. Only a few possible explanations can clarify these correlations (1) either small scale societies conserve or enhance biological diversity; (2) biological diversity directly enhances cultural diversity; or (3) large-scale, politically-complex, social systems (characteristic of unified political states) reduce both cultural and biological diversity (Smith, 2001). These hypotheses are not mutually exclusive, particularly if cultural diversification may be a product of co-evolution between social and natural environments.

Considerable evidence has accumulated since Harmon’s (1996) publication, demonstrating that languages do in fact follow similar biogeographic distribution patterns as biological diversity distributions, (Global, (Sutherland, 2003), Africa (Moore

et al., 2002), Americas (Smith, 2001; Mace and Pagel, 1995; Manne, 2003; Nettle, 1999), New Guinea (Stepp *et al.*, 2004), Review (Maffi, 2005)). Linguistic cultural diversity broadly follows the latitudinal gradient, with an increasing density of languages from the poles toward the equator (Mace and Pagel, 1995; Stepp *et al.*, 2004; Sutherland, 2003; Currie and Mace, 2009; Manne, 2003; Cashdan, 2001; Collard and Foley, 2002). There is also evidence that language diversity distributions may follow ‘Rapoport’s rule’ (Currie and Mace, 2009; Mace and Pagel, 1995): a hypothesis observed in species distributions where species’ range size increases with increasing latitude (Ruggiero & Werenkraut, 2007; Gaston, 2005; Stevens, 1989; Rapoport, 1982; Brown, 1996). Studies have considered an abundance of biophysical and socio-economic variables to explain geographic language distributions, from net primary productivity (Currie and Mace, 2009) to mean number of televisions per 1000 km² (Sutherland, 2003) with varying results as to their significance and explanatory power (see Maffi, 2005 for review). Many studies have incorporated elevation-related explanatory variables of habitat complexity or topographical heterogeneity with widely varying results (Currie and Mace, 2009; Moore *et al.*, 2002; Cashdan, 2001; Mace and Pagel, 1995; Nichols, 1990). However few studies include elevation specifically (Moore *et al.*, 2002; Sutherland, 2003), and no study has exclusively addressed whether the elevational gradient in language diversity resembles latitudinal distribution patterns in the same way biological species distributions do.

Stepp *et al.* (2005), using point-location data in New Guinea, note that mountain areas have higher linguistic and biological richness than non-mountain areas. Even though area was not accounted for in their analysis, their observations are concurrent

with biological species phenomenon: mountain areas often support higher diversity than lowland areas even though they cover smaller geographic areas (Holdridge, 1967). Nevertheless, global distribution patterns cannot be inferred from one small regional-scale investigation, nor can any underlying mechanisms be considered.

Currie and Mace (2009), the only study to utilize the language polygon data recently made available by Ethnologue (Grimes, 2005), built a convincing model explaining language range size distributions, and determined ‘political complexity’, or the degree to which multiple cultures are integrated into one political structure, to be the most important explanatory mechanism behind latitudinal patterns concurrent with ‘Rapoport’s Rule’. Currie and Mace consider numerous biophysical variables, but exclude elevation as an explanatory variable in the final regression model due to “opposite correlations than expected”, based on the ‘topography hypothesis’ as proposed by Stepp *et al.* (2005). They found language range size to be positively correlated with greater topographical heterogeneity. As an extension of ‘Rapoport’s rule’ (based on Mace and Pagel, 1995) they reasoned that if language range size was positively correlated with topographical heterogeneity, then language richness should be negatively correlated. These correlations should not be surprising, in that they corroborate many species distribution studies (Stevens, 1992). However, Currie and Mace (2009), still discard topographical heterogeneity as an important explanatory variable because it opposed the conclusion by Stepp *et al.* (2005), in their ‘topography hypothesis’: that mountain areas harbor greater biological and cultural diversity than non-mountain areas. They expected language range size to be negatively correlated and language richness to be positively correlated with topographical heterogeneity,

even though it contradicts a long history of ecological literature. As Currie and Mace (2009), rejected elevation as an important variable strictly on theoretical grounds, the elevational gradient hypothesis in language diversity distributions deserves to be adequately tested. This confusion also demonstrates the importance of independently evaluating hypotheses which address the elevational gradient in diversity from those which address the importance of mountain areas (topographical heterogeneity) known for heightened diversity and endemism.

These many conceptual confusions as to whether elevation is truly important in explaining language diversity distributions may be due, at least in part, to the numerous methodological concerns commonplace in the literature. Very few publications explaining language diversity distributions have addressed the species-area relationship and accounted for sampling intensity in their analyses (Sutherland, 2003; Manne, 2003). Currie and Mace (2009), used standard deviation of altitude within language polygons to represent topographical heterogeneity without standardizing by area of the polygon. It is well known that increasing local extent also increases local heterogeneity of the underlying landscape being sampled (Fortin and Dale, 2005). Their result that language range size was positively correlated with topographical heterogeneity should not be surprising; for larger language polygons are likely to have greater heterogeneity and higher standard deviations of altitude; but simply as a function of the sampling method employed and regardless of the actual relative topography. Stepp *et al.* (2005), describe the number of languages on New Guinea without standardizing for the area represented by mountain areas and non-mountain areas, and assume global parallels to the local pattern based on visual interpretation of global maps showing language

diversity being concentrated in mountain regions. Manne (2003), investigated language distributions at a 2° spatial resolution, where as others utilize a 30 arc-second spatial resolution (Currie and Mace, 2009), and still others evaluate distribution patterns based on political boundaries, using countries as the unit of analysis (Sutherland, 2003). Of the research which has addressed the geographic distributions of languages, few have founded their questions in biogeographical theory, properly addressed/acknowledged the assumptions of their methods, or controlled for sampling intensity in their analyses. Not surprisingly, the current literature on the distribution of language richness is inconsistent, and in some cases, in conflict, particularly about the importance of elevation as an explanatory variable.

Species distribution patterns along environmental gradients have been well-documented, and even causal mechanisms of numerous confounded biological and physical factors including moisture, temperature, and energy have been proposed (Whittaker, 1953; Lawton *et al.*, 1987; Currie, 1991). If humans have coevolved with the other biota along these underlying environmental gradients, I hypothesize that the intraspecific variation in human language distribution patterns would follow general biogeographic principles observed in species distributions. This research may demonstrate that the human species and our distributions may be correlated with similar evolutionary drivers and biogeographic principles as species distributions. As correlation is not causation, the deeper examination of the underlying mechanisms behind these patterns will be left to future investigations.

The purpose of this research and its three primary questions was to establish whether global language diversity distributions are consistent with just one of

biogeography's fundamental principles: the elevation gradient. In order to specifically address the influence of elevation on language diversity distribution patterns, this study intentionally ignores all other potential explanatory variables.

Research questions. Language distribution patterns along elevation gradients were comprehensively addressed through three primary research questions:

1. Does language richness follow the elevational gradient known from species distributions; does richness decrease at higher elevations?
2. Do languages follow Rapoport's rule; does range size increase at higher elevations?
3. Do global mountain areas harbor greater language diversity than lowland areas?

The first question will determine, is there an elevational gradient of decreasing language diversity parallel to species diversity distribution patterns? As human populations generally decline with increasing elevation, I expect that their intraspecific language richness may also decrease along the elevational gradient (CIESIN *et al.*, 2004; Huddleston *et al.*, 2003). I expect that language diversity patterns along gradients in elevation will resemble the 'latitudinal gradient' in diversity (Stepp *et al.*, 2004; Currie and Mace, 2009; Manne, 2003; Cashdan, 2001; Moore *et al.*, 2002); as elevation increases language richness is expected to decrease at least in part due to the species-area relationship. As has been demonstrated in studies quantifying the elevational gradient in species diversity (Rahbek, 1995, 1997; Lomolino, 2001), I expect that when diversity data are standardized by land area, there will be a uni-modal 'hump' in language richness at the intermediate elevations due to the 'mid-domain effect' in the underlying resource gradient. At the global scale of analysis, I anticipate these broad biogeographical patterns to be fairly evident in language diversity distributions; however

at finer regional scales of analysis, there will probably be more variability in the conformity to the general biogeographic patterns. Particularly in Australia and North America, as appears through visual interpretation (Figure 2-1), there may be a divergence in the regional patterns from the general global rule.

The second question will investigate, do language range size distributions follow Rapoport's rule' along the elevational gradient? (Ruggiero & Werenkraut, 2007; Gaston, 1996, 2005; Stevens, 1992; Rapoport, 1982). This research will determine if global language range sizes do in fact increase with increasing elevations as has been shown in relation to the latitudinal gradient (Mace and Pagel, 1995; Currie and Mace, 2009). Again, I expect the regional analyses to express greater variability than global analysis of this broad-scale pattern.

Finally, the third question will test inferences made by Stepp *et al.* (2005) and determine, do global mountain areas harbor greater language diversity than non-mountain areas? Overall, I expect mountain areas will have higher language richness than lowland areas when data are standardized by area.

These three questions comprehensively evaluate the pattern of language diversity distributions relative to an important biogeographic pattern of species distributions; the elevation gradient hypothesis. This work is a step in resolving the inconsistencies throughout the literature, as well as identifying parallels between species and cultural diversity distributions which may share underlying historical mechanisms of diversification and dispersal.

CHAPTER 2 DATA AND METHODS

Data

Elevation Data

A Digital Elevation Model (DEM) at a 10-minute spatial resolution was obtained from www.worldclim.org where global mosaics of The Shuttle Radar Topography Mission (SRTM) derived DEMs are made freely available (Hijmans *et al.*, 2005). DEMs were reclassified into 100- m elevation zones for analysis, as the smallest unit commonly used in the literature to analyze elevation gradients (Gentry, 1988), and was then used to create global contours per 100 meter relief in elevation in the second question (Mace and Pagel, 1995). The DEM was further transformed to create % slope and latitude variables for the third question's global analysis.

Language Data

Language data were obtained from the Ethnologue 15th edition (Grimes, 2005). There are currently 6,909 extant languages documented in the database. These languages were compiled from numerous published sources, and represent languages which have been known to exist in the past 50 years as a person's 'first language.' As there are hundreds of languages with fewer than 50 speakers, some of these may have already gone extinct, but would still be included in the database until a peer-reviewed publication could verify that language has gone extinct. Until recently, language data were only available as point locations, which is problematic particularly at finer spatial resolutions. Point data do not always best represent geographic locations of languages, especially in wide-spread and/or discontinuous language groups whose point locations

were sometimes arbitrarily placed in areas where there were few or no actual speakers. Polygon data, albeit not perfect, are a more reliable dataset for considering language distribution patterns, as their ranges have been drawn by linguists to represent the approximate boundaries of the actual geographic range where the language is spoken (Maffi, 2005). No claim is made by Ethnologue as to the precision of these boundaries, however these data are widely recognized as the most comprehensive and accurate global data available on geographic distributions of languages (Currie and Mace, 2009; Stepp *et al.*, 2004; Maffi, 2005). In many cases these polygons overlap, just as they will at broad scales. Although in reality, at fine-scales (i.e. household to community level) languages usually do not overlap; therefore these data may be more appropriate for broad scale analyses. Where the language range is not known, there was no polygon drawn representing its range, and thus these languages were excluded from analysis. Within regional analyses all languages on the major landmass were included but island languages were excluded to mitigate the influence of island biogeography. In the final global analysis, 5725 language polygons were evaluated of the 7719 known extant languages.

These polygon data depict the traditional linguistic homelands of each language, and do not attempt to map immigrant languages or those populations of speakers away from their homelands. Macrolanguages, the 55 languages which are defined as “multiple, closely related individual languages that are deemed in some usage contexts to be a single language” (Grimes, 2005), are usually considered “colonial languages,” and span over many political boundaries, have not been included in these analyses (i.e. English in the USA, Portuguese in Brazil, and Swahili in Tanzania). Polygons were not

provided for languages which are considered widespread in a country, and would be essentially identical to the country boundary, with few exceptions. There is certainly a debatable conceptual argument in determining the languages which “count” versus those that don’t “count.” However, these languages have been historically excluded by linguists in analyses of the patterns and processes underlying language distribution, and it can be argued that these macrolanguages and widespread languages may not represent the long historical process driving language diversification (Lewis, 2009). Furthermore, these data represent languages known in the past 50 years, and certainly hundreds of indigenous languages were lost in South America alone during the colonial period (Kaufman, 1994:47). Certainly these data are not complete representations of the historical evolutionary patterns and processes of language distributions, but represent our current understanding, and may call into question continental regions being analyzed with a strong history of colonization such as the Americas and Australia (Nettle, 1998). However these data are the best available, and even considering their limitations, are constructive in helping us understand the patterns of intraspecific diversification. The complete picture of pre-colonial language distributions may never be fully understood, however colonial imperialism greatly influenced biotic species distributions as well, and headway has been made in understanding the evolutionary processes driving these patterns.

As the meaning of ‘diversity’ differs dramatically in the biological (Mayr, 1963; Abruzzi, 1982) and linguistic literature (Nettle, 1998), it should be made clear that I am investigating solely the intraspecific variation of human language richness and their distributions. As Nettle (1998) notes, linguists tend to agree on the definition of

languages for the purpose of continental scale comparisons (the focus of this study), however at finer scale resolutions the comparability of languages becomes much more complicated (Romaine, 1994), and will therefore be avoided in this investigation. Language diversity, like biodiversity, can be measured in a variety of different ways; in this study, language diversity will be measured simply by the number of languages in a given area.

Methods

Language Richness along the Elevational Gradient

The global 10-minute DEM was reclassified into 100 m elevation zones (Figure 2-1). As stated above, the total number of language polygons analyzed ($n = 5725$), included only those found on continental landmasses, and excluded the 55 macrolanguages and those whose physical location has not been recorded. Within each 100-m elevation zone, the number of languages was counted at global and sub-continental regional scales. Regional analyses included major non-island landmasses: Australia, Asia, Africa, Europe, North America, and South America (Figure 2-3).

Language richness within each 100-m elevation zone was standardized per 1,000 km². Language richness was plotted globally and by region; extreme values (at the very low and very high elevations) were removed and analyses were performed on these truncated data. As the lowest and highest elevations in the ‘tails of the distribution’ tended to represent less than 1% of the total land surface area, truncation points were utilized to include only the elevation zones which represented as close as possible to, but not less than, 99% of the total land surface area (Figure 2-2, Table 3-2).

Spearman’s rank correlations were calculated for language richness and standardized language richness at global and regional scales. Data were evaluated

using ordinary least squares (OLS) multiple regressions at the global and regional scales. After utilizing stepwise selection techniques the final variables in the non-standardized model included elevation zone (ez), square root of elevation zone (sqrt_ez), dummy variable for elevation above 2500 m (d_2500), and square root of elevation zone multiplied by the dummy variable (sqrt_ez*d_2500). The final model of standardized language richness per 1,000 km² included elevation zone (ez) and square root of elevation zone (sqrt_ez).

Rapoport's Rule along the Elevational Gradient

Global range sizes of language polygons, as well as the log-transformed range sizes, were plotted with frequency histograms to evaluate the overall probability distribution patterns. ‘Rapoport’s rule’ was evaluated using methods employed by Mace and Pagel (1995) in relation to the latitudinal gradient hypothesis in North America. The elevation zone data described above were used to create contours of each 100 meter change in elevation (Figure 2-4). Only language polygons which intersected these global contours were counted to overcome issues of spatial autocorrelation. Language richness values were then standardized by length of each contour to account for sampling intensity, and then were plotted for each 100-m contour along the global elevational gradient. Identical analyses were conducted at the regional scale using the continental divisions used through the first question’s analyses (Figure 2-3) to observe regional scale patterns of language range size along the regional elevation gradients.

Global Mountain Areas and Their Importance for Language Diversity

To evaluate the Stepp *et al.* (2005) ‘topography hypothesis’ at a global scale, the global DEM raster was reclassified into mountain and non-mountain zones based on the Stepp *et al.* (2005) criteria: areas with mean slope > 5%, areas above 1000 m and

slopes > 2%, and areas above 2500 m on a 100 km² grid (Figure 2-5). I do not mean to imply these criteria are the most appropriate for a global analysis as there are numerous ways to define mountains. These criteria were utilized strictly to assess the observation posited by Stepp *et al.* 2005 that mountain diversity patterns in New Guinea also apply to mountains globally. Stepp *et al.* (2005) criteria are a conservative estimate of mountainous land areas and may be tropically biased. Language polygons within mountain areas and non-mountain areas were counted, standardized by 10,000 km² and graphed.

Software

All data preparation was conducted using ArcInfo 9.3 (ESRI, Redlands, CA, 2008) and Hawth's Tools, Version 3.27 (Beyer, 2007) analysis pack. All statistical analyses were conducted using NCSS 2007 software (Hintze, 2007).

