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35

HUMAN HEALTH IN THE BIODIVERSITY HOTSPOTS

Applications of Geographic Information System Technology and Implications for Conservation

Larry J. Gorenflo

As we enter the second decade of the 21st century, our planet seems out of balance on several fronts. One of the most apparent problems is persisting widespread poverty, and associated human misery, throughout much of the world (World Bank 2010). Despite the definition by the United Nations of "Millennium Development Goals" to improve the human condition, progress toward meeting fundamental human needs and broader achievement of basic human rights have been uneven, and in many countries likely will fall well short of 2015 targets (UN 2010). Another serious problem is the deterioration of natural systems, a consequence of a rapidly expanding human footprint as natural resources are extracted at unprecedented rates to support the increasing demands of Earth's human inhabitants (Wackernagel and Rees 1996; UNDP et al. 2000; Sanderson et al. 2002; Chivian and Bernstein 2008). Conservationists have long pointed to the biological implications of such pressure on nature, noting that species loss at rates 1,000 times or more greater than historical background levels indicates mass extinction of a magnitude witnessed only a few times in our planet's entire history (Pimm et al. 1995). As global human population continues to grow by more than 200,000 per day (Gorenflo 2006), the challenges of improving human well-being at a large scale and maintaining key natural components of our world will grow accordingly in coming decades (J.E. Cohen 1995, 2003; Cincotta and Engelman 2000).

At first glance, the plights of humans and nonhumans appear largely at odds, with meeting human needs seemingly compromising the needs of nature (Ferraro 2002; Sanderson and Redford 2003; Roe and Elliott 2004; Chan et al. 2007). Apparent competition between people and nature emerges on a global scale in terms of the growing human appropriation of the Earth's primary productivity (Vitousek et al. 1997) and in modification of roughly 50% of the planet's surface for human use, the total converted anticipated to increase to 70% in coming decades (FAO 2002; UNDP 2002). However, the seventh Millennium Development Goal, "Ensuring Environmental Sustainability," alludes to a necessary connection between people and nature in the form of mutual benefits, arguing for improvements to the natural environment in the interest of promoting long-term human well-being (UN 2000). In recent years, this relationship between the human condition and nature has been defined more broadly in terms of *ecosystem services*—the benefits to people of functioning ecosystems categorized as provisioning (e.g., food, water), regulating (e.g., climate regulation), cultural (e.g., spiritual, aesthetic), and supporting (e.g., soil formation) services (Millennium Ecosystem Assessment 2005; Melillo and Sala 2008). The benefits to humans from nature, through maintaining natural cycles upon which humans and other species rely (Fisher 2001), and the consequences of interrupting such cycles, are increasingly accepted, providing a link between people and the natural environment that introduces potentially tangible contributions of conservation to human well-being (Rosenzweig 2003). But how these relationships play out can vary, depending on the human systems, associated natural conditions, and links between them.

This chapter examines the relationship between people and the natural environment by focusing on human health in 34 biodiversity hotspots, regions of global importance for conserving the diversity of life on our planet. In addition to their role in conservation, hotspots contain large numbers of people who affect their surroundings and in turn are affected by those surroundings. The approach used here explores human health in hotspots by estimating values for selected health indicators, both to define general health conditions in individual regions and to enable comparisons among regions. The study begins by examining health status in the hotspots, revealing a wide range of variability. It then examines possible connections between human health and the natural environment at a regional scale, considering apparent benefits of maintaining natural habitat amid the broad influence of poverty. Attention then shifts to subregional analyses of infant mortality to explore the health implications of natural habitat in the hotspots and the potential connections between maintaining habitat, diarrheal diseases, and the compromised water sources that often transmit these diseases. The chapter closes by proposing more geographically focused analyses to identify specific settings where conservation can complement more conventional development interventions that emphasize public health.

SELECTED HUMAN WELL-BEING INDICATORS IN THE BIODIVERSITY HOTSPOTS

This chapter focuses on biodiversity hotspots (Fig. 35.1). Biodiversity is the diversity of life on Earth, measured in terms of genes, species, populations, and ecosystems (Wilson 2002; Pimm et al. 2008). Hotspots represent one of several templates proposed to define global biodiversity conservation priorities (Myers et al. 2000; Brooks et al. 2006), here focusing on a combination of unique biological contents (species *endemic* to each hotspot) and human threat. Originally conceived by Myers (1988), who identified 10 such regions, conservationists currently define 34 hotspots as regions containing minimally 1,500 endemic vascular plant species and having lost at least 70% of their original habitat (Mittermeier et al. 2004a). Totaling only about 2.3% of the Earth's terrestrial surface, the remaining original habitat in 34 hotspots contains more than 50% of the world's vascular plant species and at least 42% of all terrestrial vertebrate species as endemics. Hotspots are important to biodiversity conservation precisely because of the high levels of endemism they contain. Loss of an endemic species in a hotspot marks its extinction, and in light of high levels of threat in the hotspots widespread loss is imminent without conservation.