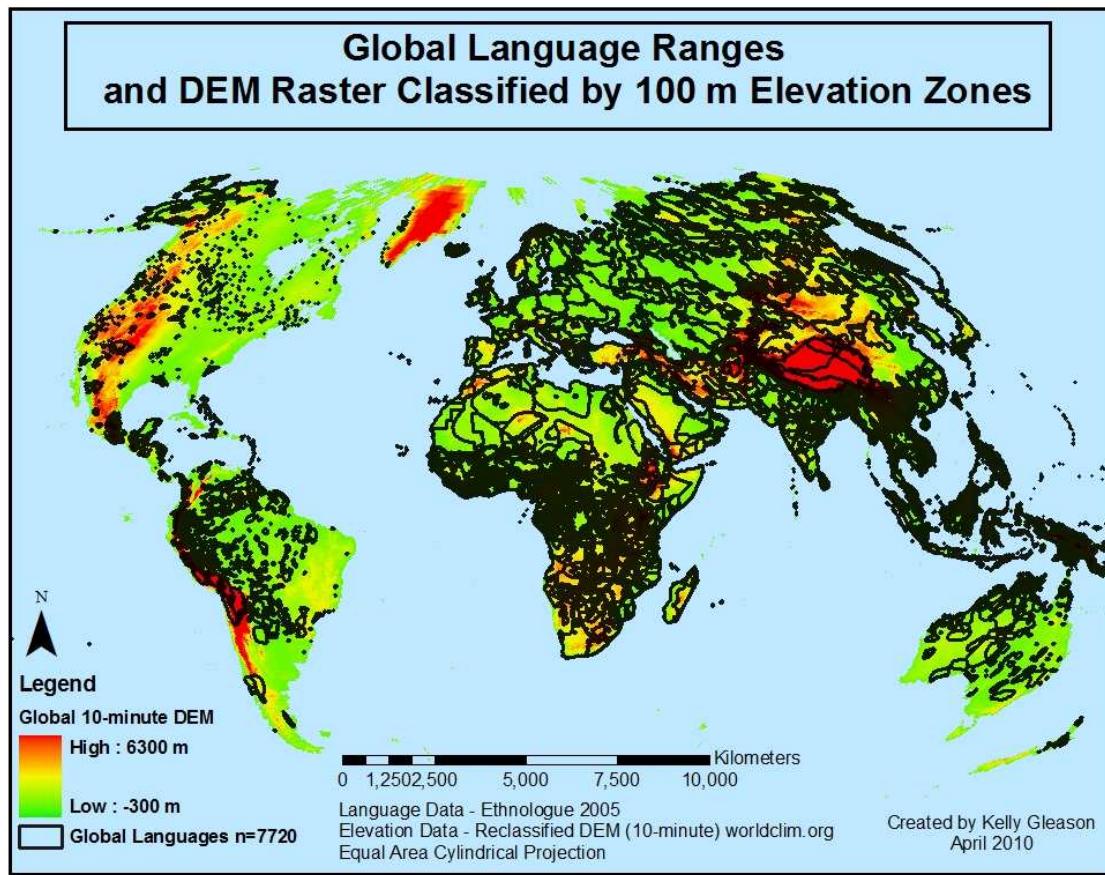


Figure 2-1. Global languages and 100 m elevation zones

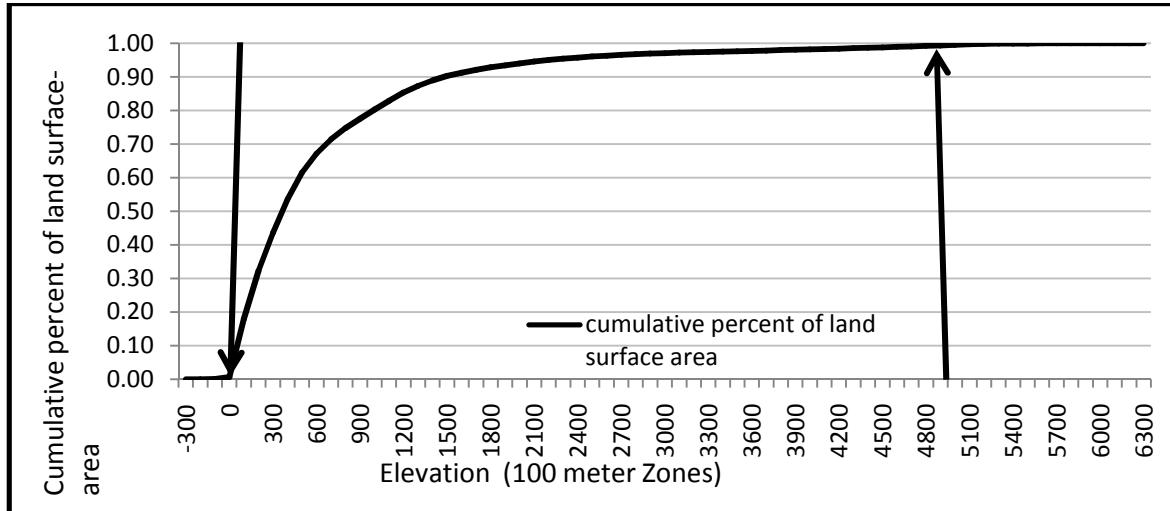


Figure 2-2. Cumulative percent of land surface area within each 100 meter elevation zone. Arrows indicate the truncation points of the global dataset (100 m – 5000 m)

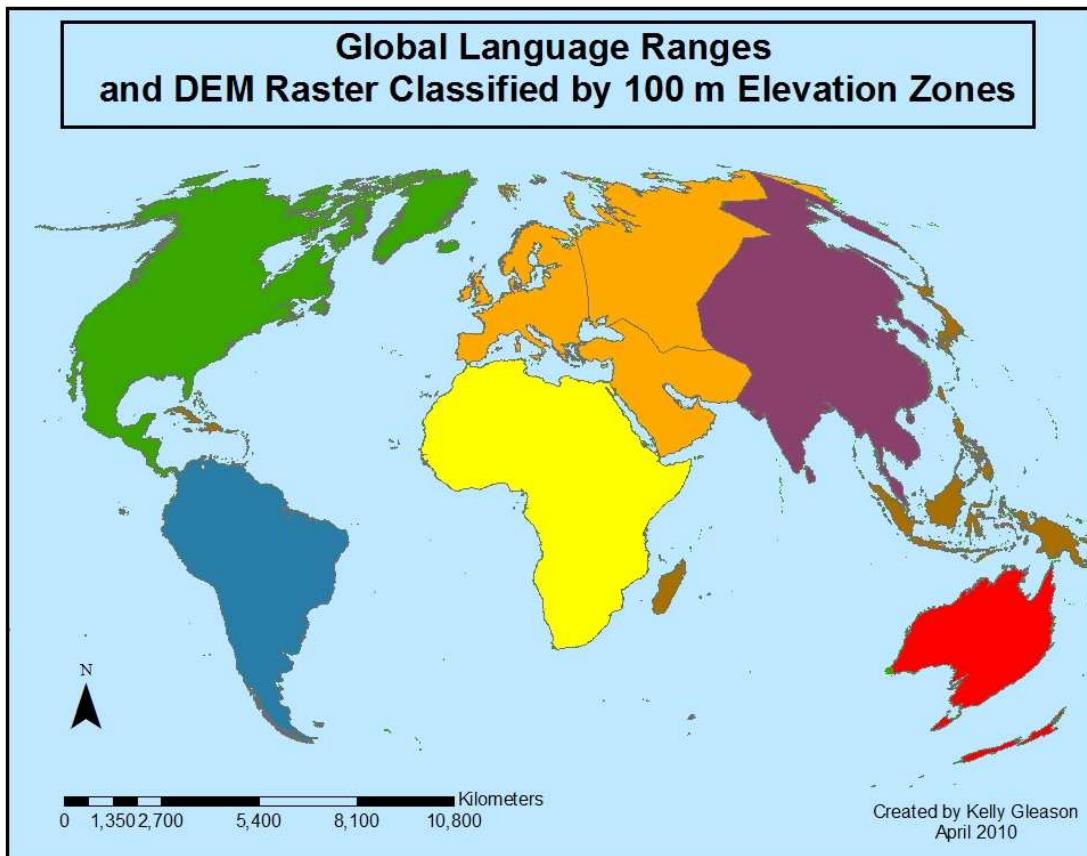


Figure 2-3. Continental regions isolated for regional analyses (Africa – yellow, Asia – purple, Australia – red, Europe – orange, North America – green, South America – blue, excluded areas from regional analysis - brown) Only the primary continental landmass was included in the regional analysis, all island areas within each continent were excluded from analysis to mitigate the effects of island biogeography on language diversity distribution patterns.

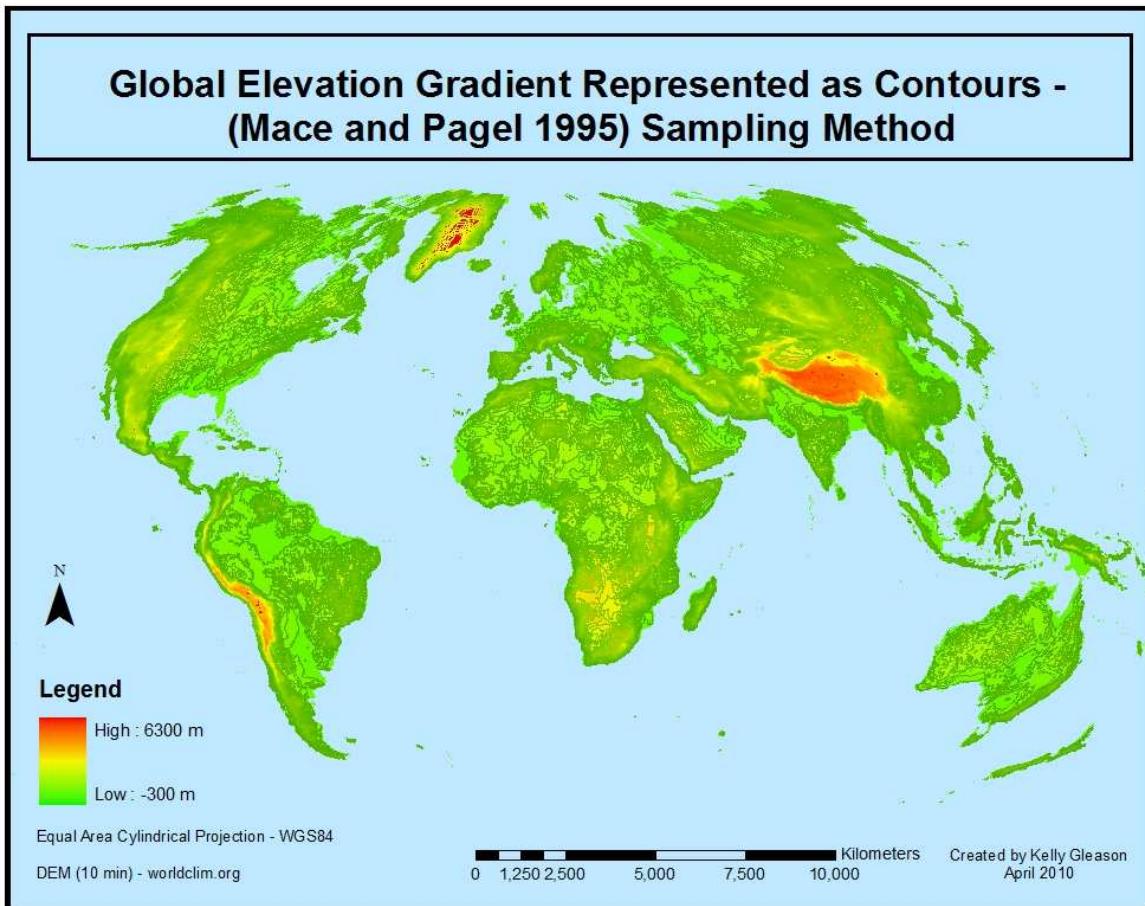


Figure 2-4. Global contour map of elevation gradient method used by Mace and Pagel 1995 to investigate Rapoport's Rule in North America.

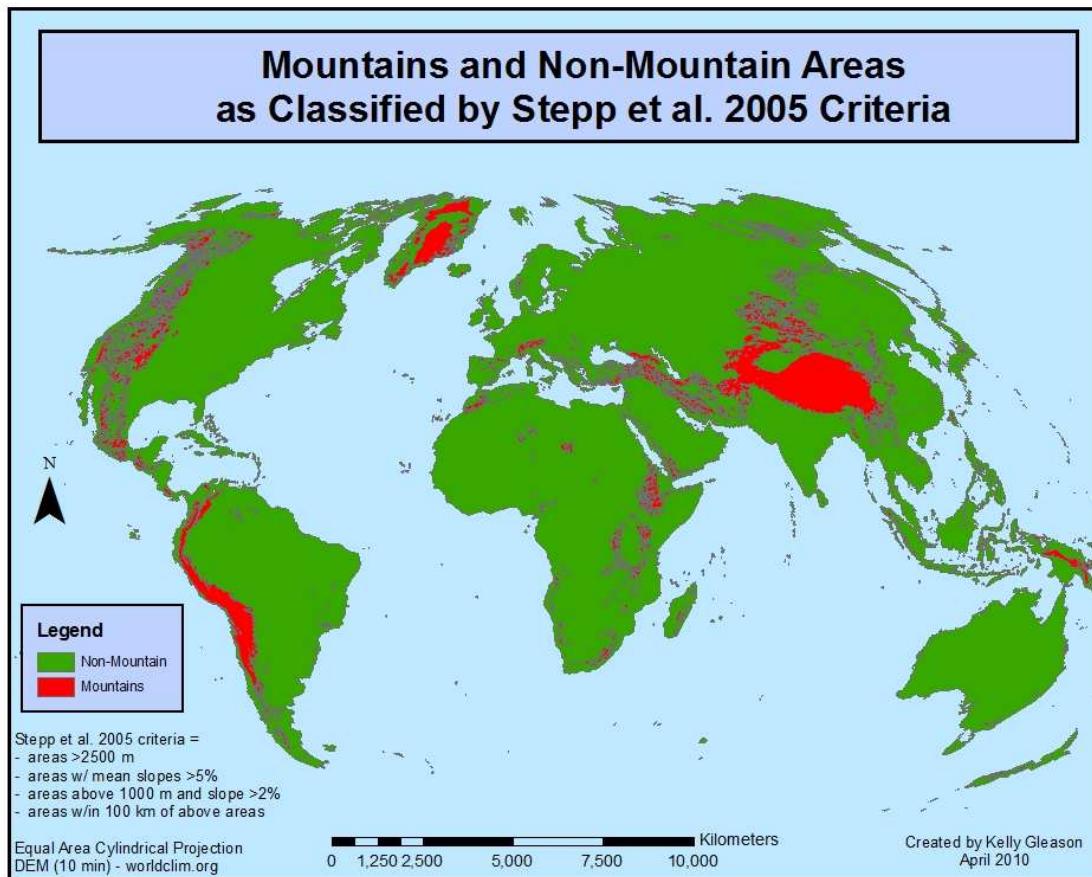


Figure 2-5. Global mountain and non-mountain areas as classified by Stepp *et al.* 2005 criteria.

CHAPTER 3 RESULTS

Language Richness along the Elevational Gradient

As predicted, language distribution does conform to the elevational gradient hypothesis at the global scale; language richness within 100-meter zones was negatively correlated with elevation, and demonstrated the expected pattern of declining diversity with increasing elevation (Figure 3-1, Table 3-1). When data were standardized by area, linear correlations were neutral at the global scale (Figure 3-2 & Table 3-1), probably due to the uni-modal ‘hump’ in language richness at intermediate elevations (Figure 3-2), which adheres to a second-order polynomial function (Table 3-4). As seen in species distribution analyses (Stevens, 1989), when these data were standardized by area or sampling effort, the very low and very high elevation areas had extremely high peaks in language richness (Figure 3-2). Stevens (1989) explained that these tails in the distribution pattern may not be truly representative of the overall diversity distributions due to the extreme differences in area represented at the very lowest and very highest elevations and are therefore ‘unreliable’ data. Therefore, a truncated curve, from 100 m-5000 m was utilized for global regression analyses, which represented at least 99.5 % of land surface-area per region (Table 3-2). Regression analyses emphasized that elevation was in fact an important factor in explaining the global geographic distribution of languages (Tables 3-3 and 3-4). When data were transformed to meet normality assumptions; extremely high R^2 values and F-ratio values demonstrated that in fact elevation has strong explanatory power in the geographic pattern of language distributions (Table 3-3 & 3-4).

At the regional scale, similar patterns emerged as at the global scale; language richness within the 100-m elevation zones was negatively correlated with elevation (Tables 3-1 & 3-2) in all regions using non-standardized data (Figures 3-3 to 3-8). However when data were standardized by area, linear correlations of Spearman Rank values were near zero due to the uni-modal hump in diversity at intermediate elevations in Africa, Asia, and South America (Table 3-1, Figure 3-3, 3-4, & 3-5). These regional patterns generally conformed to the predicted global patterns of language distribution in these three sub-continental regions which contain 75% of the languages included in these analyses. However the language diversity distribution patterns in Australia, Europe, and North America did not parallel the expected global pattern. These regions demonstrated a positive correlation in standardized language diversity along the elevational gradient (Table 3-1, Figures 3-6, 3-7, & 3-8); opposite than expected based on the ‘elevational gradient hypothesis’. The regression coefficients for Australia, Europe, and North America all demonstrated an opposite directional relationship from the global rule in all regressions performed (Table 3-3 & 3-4). Australian, European, and North American language richness, which comprises just 25% of all languages included in analyses, increases along the elevational gradient, with continuously increasing diversity at higher elevations.

Rapoport’s Rule along the Elevational Gradient

The analysis of “Rapoport’s rule” in relation to the elevational gradient, revealed another consistency between language and species distributions; global language range size distributions are highly positively skewed (Figure 3-9), but generally log-normal (Figure 3-10). At the global scale, mean language range size increased steadily

with increasing elevation (Figure 3-11 & 3-12) in support of ‘Rapoport’s rule’ in global language distributions. These data sampled using the Mace and Pagel (1995) contour method validated global results from the first question, which generally demonstrated a consistent decline in language richness with increasing elevation (Figure 3-11), and standardized data demonstrated highest richness at intermediate elevations (Figure 3-12).

At the regional scales of analyses there was, as expected, more variability in these patterns (Figures 3-11 to 3-16). ‘Rapoport’s rule’ was not clearly apparent in any regional analysis, except perhaps along the Australian elevational gradient. Unlike the results from the first question’s analyses, this regional investigation of ‘Rapoport’s rule’ demonstrated the regions which hold the majority of the world’s language diversity, namely Africa and Asia, do not adhere to the globally distinct rule. ‘Rapoport’s rule’ in language distributions may be a variable phenomenon at the regional scale, but with apparent broad scale patterns.

Global Mountain Areas and Their Importance for Language Diversity

At the global scale, over three times the language diversity can be found in non-mountain land areas, which was expected, as non-mountain areas represent 89.67% of all land surface area, as defined by the Stepp *et al.* 2005 criteria (Figure 3-19). While accounting for sampling intensity represented by the smaller land surface-areas covered by mountains; these mountain regions did, as expected, house almost three times greater language richness per unit area than non-mountain areas (Figure 3-19). The 10.33 % of the earth’s land surface area classified as mountain regions in this analysis using the Stepp *et al.* 2005 criteria may be a conservative estimate of the

global extent of mountain areas, as objective estimates of land surface area covered by mountains tend to hover around 20% of the earth's land surface area (Kapos *et al.*, 2000; Körner, 2004; UNEP-WCMC, 2003). These results confirm the observation posited by Stepp *et al.* (2005), that mountains do harbor higher cultural diversity than non-mountain areas using planimetric criteria for area.. Only 10% of the global land surface area contains almost one-third of all extant languages (Figure 3-19). These results particularly emphasize the importance of accounting for sampling effort in analyses.

Table 3-1. Spearman's rank correlation coefficients of elevation zones with language richness and standardized language richness per elevation zone.

Language richness	Global	Africa	Asia	Australia	Europe	North America	South America
Non-truncated	-0.9998	-0.7736	0.7441	-0.8544	-0.6722	-0.4197	-0.0765
Truncated	-0.7441	0.9936	0.9998	-0.9958	-0.9958	-0.8056	-0.8695
Richness standardized per 1000 km ²	Global	Africa	Asia	Australia	Europe	North America	South America
Non-truncated	0.0484	-0.7373	0.2025	-0.5529	0.5014	0.2128	0.3437
Truncated	0.2025	0.1548	0.0411	0.6	0.7091	0.7881	0.3334

Negative correlation means that higher elevations have fewer languages. All correlation coefficients are statistically different from zero at $p < 0.05$ except the standardized, truncated relationships for Global, Africa, and Asia.

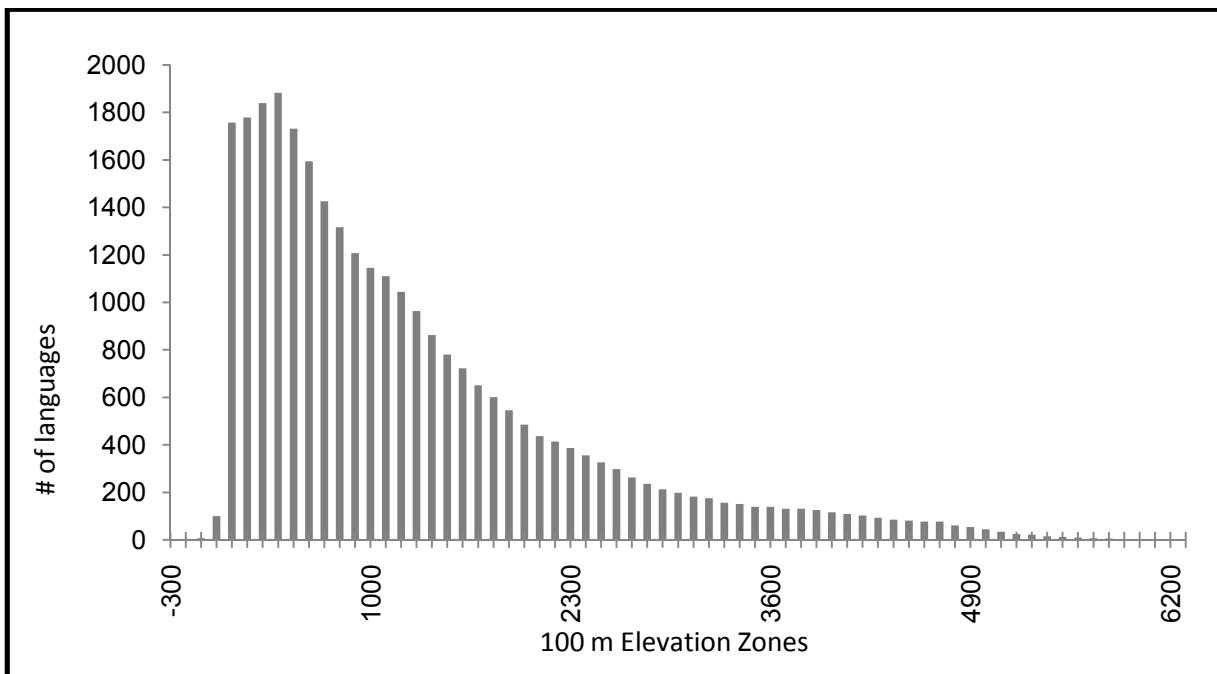


Figure 3-1. Global language richness of 100 m elevation zones.

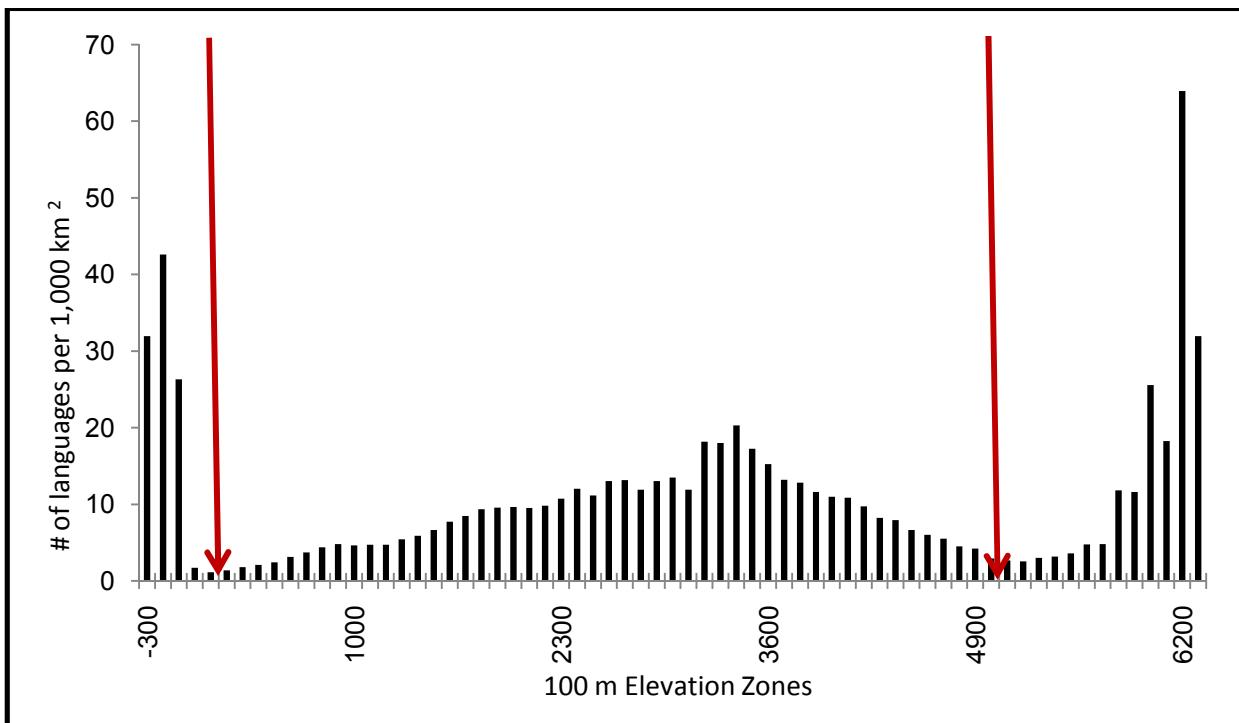


Figure 3-2. Global language richness standardized per 1,000 km² within the 100 m elevation zones. Arrows indicate truncation points, data were analyzed from 100 m to 5000 m to exclude the highly leveraging tails in the distribution.

Table 3-2. Truncation ranges which represent at least 99 % of the land surface-area per region, used to remove the highly leveraging elevations with disproportionately small land surface areas..

	Global	Africa	Asia	Australia	Europe	North America	South America
Truncated range (meters)	100-5000	400-3500	0-5000	100-1000	0-3500	100-3500	100-5000

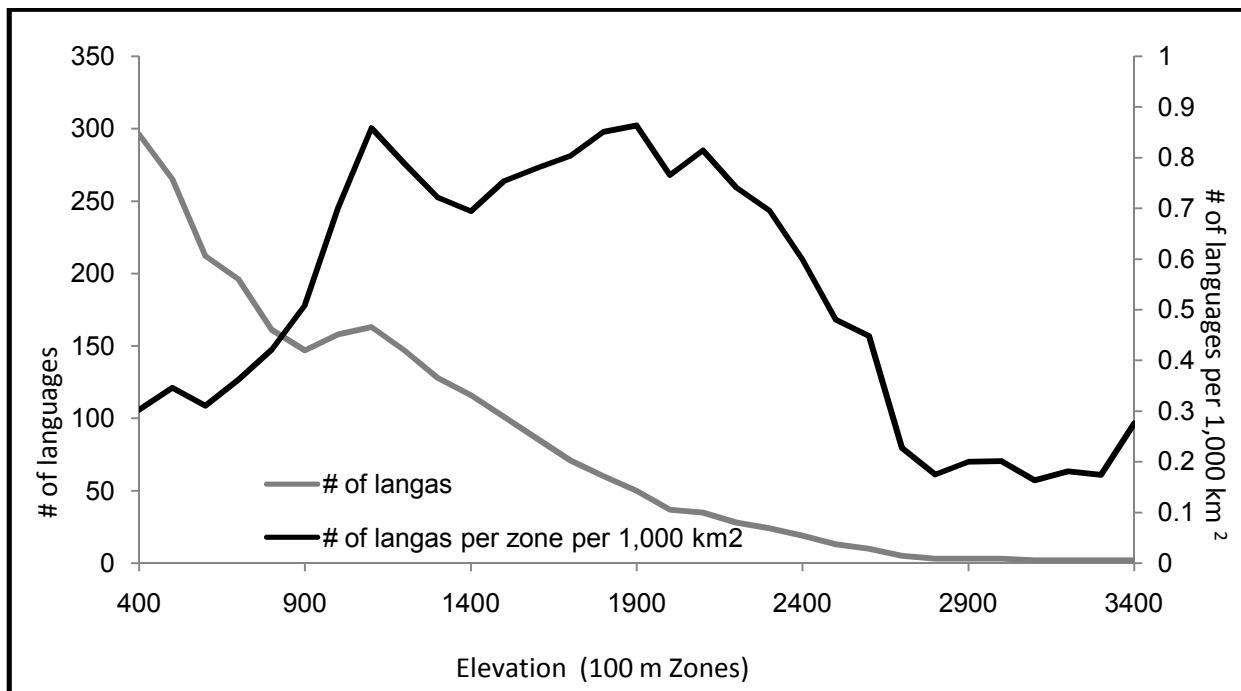


Figure 3-3. Language richness along the African elevational gradient (n=1349)

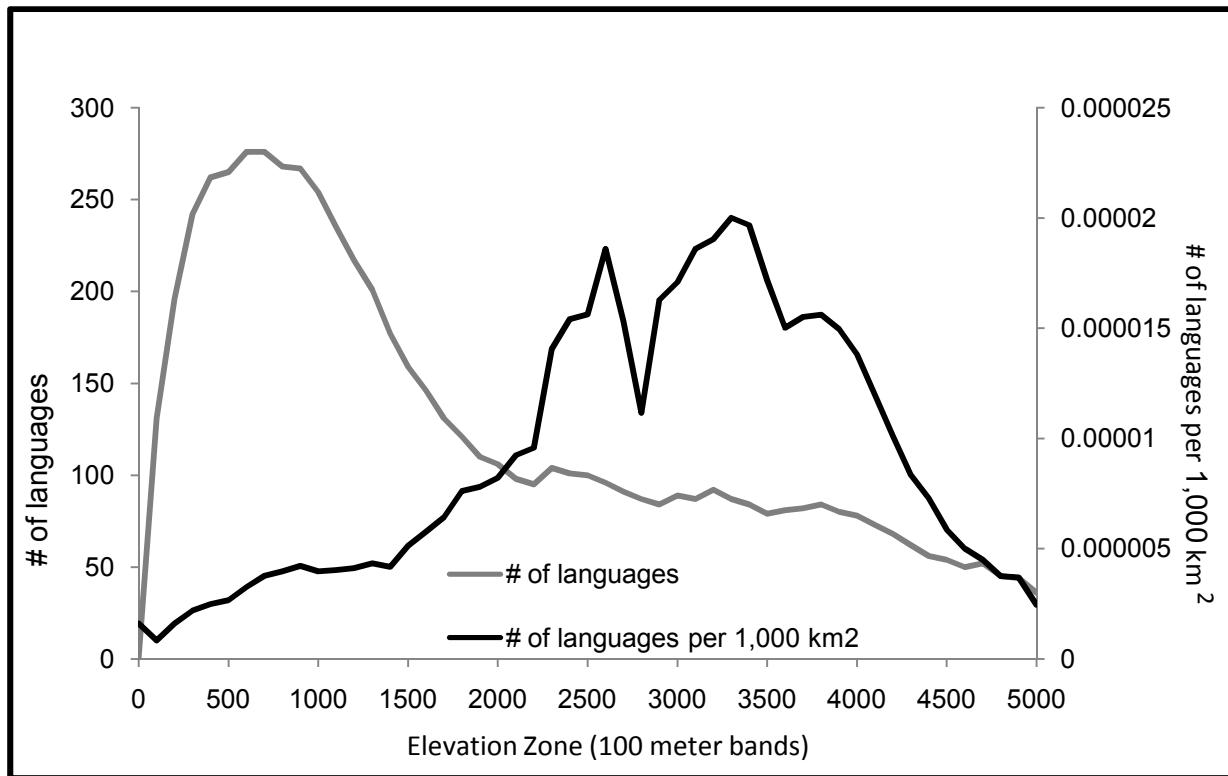


Figure 3-4. Language richness along the Asian elevational gradient (n=1000)

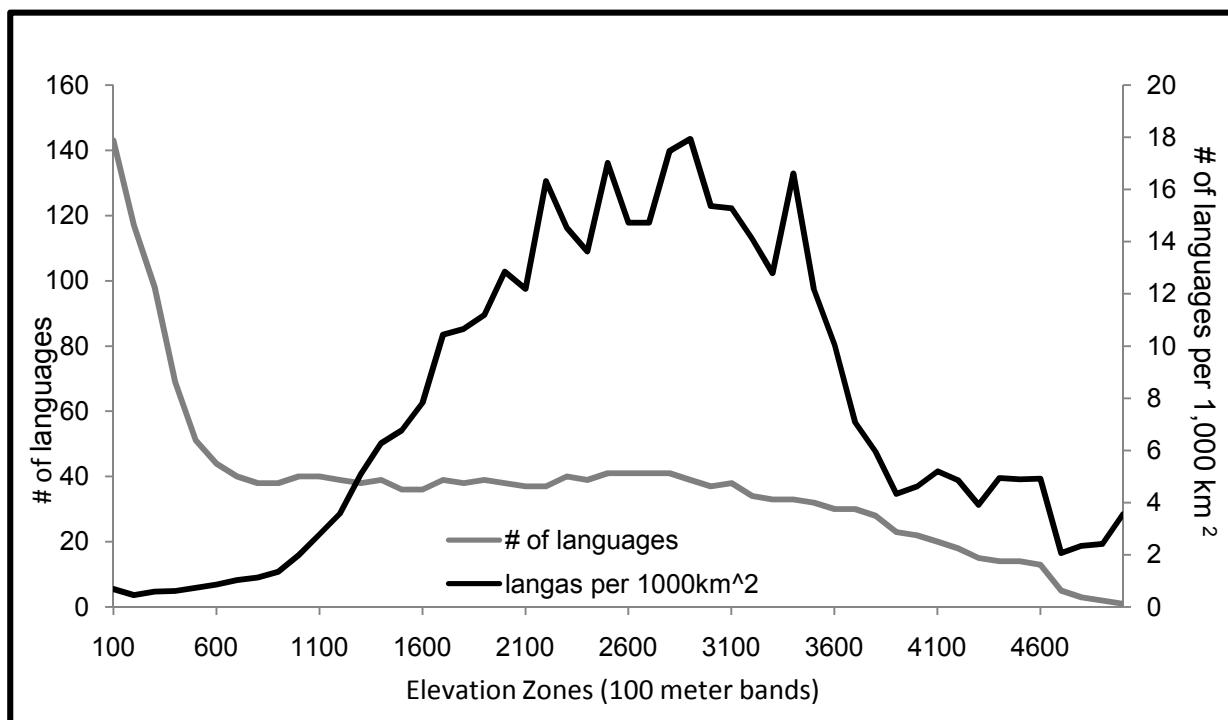


Figure 3-5. Language richness along the South American elevational gradient (n=316)

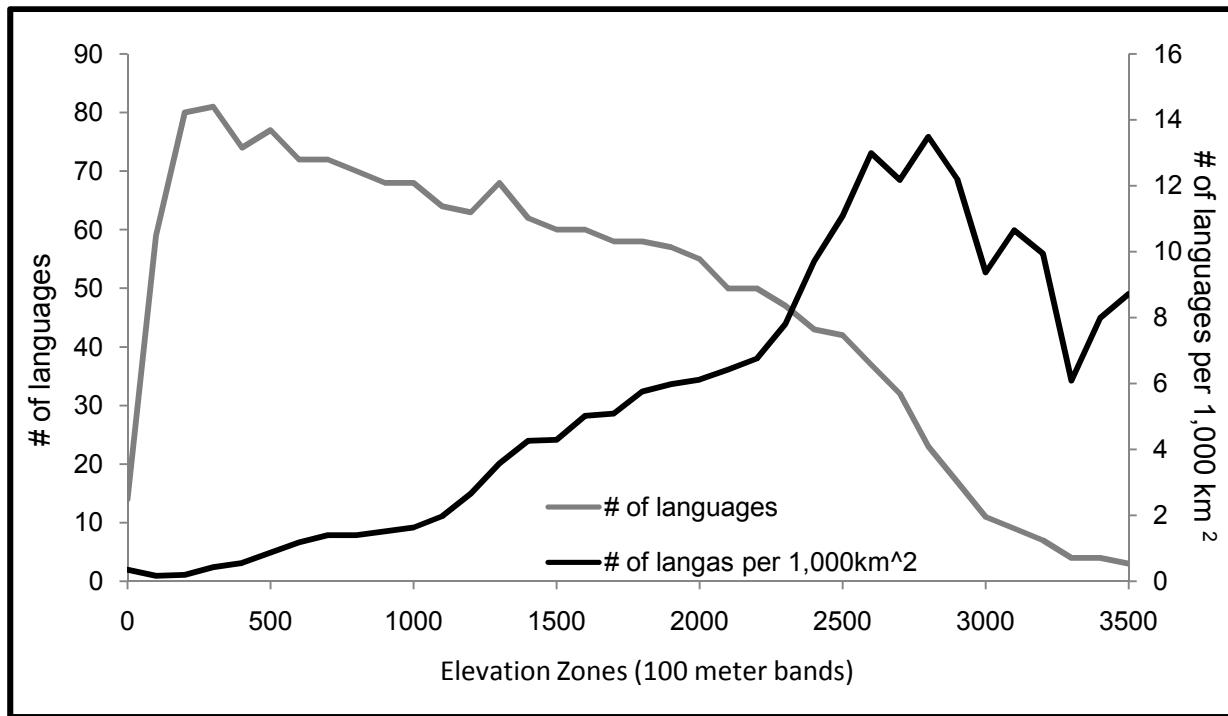


Figure 3-6. Language richness along the European elevational gradient (n=273)

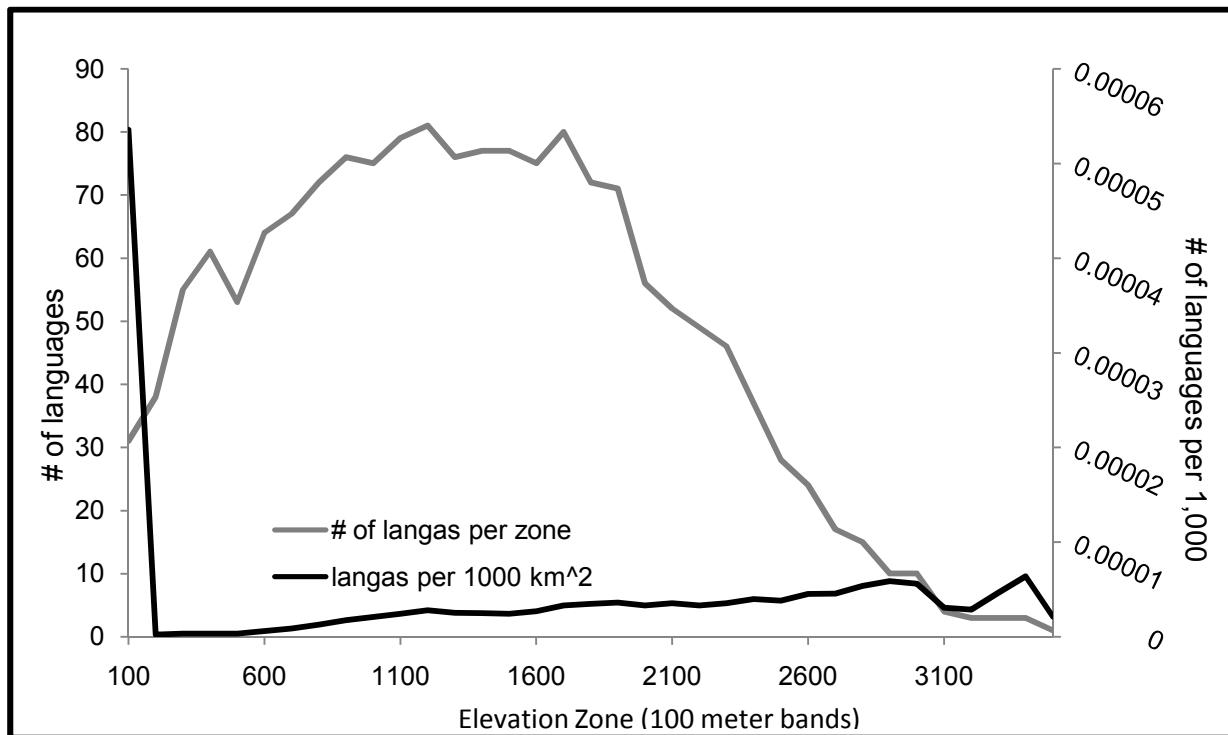


Figure 3-7. Language richness along the North American elevational gradient (n=487)

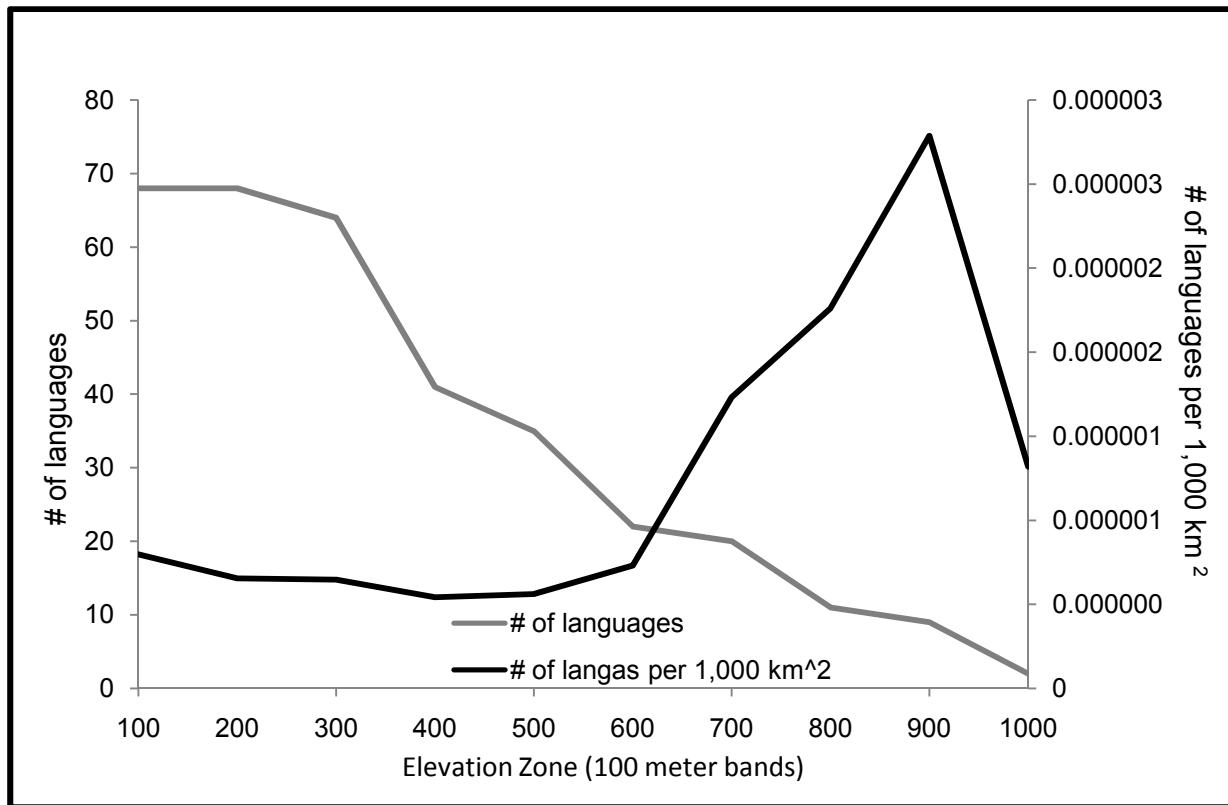


Figure 3-8. Language richness along the Australian elevational gradient (n=135)

Table 3-3. Multiple regression results with non-standardized languages – truncated to include 99% of the land surface-area per region.-Variables include elevation zone (EZ), square root of EZ (SQRT_EZ), dummy of 2500 m and above (D_2500m) and d_2500*sqrt_ez. n= number of languages in analysis, R2 indicates the adjusted R2 of the model, regression coefficient of elevation variable, and F-ratio of model.

	Global	Africa	Asia	Australia	Europe	North America	South America
n =	5725	1349	1000	135	271	487	316
R ²	0.9700*	0.9853*	0.9690*	0.9527*	0.9505*	0.9645*	0.9213*
EZ regression coefficient	0.2734*	0.1762*	0.3079*	-0.0817	-0.0671*	-0.1102*	0.1189*
F-ratio	495.307	453.412	351.814	43.533	148.798	203.791	131.610

* indicates p-value <0.001

Table 3-4. Multiple regression results with standardized languages. Variables include elevation zone (EZ) and square root of elevation zone (SQRT_EZ)

	Global	Africa	Asia	Australia	Europe	North America	South America
n =	5725	1349	1000	135	271	487	316
Truncated range (meters)	100-5000	400-3500	0-5000	100-1000	0-3500	100-3500	100-5000
% of languages after truncating	99.49%	85.99%	99.49%	99.41%	99.3%	100%	99.67%
R ²	0.5363*	0.7870*	0.5360*	-----	0.8016*	-----	0.5350*
EZ regression coefficient	-0.0086*	-0.0018*	-0.0086*	-----	0.0036*	-----	-0.0138*
SQRT_EZ regression coefficient	0.9076*	0.1447*	0.9076*	-----	-0.0008	-----	1.3218*
F-ratio	27.152	53.852	27.152	-----	137.404	-----	27.036

* indicates p-value <0.001

Australian and North American standardized language data had no variance in association with elevation and the models would not run.

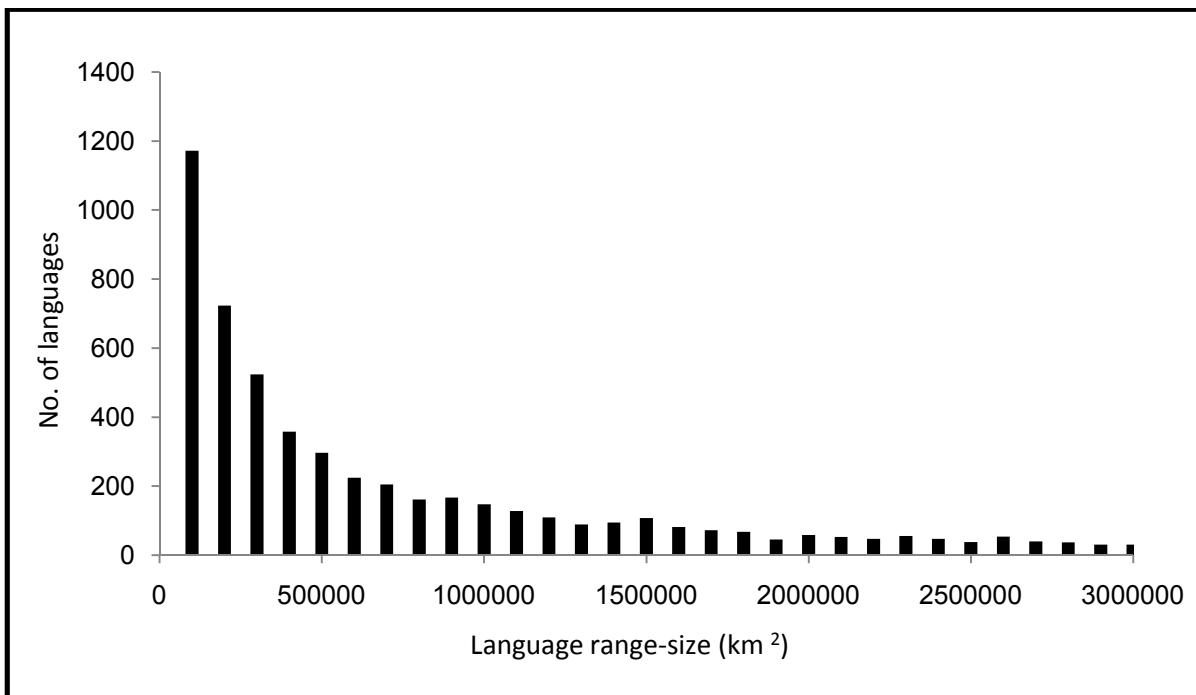


Figure 3-9. Language range size distribution is extremely positively skewed. Of the 5725 language range sizes included here, 1953 languages are not shown in the tail of this distribution.

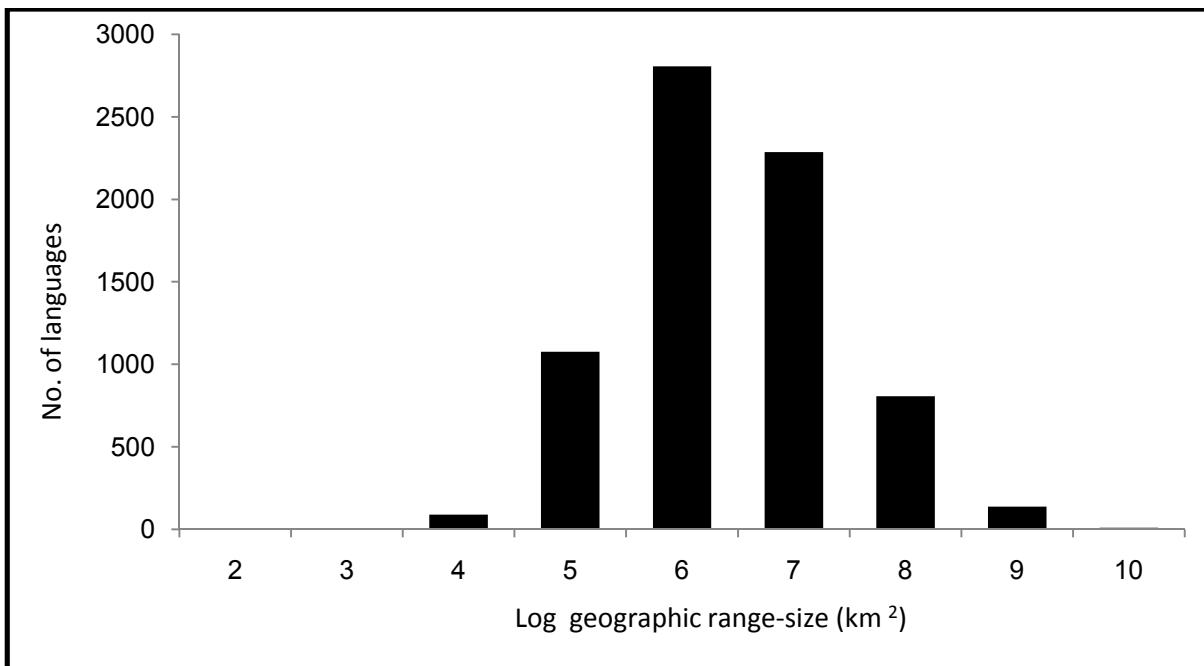


Figure 3-10. Language range size frequency distribution for \log_{10} transformed global geographic range sizes

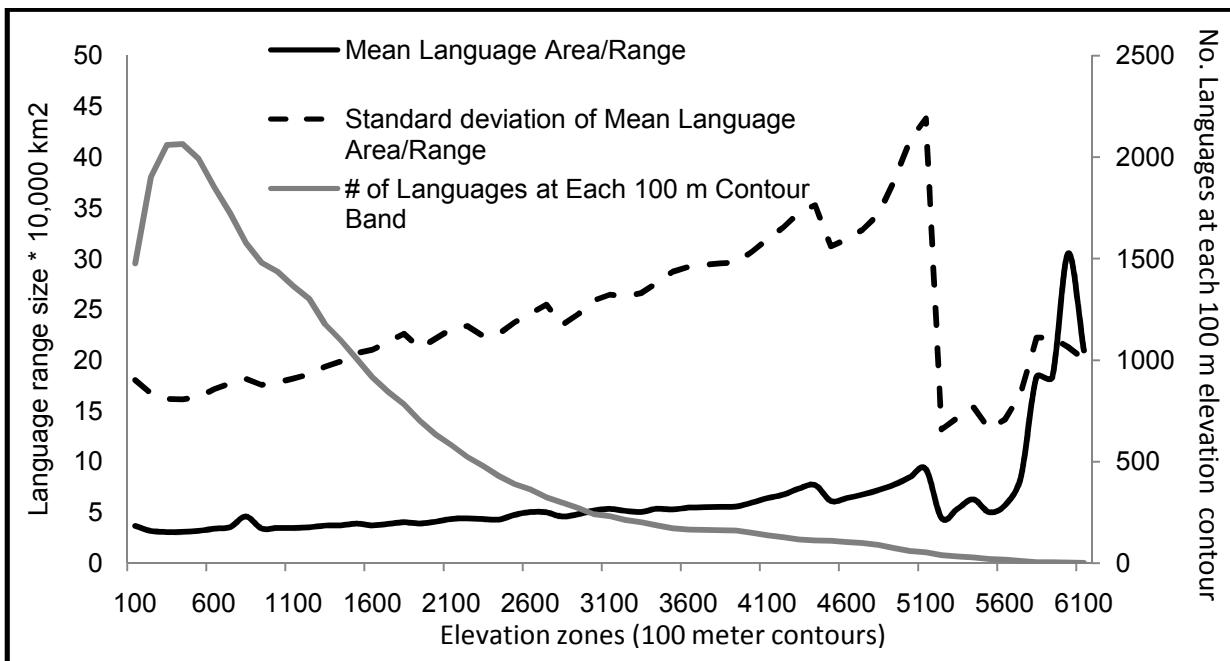


Figure 3-11. Rapoport's Rule of un-standardized language richness along the global elevational gradient. This figure demonstrates familiar steady decline in language richness, and increasing area/range size of languages with increasing elevation, as well as the increase in variability of area/range size with increasing elevation.

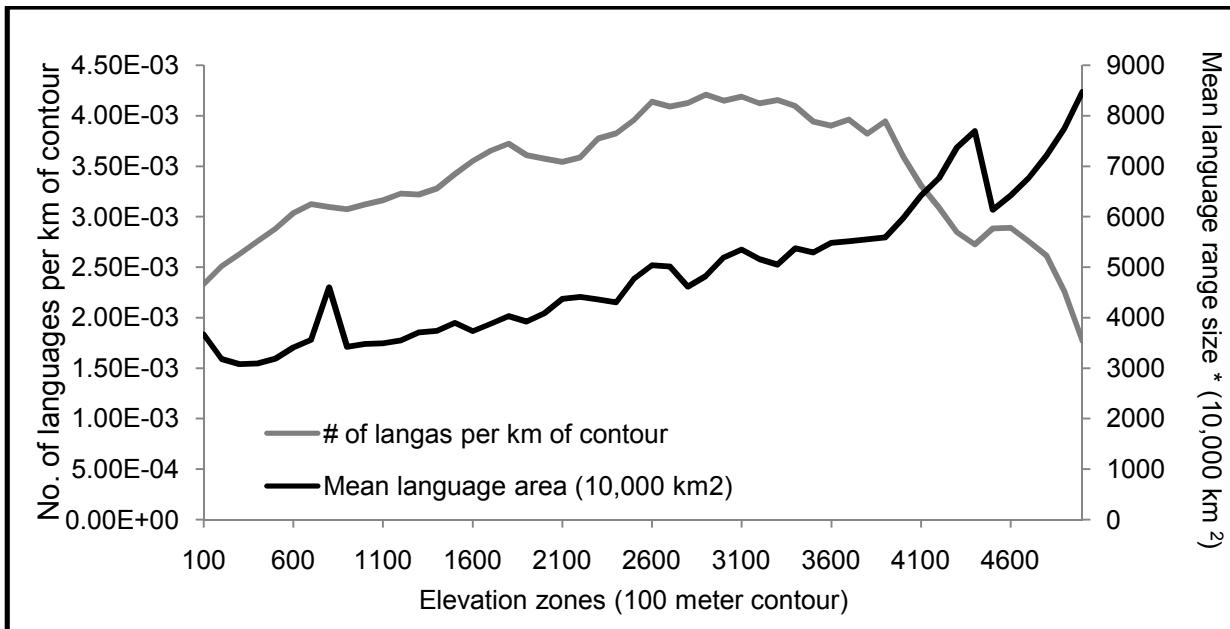


Figure 3-12. Rapoport's Rule of standardized language diversity along the global elevational gradient. Standardized languages demonstrate the highest richness uni-modal hump at intermediate elevations. Mean language area (range size) increases consistently with increasing elevations.

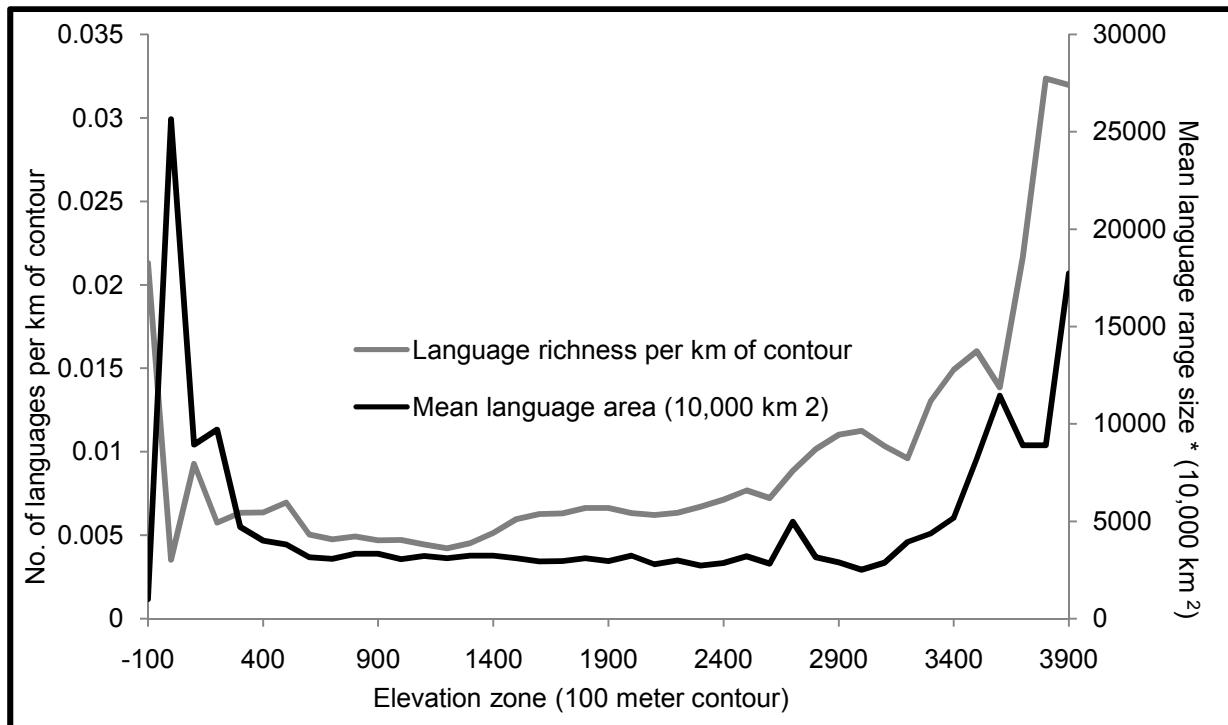


Figure 3-13. Language richness (per km of contour) and mean language area (range size) ($10,000 \text{ km}^2$) along the African elevational gradient.

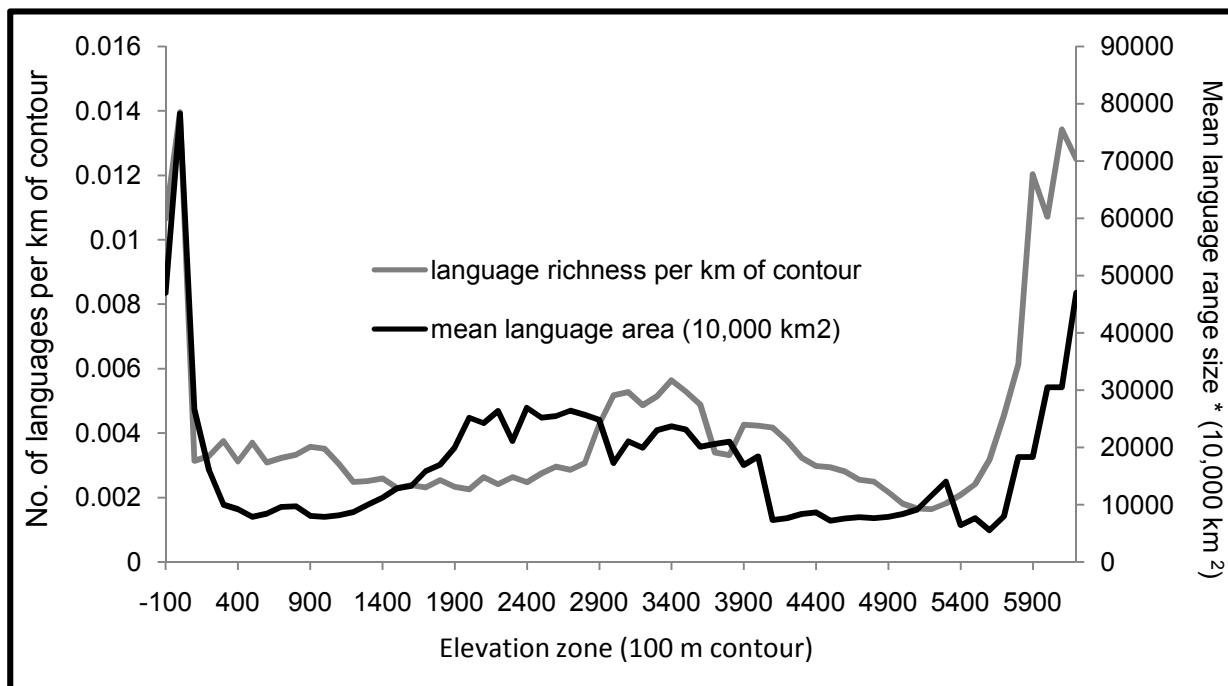


Figure 3-14. Language richness (per km of contour) and mean language area (range size) ($10,000 \text{ km}^2$) along the Asian elevational gradient.

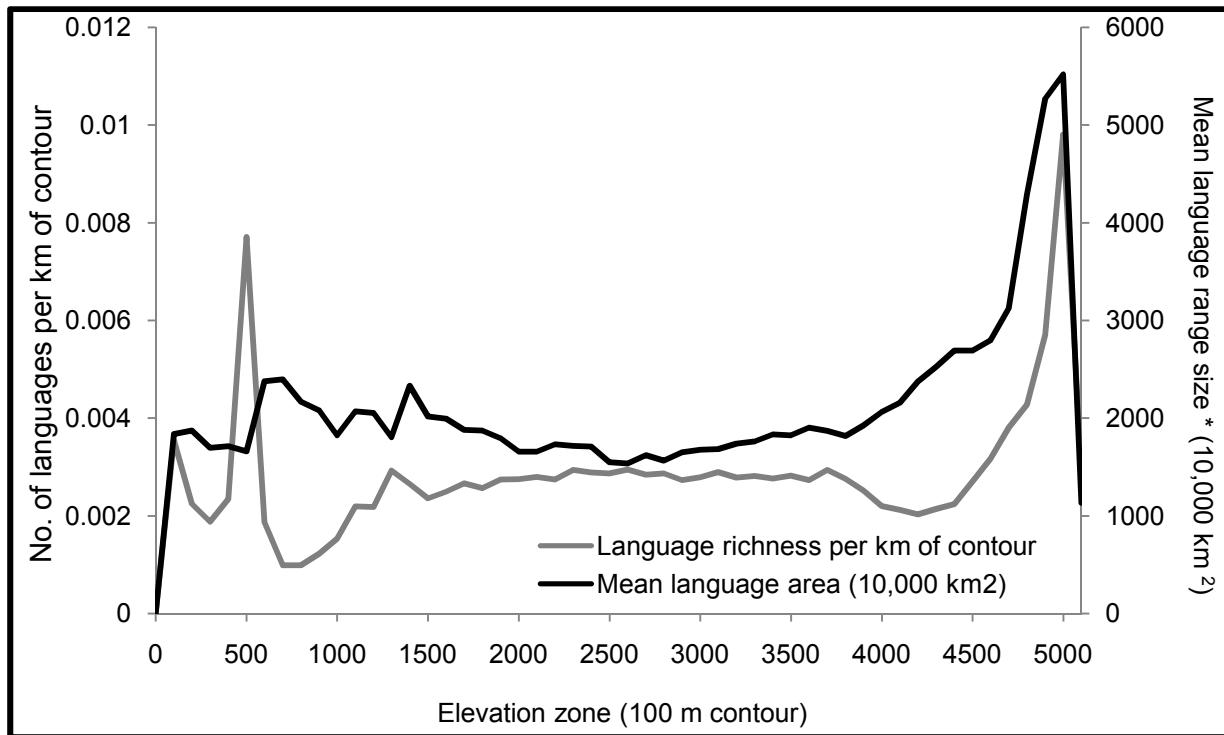


Figure 3-15. Language richness (per km of contour) and mean language area (range size) ($10,000 \text{ km}^2$) along the South American elevational gradient.

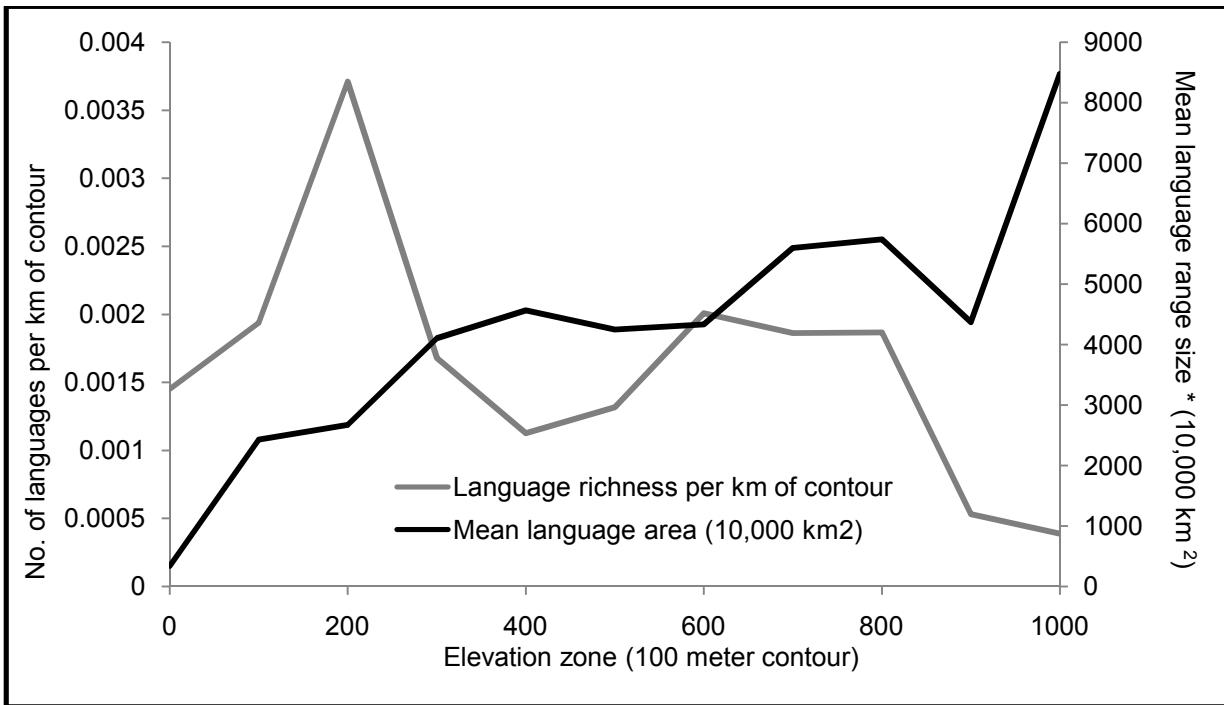


Figure 3-16. Language richness (per km of contour) and mean language area (range size) ($10,000 \text{ km}^2$) along the Australian elevational gradient.

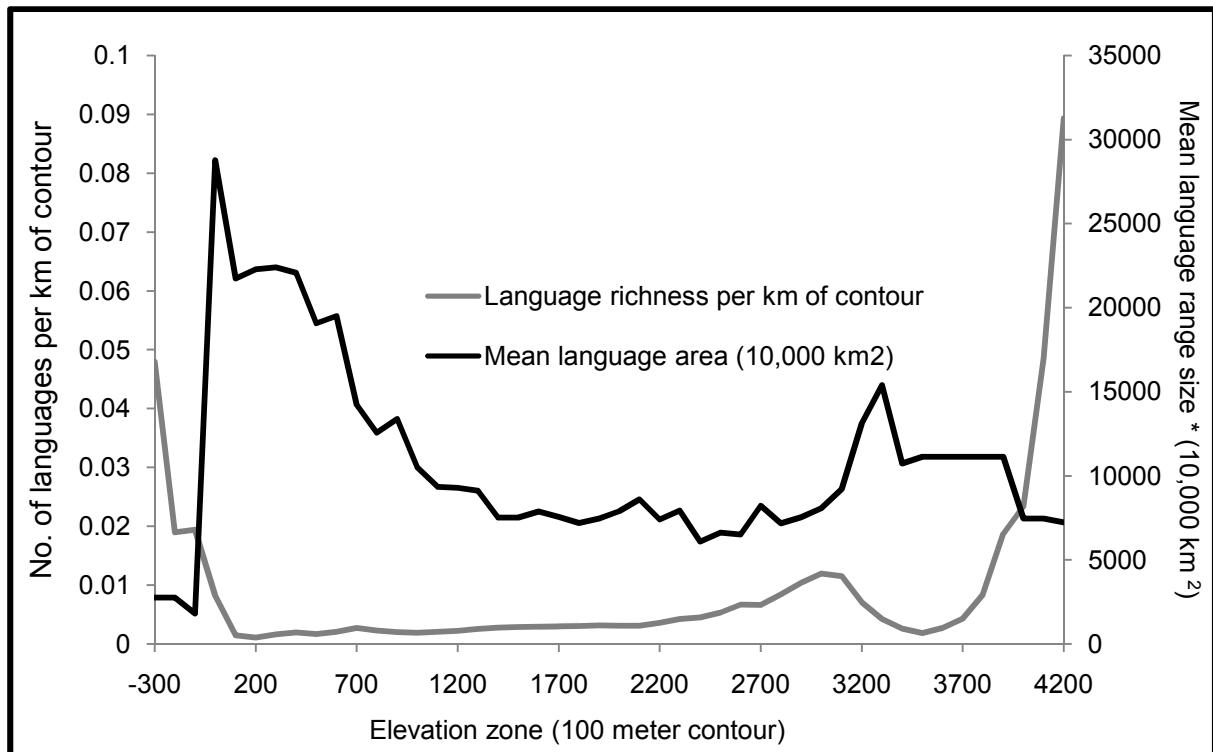


Figure 3-17. Language richness (per km of contour) and mean language area (range size) ($10,000 \text{ km}^2$) along the European elevational gradient.

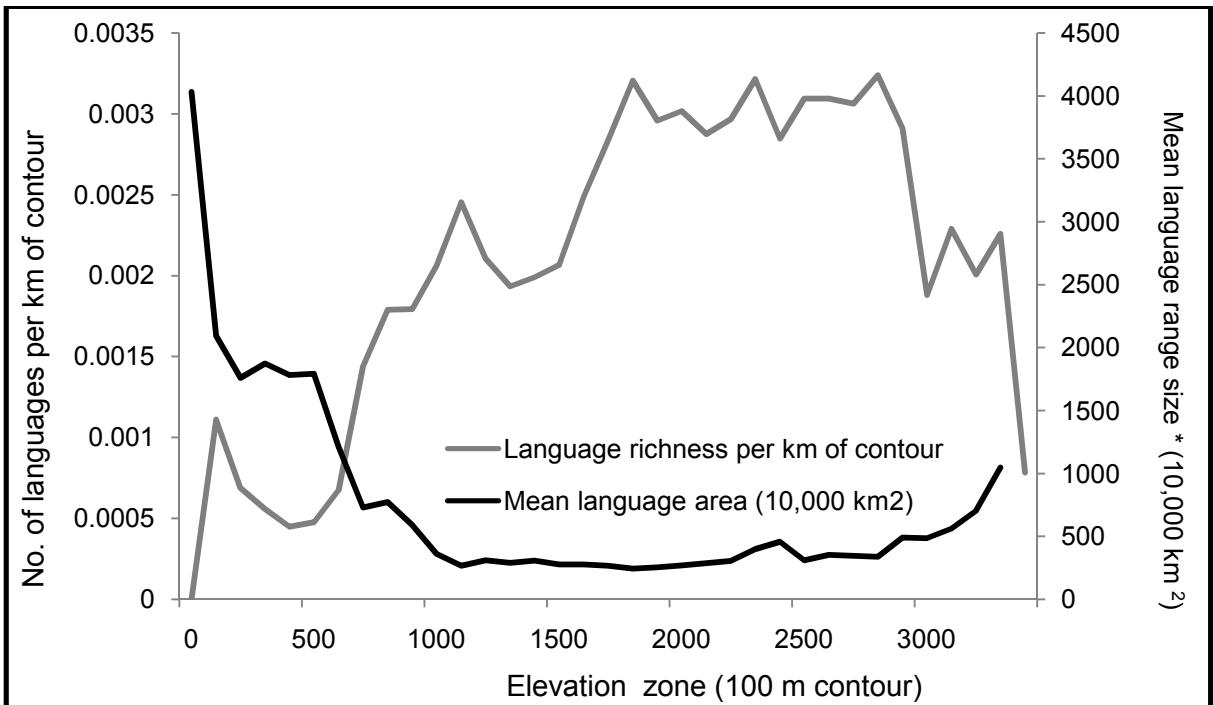


Figure 3-18. Language richness (per km of contour) and mean language area (range size) ($10,000 \text{ km}^2$) along the North American elevational gradient.

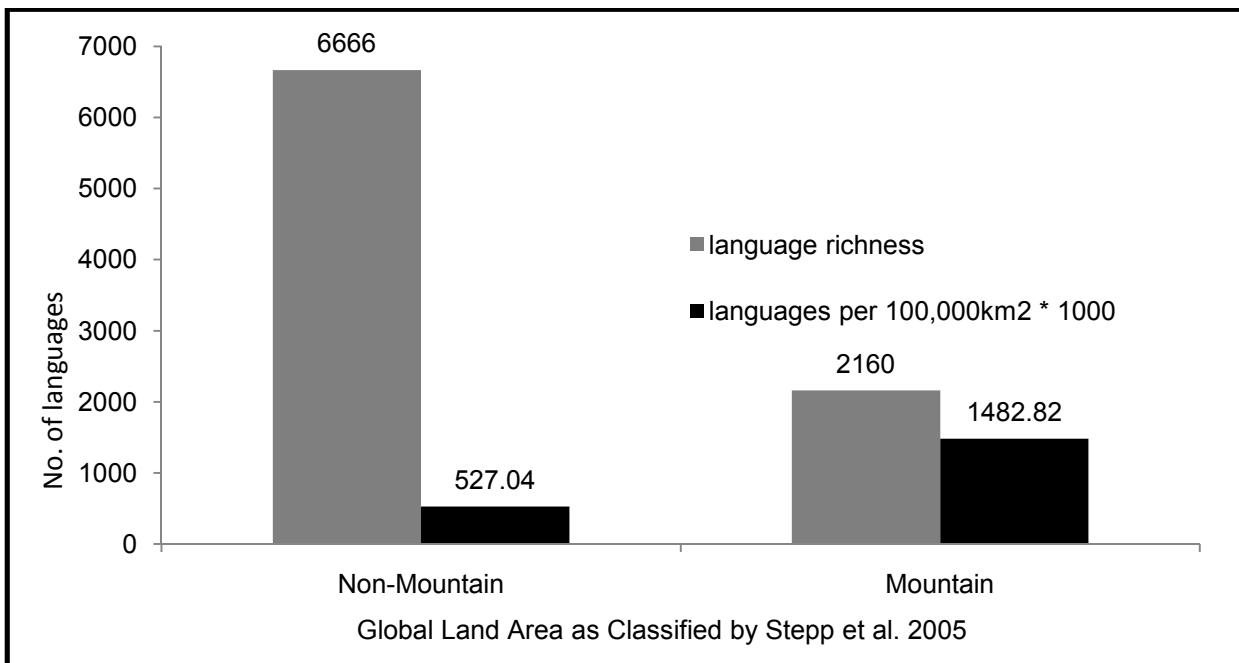


Figure 3-19. Global language richness in mountain vs. non-mountain areas (Stepp *et al.* 2005 criteria).

CHAPTER 4 DISCUSSION

As Lomolino notes (2001, pp. 3), "Spatial variation in natural resources may have been a key impetus for dispersal, migration, and colonization of early humans across the continents and to distant archipelagoes" (Howells, 1973; Clark, 1992; Flannery, 1994; Gamble, 1994). At least since the time of Linneaus, but probably since Aristotle, it has been understood that mountain slopes possess a compressed and orderly succession of climate, vegetation zones, and animals which mimic at a local scale the broader latitudinal gradient in diversity (Linneaus, 1743). Particularly as humans have a long evolutionary history coevolving with the species on which we depend along these resource gradients, it should not be too surprising that the human species may also align its distribution to some of these long established biogeographical principles. The intraspecific variation in human cultural/language distributions may or may not be comparable to inter-species variation in biodiversity distributions traditionally assessed in relation to environmental gradients. The ambiguity in the hierarchical classifications of species has many parallels in the classifications of language groups, as the structure of how groups are related is heavily debated within the fields of both biology and linguistics. The human species is clearly unique, but it is at least worth considering our own intraspecific cultural variability in the context of these long observed biogeographic patterns.

Consistent with established patterns of numerous taxa along elevational gradients throughout the globe (Rahbek, 1995), global languages demonstrate a steady decline in richness with higher elevation (Figure 3-1). Much of this pattern demonstrated by the

results from question one may be explained through the species-area relationship (Gleason, 1922; MacArthur and Wilson, 1967); due to the reduction in land surface area while ascending the elevation gradient, this monotonic decline in language richness was expected. Without accounting for this species-area relationship, language richness does decrease monotonically from sea-level to the highest mountain-tops, akin to geographic variations in species distributions (Whittaker, 1960, 1977; Yoda, 1967; Kikkawa and Williams, 1971; Terborgh, 1977; Heaney, 1991; Daniels, 1992; Sfenthouraskis, 1992; Fernandes and Lara, 1993; Patterson *et al.*, 1996, 1998).

When data were standardized to account for sampling intensity, language density like species density was greatest at intermediate elevations (Whittaker, 1960, 1977; Whittaker and Niering, 1975; Brown, 1988; Rosenzweig, 1992, 1995; Rahbek, 1995, 1997; Fleishman *et al.*, 1998; Heaney, 2001; Rickart, 2001; Sanders, 2002; Sanders *et al.*, 2003; Bhattacharai *et al.*, 2004; Lee *et al.*, 2004) and demonstrated a familiar uni-modal hump shaped density distribution. Language richness increases gradually from sea level, and ascending more rapidly towards the foothills or mid-elevations of mountains, and then declining again as elevations approach mountain summits (Figure 3-2 to 3-9). The counter-effects through opposite directional patterns of biotic factors, such as isolation dependent immigration rates and heightened endemicity, as well as opposing abiotic interactions of climate along this underlying environmental resource gradient may contribute to the hump in language richness at intermediate elevations (Rosenzweig, 1995, 1997; Lomolino, 2001; Lomolino *et al.*, 2006). Surely there are numerous other environmental and socio-political variables which contributed to the distribution of global languages; but as hypothesized, there is a distinct elevational

gradient in language richness that resembles trends in the latitudinal gradient of language richness (Stepp *et al.*, 2004; Sutherland, 2003; Mace and Pagel, 1995) as well as fundamental biogeographical principles of global species distributions (Humboldt, 1849; Darwin, 1859; Wallace, 1876; Merriam, 1890; Whittaker, 1960; Brown, 1978).

Overall, sub-continental regional-scale analyses revealed results similar to predicted global scale patterns, and demonstrated that trends in language diversity distributions along the elevational gradient may in fact be a global phenomenon at the regional scale as well. Africa, Asia, and South America all demonstrated negative correlations of regional language diversity with increasing elevation. However when data were standardized by area, these correlations were neutral (Table 3-1); probably linear correlations represented by the Spearman's statistics were balanced by the unimodal 'hump' in language richness which occurred at intermediate elevations (Figures 3-3 to 3-5). As Africa, Asia and South America contain 75% of languages being analyzed on just over half the earth's land surface area, it is not surprising that these dominant sub-continental regions reflect the global pattern. However the non-conformity in the regional differences of the remaining 25% of the languages analyzed from over 40% of the earth's land surface area may be more reflective of the non-biogeographic driving mechanisms of language distributions. In contrast to the patterns of predicted conformity seen thus far, the regional diversity distributions in Australia, Europe and North America, did not follow predicted patterns posed by the elevational gradient hypothesis. Interestingly, two regions with recent histories of colonization, Australia and North America, as well as the region of their colonizers, Europe, did not follow predicted patterns based on solely biogeographic principles. Most continents

have endured their own unique history of brutality and colonization for millennia (Krauss, 1992), which is not unique to just Australia, Europe and North America. Nevertheless, these three continents demonstrate distinctly different patterns of extant language distributions relative to elevation gradients in the rest of the world. When data were standardized by area, Australian, European, and North American language distribution patterns show an unexpected positive correlation (Table 3-1) of increasing language diversity richness with increasing elevation (Figures 3-6 to 3-8). The regional variability in distinct biogeographic patterns may be explained through the complex evolutionary and socio-economic histories which distinguish us as humans. Further analysis of these patterns from a historical perspective would provide the additional layer of explanatory detail behind the sub-continental regional variability.

As these regional results are incongruent with the global pattern, it is likely that these variable patterns represent more than general biogeographic drivers of biotic-abiotic interactions, but reflect the socio-political-economic histories of human cultural historical processes or driving mechanisms of extant post-colonial language distributions. These data utilized in this investigation capture extant languages known only since the beginning of Ethnologue's efforts to record language data in the 1950's. It is unfortunate, but likely that these data are not complete, and that knowledge of native language locations and ranges may not represent the full history of diversification processes. I expect the incongruous regional patterns between Australia, Europe and North America, and the rest of the world, to be a combination of both compromised data based on lost linguistic history in these regions, as well as the influence of non-

environmental drivers like colonization which affected the present-day North American and Australian language distributions.

The parallels of ecological and cultural diversity distributions along the latitudinal and elevational gradients are further emphasized by the results from my second question which support ‘Rapoport’s rule’ in languages along the global elevational gradient (Figure 3-11 and 3-12). The global language range size distribution is highly skewed (Figure 3-9), however generally log-normal (Figure 3-10), just as are range size distributions in numerous other taxa (Gaston, 1996). Using the contour method to assess the pattern of language distribution patterns, the broad scale global results support those from the first analysis. At the global scale, language richness consistently decreases with increasing elevation, or when contours are standardized by area the expected uni-modal hump of greatest diversity at intermediate elevations parallels the results from the previous analysis. The mean range size of languages intersecting the 100 m elevation contours increases with increasing elevations (Figure 3-11 & 3-12), demonstrating a negative relationship between language richness and language range size and that at the global scale languages generally do follow ‘Rapoport’s Rule’. Biological species distributions generally follow ‘Rapoport’s rule’ at the broad global scale (Rapoport, 1989; Gaston, 2005) but demonstrate much greater variability at finer regional and local scales which has driven much of the controversy as to the universality of the rule (Ruggiero and Werenkraut, 2007).

As expected, regional analyses of ‘Rapoport’s rule’ in relation to language richness and range size reveal much more variable results and do not adhere to any general global pattern (Figures 3-13 to 3-18). In the question one results, the regions with the

greatest proportion of the world's languages demonstrated the most parallel biogeographic pattern to the global rule. However the results of 'Rapoport's Rule' which utilized the Mace and Pagel (1995) contour approach, are much more unpredictable at the regional scale; congruent with the non-conformity of biological species distributions to 'Rapoport's rule' at regional and local scales.

The results from the third question demonstrated that global 'mountain regions' do have higher language richness than 'non-mountain regions', as predicted by Stepp *et al.* 2005 from their analyses of language richness on New Guinea, but only when data were standardized by land area. As the species-area relationship is well understood (Gleason, 1922), it would be inappropriate to consider these results without accounting for area, as it has been in all previous work of language diversity distributions in relation to mountains. For only 10.33 % of the earth's land surface-area is defined as 'mountain region' by the Stepp *et al.*, (2005) criteria. If sampling intensity or land surface-area covered by mountain regions was ignored, the results then reflected an opposite pattern to that predicted by Stepp *et al.*'s (2005) 'topography hypothesis' (Figure 3-19). Currie and Mace (2009), used these non-standardized local predictions in selecting important explanatory variables of 'Rapoport's rule' in global language range distributions. Finally, these results emphasize the critical importance of standardizing data by sampling area in analyses. This fundamental principle of the species-area relationship (MacArthur and Wilson, 1967; Gleason, 1922) has commonly been ignored in most previous publications of language distribution patterns, and is one methodological concern that is likely responsible for much of the inconsistency in the literature.

Globally, mountains do hold a greater number of languages per unit area than lowland areas. The underlying mechanisms of this heightened and concentrated language diversity probably depend on the compression of numerous life zones in the underlying resource gradient utilized by human cultures along a relatively small geographic area (Holdridge, 1967; Lomolino, 2001; Körner, 2004). Globally mountain regions known for high endemism and biodiversity must also be acknowledged as important hotspots for language and cultural diversity. Particularly if mountains are both isolated and large enough to allow population persistence and divergence over evolutionary time, mountain environments may promote heightened language diversification as well as the parallel increased species diversification through co-evolution.

Coevolution of humans and our natural resources: The human species is clearly unique in our ability to overcome geographic constraints unlike most other species; however the intraspecific variation of human language diversity does in fact follow the elevational gradient pattern. As was also previously demonstrated along the latitudinal gradient (Mace and Pagel, 1995; Cashdan, 2001; Moore *et al.*, 2002; Manne, 2003; Sutherland, 2003; Stepp *et al.*, 2004), language diversity distribution patterns do mimic biogeographical patterns shown in numerous biological taxa. Patterns revealed in these analyses indicate that language diversification patterns may have been driven, at least in part, by similar evolutionary mechanisms which promote species diversification and distribution patterns. As was eloquently stated by Theodosius Dobzhansky (1937) – “Nothing in biology makes sense except in the light of evolution”.

Trends in language diversity along latitudinal and elevational gradients likely represent human evolutionary adaptation to the myriad of interacting underlying environmental variables and overarching climatic variables captured in resource gradients (Harmon, 1996; Smith, 2001). This research demonstrates that biogeographic factors which characterize environmental gradients may play an important role in explaining these patterns. I expect evolutionary adaptations to the biophysical environment, in addition to the interactions of social, cultural, economic and political histories within that environmental context to be the key in finding these explanations at a regional scale. As shown in Australia, North America and Europe, there are clearly other important non-biophysical geographic variables influencing the distribution patterns of languages at the regional scale (Crosby, 1986). The regional socio-economic historical variables which were not included in this analysis will likely fill the gap in understanding the finer scale variability in distribution patterns.

Further analyses need to expand the explanatory models of language distributions at multiple scales to incorporate the myriad of social and environmental variables, but should still be founded in biogeographic and evolutionary principles, and inspired by the deep personal local histories which have promoted such exceptional diversity in our own human species. As we continue to seek general principles in ecology to explain patterns of species distributions, we should not fail to consider *Homo sapiens* as a species dependent on resource gradients and vulnerable to driving mechanisms of diversification in our own intraspecific distributions.

APPENDIX A
ANTHROPOGENIC LAND-USE / LAND-COVER CHANGE AND THE GLOBAL
DISTRIBUTION OF THREATENED AND ENDANGERED LANGUAGES

This additional appendix has been included because it was a worthwhile graduate-level class research project that investigated a potential causal factor behind the correlations of global biological and cultural diversity distributions. However there were no significant results indicating global anthropogenic land-use/land-cover change (LULCC) from 2001-2007 had any influence on the distributions of threatened and endangered languages. There is more research to be done on this interesting topic; however there are fundamental issues in assessing a long-term process of language extinction within the context of just a 6-year window of LULCC in a general analysis at the global scale. This appendix should be considered a seed for future research directions. Without incorporating a much broader historical context or refining the analysis to very specific and fine-scale spatial extent where longer temporal scales of data are available, this analysis has little meaning. Therefore, it was kept separate from the thesis body.

Abstract

There have been numerous studies identifying Land Use Landcover Change (LULCC) as an influential driver affecting biodiversity richness and its distribution (Diggelen *et al.*, 2005). Correlations between distribution patterns of biological and cultural diversity have also been recently highlighted (Maffi, 2005; Sutherland 2003). However little is known about the influence of LULCC to cultural diversity distributions and persistence. Using MODIS IGBP Classified Global Mosaic Data from 2001 and 2007, Landcover Change Trajectory maps were used to quantify rates and types of landcover change within 100 km of 6659 extant languages, classified into critical, endangered and vulnerable threatened categories (with fewer than 500, 1000, and 10,000 speakers respectively). Change in any landcover classification to cropland, urban and built, and cropland/vegetation mosaic categories, where merged in analysis of anthropogenic disturbance. Results indicate over twice the mean anthropogenic landcover change to cropland, urban and built, and cropland/vegetation mosaic classifications occurred in non-threatened language buffers, than in threatened language buffers. Buffer zones of extinct language locations had magnitude of landcover change significantly different from endangered languages, however not significantly different from non-threatened language buffers. This result indicates that historical processes driving language extinction patterns may differ from current threats. Potential correlations between magnitude of LULCC and threatened status of languages may guide inferential understanding of causal mechanisms influencing the persistence and health of earth's cultural heritage.

Introduction

Numerous biogeographical principles have been studied in relation to the distribution of biodiversity on a global scale (MacArthur and Wilson, 1967; MacArthur, 1972; Hubbell, 2001; Willig *et al.*, 2003; Hillebrand, 2004). Although significant correlations in the global distribution patterns of biological and cultural diversity (Mace and Pagel, 1995; Nettle, 1999; Maffi, 2001b; Sutherland, 2003; Stepp *et al.*, 2004; Maffi, 2005; Curry and Mace, 2009) have been noted in the literature over the past two decades, still little is known of ‘bio-geography’ of language diversity, and even less of the geographic relationship of threatened languages and endangered species.

Mace and Pagel (1995), recognize latitudinal patterns of language diversity decreasing and language range increasing away from the equator towards the poles. Stepp *et al.* (2004), demonstrate the convincing relationship in the diversity of languages and plants worldwide (R^2 value of 0.9675). Nettle (1998), argues that the distribution patterns of language diversity and home range are mostly driven by ‘ecological risk’, where the lesser the climate variability in an area, the more insular a culture can remain, restricting the spread and overall range size of a particular language. Currie and Mace (2009), recently found little bio-physical evidence for language diversification and attribute global distribution patterns to ‘political complexity’ of the geographic region.

There are well known global threats to biodiversity with current extinction rates well above historical levels (Chapin, 1999). Although less studied, numerous human languages have also become extinct, while over 50% are considered threatened with extinction (Krause, 1992; Crystal, 2000). Sutherland (2003) demonstrated that by applying internationally agreed criteria for classifying species extinction risk, that

languages are more threatened than birds or mammals. Rare languages are more likely to show evidence of decline than commoner ones. Sutherland showed that areas with high language diversity also have high bird and mammal diversity and all three show similar relationships to area, latitude, area of forest and for languages and birds, maximum altitude. However the time of settlement has had little effect on current distribution of language diversity. Although similar factors explain the diversity of languages and biodiversity, the factors explaining the extinction risk for birds and mammals (high altitude, high human densities and insularity) do not explain the distributions of endangered languages.

Linguists who had taken up the study of indigenous minority languages have expressed concern for the future prospects of these threatened languages and their speakers in light of ever increasing social, political, and economic change. It was only during the 1990s that this concern came to a head with a rapid and exponential rise of interest in the issue (Dorian, 1989; Hale *et al.*, 1992; Dixon, 1997; Grenoble and Whaley, 1998; Crystal, 2000). To a large extent, this rise of interest was due to the accumulation of a growing mass of data not only on the grammatical and lexical features of the world's languages but also on the state of vitality of languages (Grimes, 2005). Throughout the world, the indigenous and minority languages of the world have been disappearing at an alarming and accelerating rate, replaced by a small number of ever-expanding, majority languages (referred to as 'killer' languages in Skutnabb-Kangas, 2000). 'Clarion calls' about this language endangerment crisis have been issued by linguists – projected to threaten the survival of 50-90% of the world's languages in the next 100 years (Krauss, 1992). While linguists and practitioners

worldwide rose to the call to increase awareness and resource availability to protect the world's endangered languages. At the same time, other reasons for concern emerged during the 1990s centered on what might be lost to the speakers themselves.

Links were suggested between linguistic (and cultural) diversity and biodiversity as distinct but mutually supporting manifestations of diversity of life on earth. (Harmon, 1996; Krauss, 1996; Muhlhausler; 1996; Maffi *et al.*, 1999; Maffi, 2001a). Crystal (2000) argues that links between biological and linguistic ecologies are not just metaphorical but mutually related through human knowledge, use and management of the environment by diversity of cultures. Maffi (2005) calls for this relationship to be brought out and studied in depth, to give substance to the international effort for the protection of linguistic human rights. Analogous with the efforts to understand and protect biodiversity and the state of the world's ecosystems, monitoring global trends in linguistic diversity would benefit the protection. A goal of assessing and monitoring the state of biological and linguistic diversity in an integrated fashion could concentrate efforts efficiently and provide a new perspective and global diversity patterns and persistence.

Despite the recent recognition of the threat to global languages as well as the relationship of cultural and biological diversification patterns have drawn in the literature, very few researchers have investigated spatial patterns in endangerment or extinction of language and biological entities (Sutherland, 2003). Sutherland's (2003) investigation analyzed extinction risk to languages, birds and mammals within political country boundaries, when it is well known that biophysical and often cultural values and linguistic expressions are not confined by these political boundaries. Hence, this study

investigated the threat of extinction to languages within local context of landcover change, shown to clearly influence threats to biodiversity. Although recent studies have identified Land Cover Change (LCC) as an influential driver affecting biodiversity richness and its distribution (Diggelen *et al.*, 2005), little is known about the influence of LCC to cultural diversity distributions and persistence.

Using MODIS IGBP Classified Global Mosaic Data from 2001 and 2007, Landcover Change Trajectory maps were used to quantify rates and types of landcover change within 100 km of 6337 extant languages, classified into critical, endangered and vulnerable threatened status categories (with fewer than 500, 1000, and 10,000 speakers respectively). Potential correlations between magnitude of LULCC and threatened status of languages may guide inferential understanding of causal mechanisms influencing the persistence and health of earth's cultural heritage.

Endangerment and extinction events may be historically related to environmental changes, fragmentation, loss of their habitat, whether they be due to 'anthropogenic' disturbance due to development or 'natural' disturbance due to 'climate change'. As Sutherland (2003) states, the threatened status of a language is highly related to its population size, as is evidence from biological diversity patterns. If language diversity patterns adhere to biological diversity patterns; could the threatened status of a language have a relationship with magnitude of landcover change across the landscape? Do spatial patterns of threatened or extinct languages adhere to spatial patterns of threatened species? Based on this relationship or spatial correlation of the distribution of biological and cultural diversity, one cannot assume that similar processes underlie these correlated distributions.

Methods

Language data were obtained from Grimes (2005), Ethnologue 17th edition. Of the 7719 classified languages in the database only 6337 extant languages where used in the analysis due to data limitations. Of these 6337 languages, over half of them are considered Vulnerable with fewer than 10,000 speakers, about a quarter of them are considered Endangered with fewer than 1000 speakers, and about a fifth of them are considered Critically Endangered with fewer than 500 living speakers. Also included in the analysis were 270 extinct languages known to have disappeared since 1600 A.D. (Figure A-3).

Landcover Change information was derived from a Change Analysis of Modis IGBP (International Global Bio-sphere Project) Classified Global Mosaic from 2001 and 2007 (MCD12C1 – NASA) 1 km spatial resolution (Figure A-4) conducted in IDRISI (Eastman 2009). The IGBP has 16 landcover classifications including Water, Evergreen Needleleaf Forest, Evergreen Broadleaf Forest, Deciduous Needleleaf Forest, Deciduous Broadleaf Forest, Mixed Forest, Closed Shrubland, Open Shrubland, Woody Savannah, Savannah, Grassland, Cropland, Urban and Built, Cropland/Natural Vegetation Mosaic, Snow and Ice and Barren. Cropland, Urban and Built, and Cropland/Natural Vegetation Mosaic LandUse categories were merged to investigate overall Anthropogenic Landcover Change within 100 km buffer of the language centroid. A 100-km buffer was selected based on Maffi's (2001b) publication noting that language diversification increases outside a 100-km buffer of development.

Landcover Change was quantified using a trajectory analysis, where total and mean change in cells' landcover classifications between 2001 and 2007 images was determined. Of the total Landcover Change shown in the trajectory analysis the three

'anthropogenic' land use classifications (Cropland, Urban and Built, and Cropland/Natural Vegetation Mosaic) were isolated and the total and mean change to anthropogenic land use categories was determined within 100km buffer of languages (Figure A-5). Overlaying global spatial data of extinct, endangered and extant language distributions with the model's output, spatial analysis techniques (Rosenzweig, 1995) were utilized to investigate a possible correlation between LULCC to the status and survival of languages worldwide.

Using NCSS (Hinze, 2007), mean, overall and anthropogenic LCLUC, was compared using a regression analysis of magnitude of LULCC and size of population of a language's remaining speakers. Then each threatened status group was isolated and statistics gathered for each group. Overall change and 'anthropogenic' LULCC were compared for each status group with statistics of change in non-threatened languages. Overall and strictly anthropogenic patterns of LULCC were analyzed using a Chi-square test.

Results

There was huge variability in the extent of landcover change within all status groups of languages, which likely contributes to no overall pattern in change and number of remaining speakers within a language. The regression analysis of total population of speakers of all languages with the number of overall landcover change cells was not at all related ($R^2 = 0.0009$, $p > 0.05$). Nor were there any correlations in the regression analysis of total population of speakers of all languages with the number of strictly anthropogenic landcover changes ($R^2 = 0.015$, $p > 0.05$).

Chi-squared analysis of change detection demonstrates no difference in the overall pattern of landcover change, or anthropogenic landcover change classifications between threatened and non-threatened languages (all change: $X^2 = 0.03$, $p > 0.05$, anthropogenic change: $X^2 = 0.015$, $p > 0.05$).

However, comparisons of LULCC that has occurred between 2001 and 2007 within 100 km buffer areas of languages show significantly greater overall as well as anthropogenic LULCC in non-threatened language buffers than in all status groups of threatened languages (Table A-1). Shown in Figure A-7, stable cells with no landcover change dominate the landscape. Of the fraction of change cells demonstrating landcover change, there is less anthropogenic change (to cropland, urban and built, and cropland/vegetation mosaic) than overall change in classifications of non-anthropogenic landcover change.

All threatened classifications (Critical, Endangered, and Vulnerable) show this significant pattern of less than half the mean change of non-threatened languages per 100 km language buffer ($p > 0.0001$). Critical, endangered, and vulnerable languages have less overall change and less anthropogenic change than non-threatened languages.

Comparisons of landcover change within 100 km buffer of extinct language locations show perhaps the most interesting result of this study. Areas of extinct languages have greater change than areas of critical and endangered languages (critical: mean- 21.74, $p < 0.001$, endangered: mean- 23.98, $p < 0.001$). However there are no differences in the extent of change in extinct language areas and non-threatened

extant languages, demonstrating almost twice the amplitude of change in non-threatened and extinct language locations than in threatened language locations.

Discussion

As increasing attention is drawn to the spatial correlations of linguistic and biological diversity worldwide, still there is little consensus on the processes which underlie these patterns. This investigation demonstrates significantly greater landcover change as well as anthropogenic landcover change within 100 km of extant non-threatened languages ($10,000 < \text{speakers}$) than within 100 km buffer of critically endangered ($500 > \text{speakers}$), endangered ($1,000 < \text{speakers}$), and vulnerable ($10,000 > \text{speakers}$) languages. Although the distributions of threatened languages and threatened species may be spatially correlated, LULCC may not influence threatened language in the same way as threatened species' distribution. Concurrent with Sutherland's (2003) finding that threatened languages are not related to human density variable unlike threatened birds and mammals, this study demonstrates anthropogenic disturbance may not be a significant driver in language endangerment. Threats of extinction may be more relative to overall diversity as proposed by McArthur and Wilson (1963) in relation to language as well as biological diversity.

Probably the most interesting finding in this research, that extinct languages as well as non-threatened extant languages demonstrated over twice the overall and anthropogenic LULCC than threatened extant languages which reflects temporal bias within this study. Historical language extinction events may have been driven by different underlying processes than those driving current threats of language extinction. However, this study only analyzed the LULCC since 2001, and probably does not capture the long term change that has lead to current and observable distribution

patterns. In order to fully assess the relationship of landcover change as a driver in language extinction or threatened status, it is imperative that future analyses utilize historical records to expand the temporal scale of analysis.

Regardless of spatial correlations in cultural and biological diversity, there are clearly differing processes underlying their overall distributions. Regional variability in both environmental variables, as well as in the complex history of interactions between people, species and resources, surely reflect much inner variability regardless of the scale of the analysis. This global analysis of threatened languages and anthropogenic landcover change may allude to broad scale patterns in a globalized world, however there are certainly many different individual stories to be told in the history of language and culture. Much variability in needed future analysis at a more regional scale is to be expected, and it will be important to include more socio-economic historical and bio-physical variables to understand the full picture of factors influencing language diversification and threats of extinction. In future analyses LULCC-potential maps to investigate areas and languages that will most likely to endure future change and use will be useful. These current trajectories could calibrate historical models to better understand the influence of LULCC in relation to language diversification and extinction.

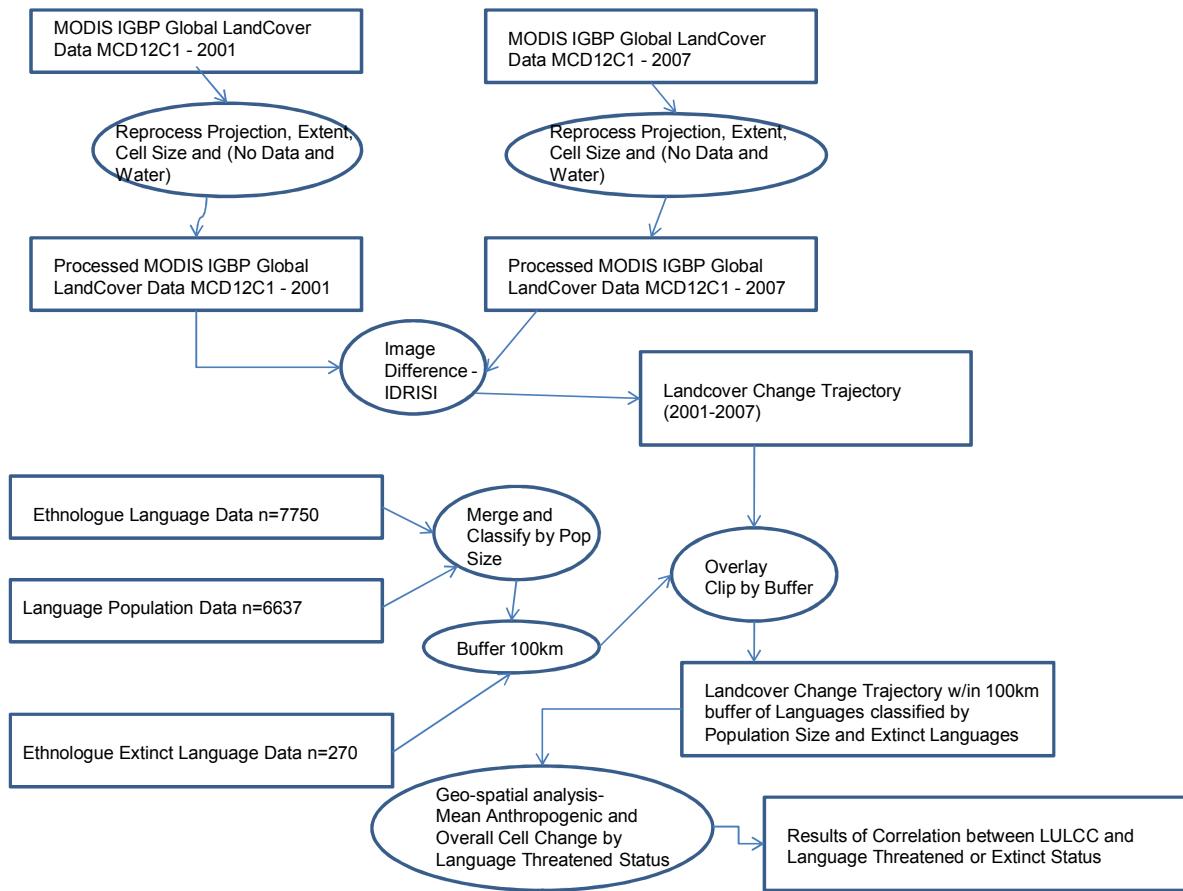


Figure A-1. Flowchart of analysis procedures

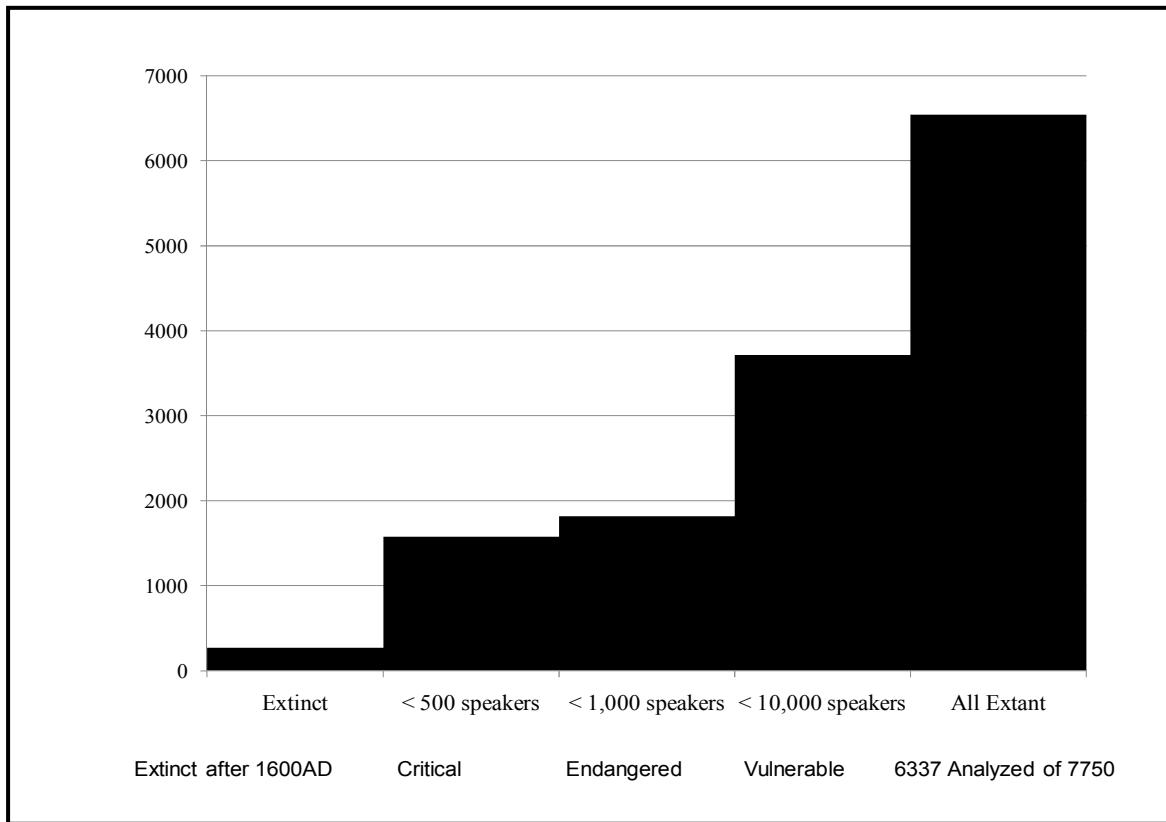


Figure A-2. Cumulative frequency of global languages (Krause's endangered language levels)

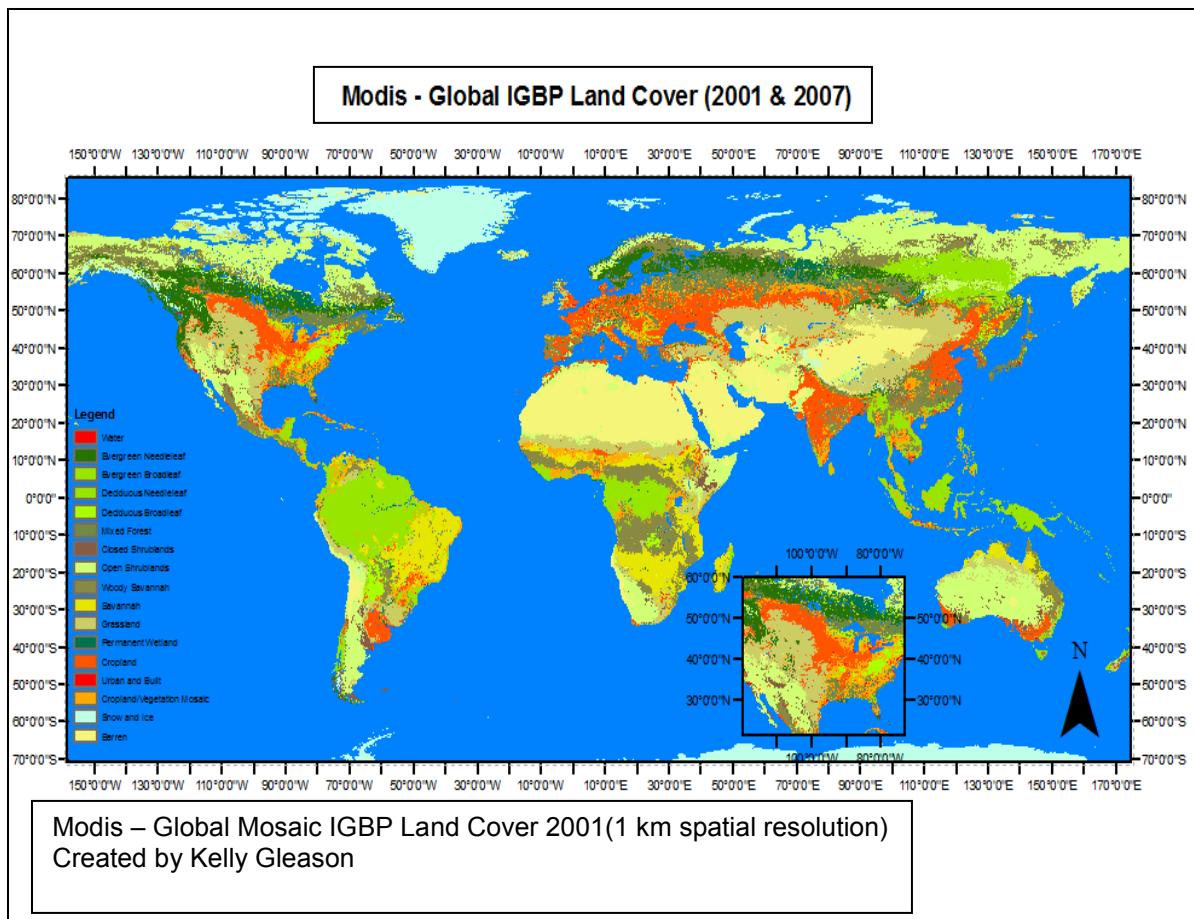


Figure A-3. MODIS – Global IGBP landcover 2001 mosaic

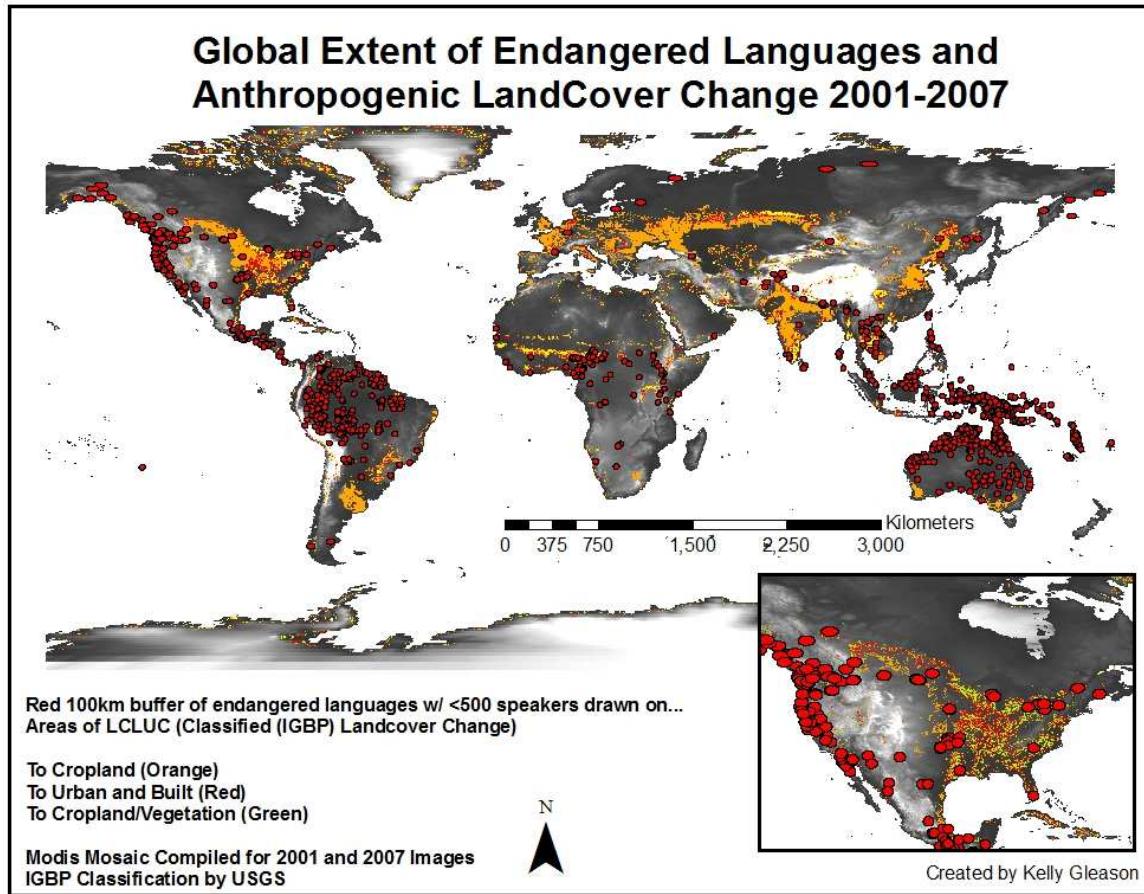


Figure A-4. Global extent of critically endangered languages and anthropogenic LULCC 2001-2007

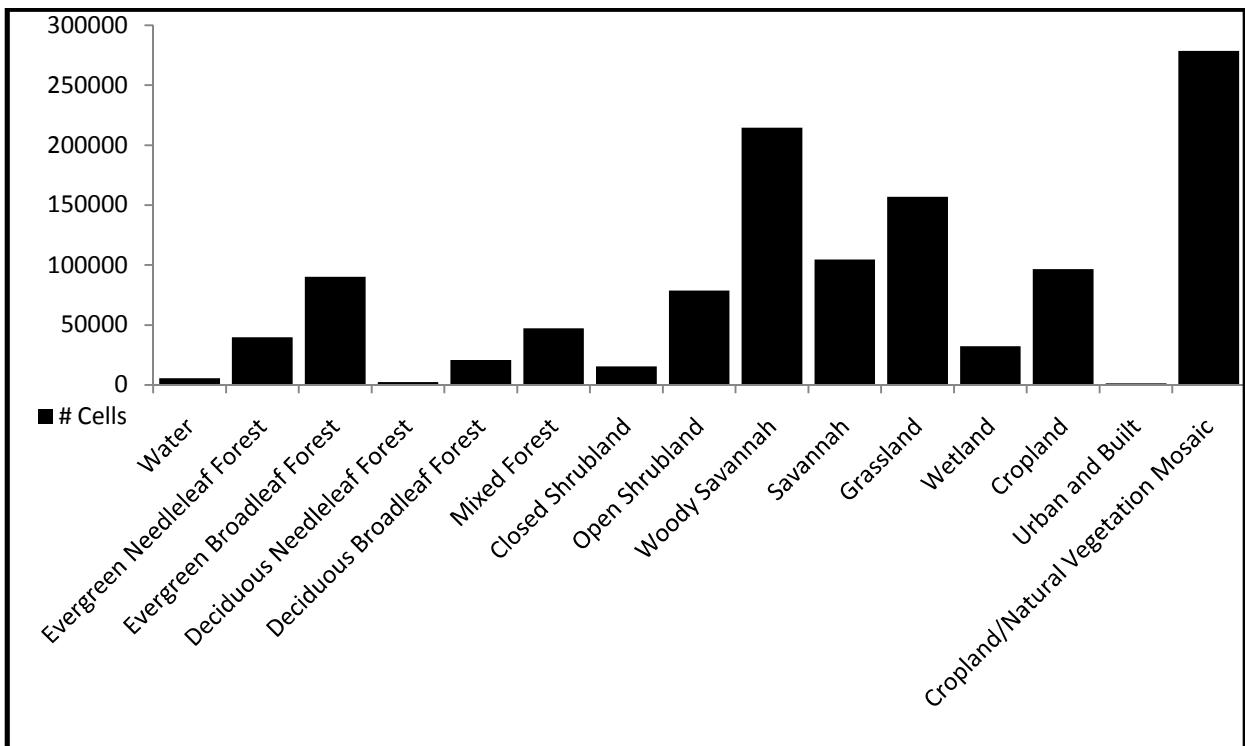


Figure A-5. Total global landcover change from 2001-2007

Table A-1. Comparison of mean anthropogenic landcover change within threatened language categories

	Mean # of change cells	P-value	T-stat
< 500 speakers	21.75*	< 0.001	-27.0112
< 1,000 speakers	23.98*	< 0.001	-18.6867
< 10,000 speakers	36.28*	< 0.001	-13.9802
All extant languages	104.77	> 0.1	-----

* indicates significant change ($p < 0.05$)

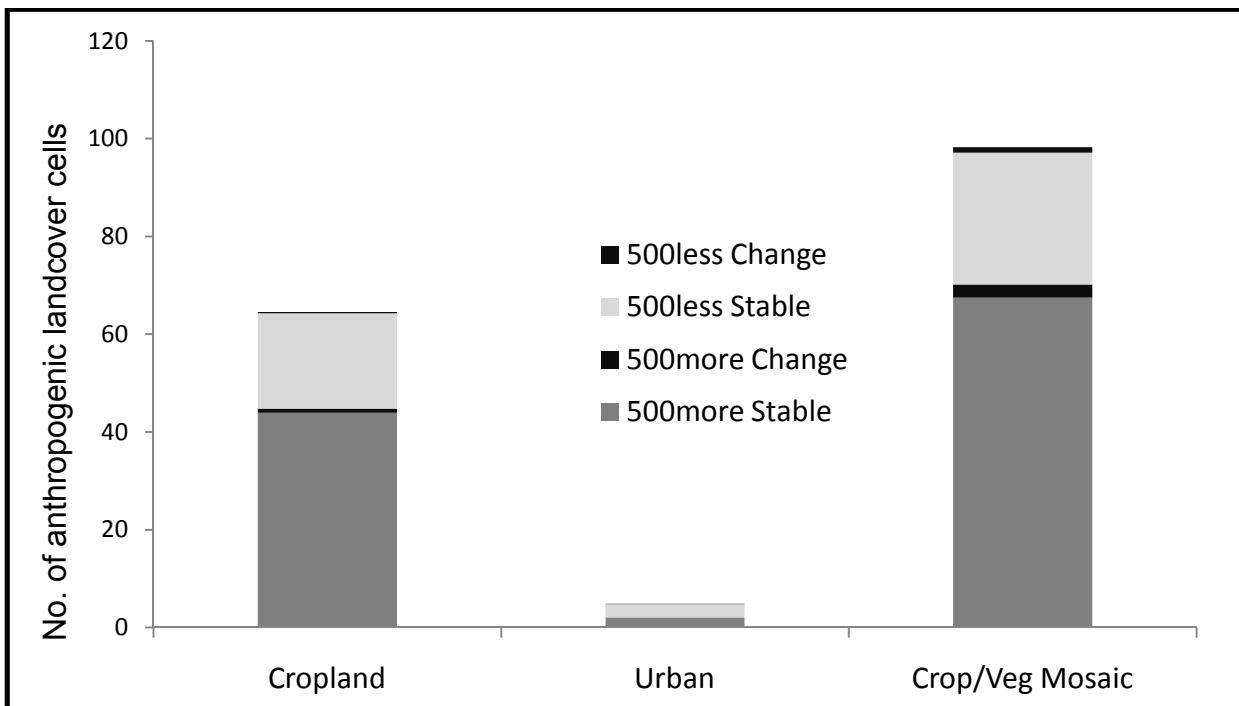


Figure A-7. Mean number of change and stable anthropogenic landcover cells (500 or less, n=1302 & 500 or more, n=5702)

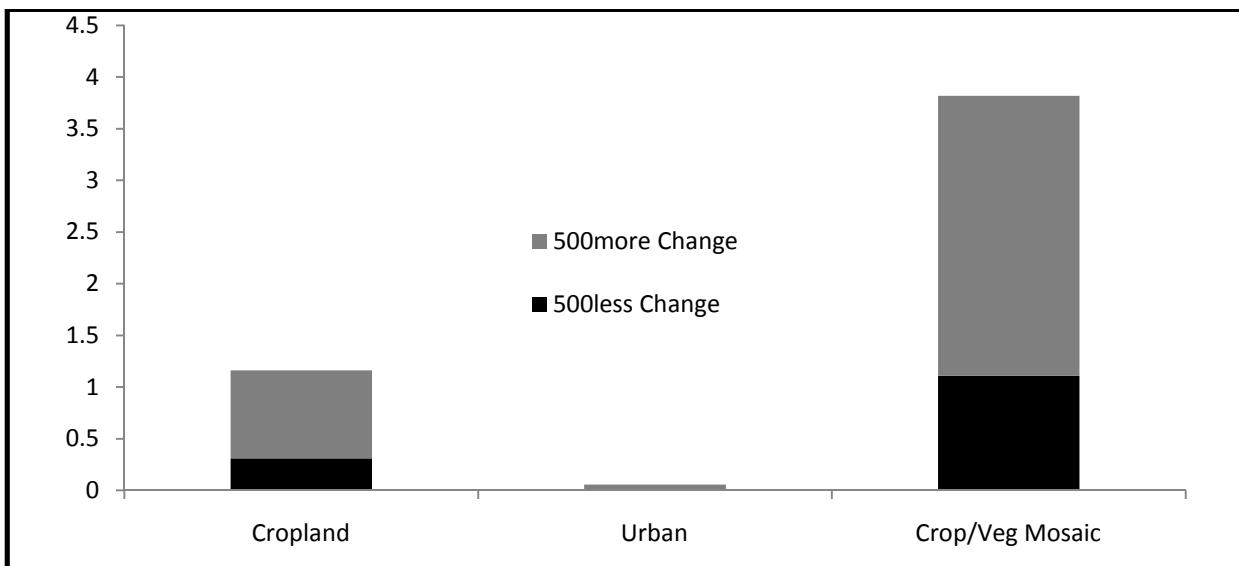


Figure A-8. Mean change in anthropogenic landcover within 100 km of critical languages

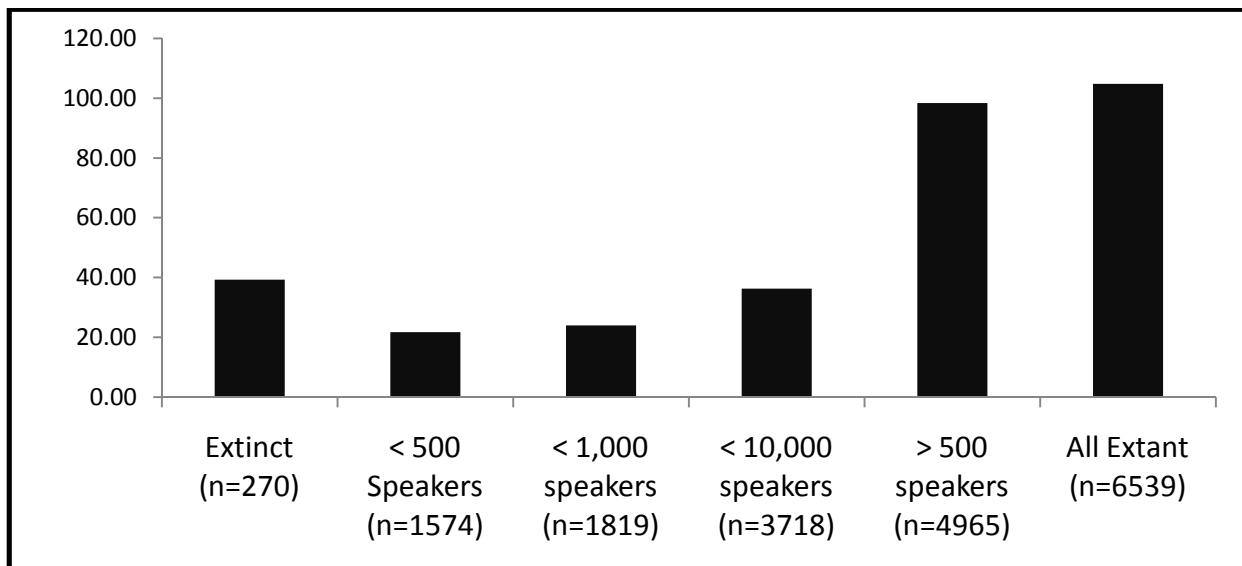


Figure A-9. Mean increase in anthropogenic landcover by threatened status

Table A-2. T-test results comparing number of cells of anthropogenic landcover change in extinct versus extant and threatened status languages' 100 km buffer around centroid location

Language status	Mean change	P-value	T-stat
Extinct (n=270)	39.27	—	—
< 500 Speakers (n=1574)	21.75*	< 0.001	6.4651
< 1,000 speakers (n=1819)	23.98*	< 0.001	4.1337
< 10,000 speakers (n=3718)	36.28	> 0.1	0.7846
> 500 speakers (n=4965)	98.43	> 0.1	0.6075
All extant (n=6539)	104.77*	< 0.05	1.8150

* indicates significant change (p < 0.05)

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BIOGRAPHICAL SKETCH

Kelly Erika Gleason grew up outside Seattle, in Mercer Island, Washington. She attended college at The Evergreen State College, Olympia, Washington, and graduated with full honors with a Bachelor of Science in plant ecology in the spring of 2002. Kelly immediately began working as a canopy field ecologist for the United States Forest Service and Bureau of Land Management. She continued her work as a field ecologist taking part in numerous research projects for universities and government agencies for the next 6 years besides a 2-year hiatus as a Peace Corps Volunteer in Paraguay. Kelly returned to graduate school, in the fall of 2008, at the University of Florida in the School of Natural Resources and Environment to focus on geography and GIS applications. She received her Master of Science from the University of Florida in the summer of 2010. Kelly will continue on for her doctorate degree at Oregon State University's Department of Geography to focus on alpine forest-snow-water dynamics through remote sensing and mountain hydro-morphological research.