Given the large amount of habitat loss in the hotspots, clearly these regions all have a substantial human presence. Studies using geographically referenced global population data have yielded estimates of population in these regions. In 1995, approximately 1.1 billion people inhabited the 25 hotspots defined at the time of that analysis (Cincotta et al. 2000). Using data tied to the most recently available round of decennial censuses (CIESIN and CIAT 2005), a subsequent analysis reported that by 2000 population in the 34

1 Several datasets on global population exist, presenting data in gridded map format at resolutions as fine as 1-km grid cells for years as recent as 2010. Although the 2000 global data are more than a decade old, they are the most recent available data tied to a large number of censuses (generally conducted at the beginning of a decade). More recent global population datasets are based on estimates rather than censuses, introducing an additional source of error in many cases that is desirable to avoid. Results of the most recent round of censuses, conducted in or around 2010, were not available when I completed this study.

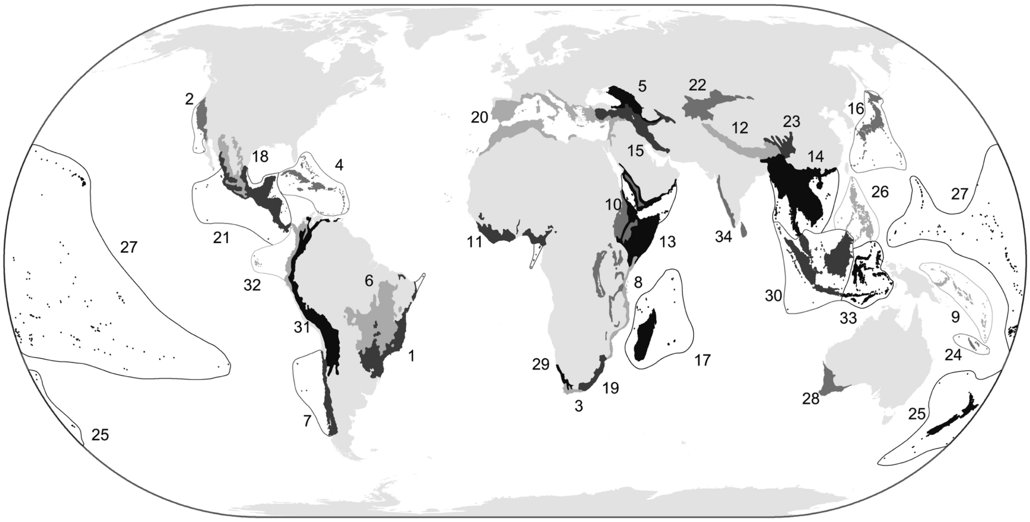


Figure 35.1:
Biodiversity hotspots. 1: Atlantic Forest; 2: California Floristic Province; 3: Cape Floristic Region; 4: Caribbean Islands; 5: Caucasus; 6: Cerrado; 7: Chilean Winter Rainfall-Valdivian Forests; 8: Coastal Forests of Eastern Africa; 9: East Melanesian Islands; 10: Eastern Afromontane; 11: Guinean Forests of West Africa; 12: Himalaya; 13: Horn of Africa; 14: Indo-Burma; 15: Irano-Anatolian; 16: Japan; 17: Madagascar and the Indian Ocean Islands; 18: Madrean Pine-Oak Woodlands; 19: Maputaland-Pondoland-Albany; 20: Mediterranean Basin; 21: Mesoamerica; 22: Mountains of Central Asia; 23: Mountains of Southwest China; 24: New Caledonia; 25: New Zealand; 26: Philippines; 27: Polynesia-Micronesia; 28: Southwest Australia; 29: Succulent Karoo; 30: Sundaland; 31: Tropical Andes; 32: Tumbes-Chocó-Magdalena; 33: Wallacea; 34: Western Ghats and Sri Lanka.

hotspots totaled 1.9 billion, or roughly one third of the global population at the time (Mittermeier et al. 2004b; Fig. 35.2).[1] In 22 of the 34 hotspots, population density exceeded the global average in 2000 of 45 persons/km^2, while in 23 cases population growth exceeded the 1.4% worldwide annual rate of increase. The presence of so many people, their numbers in many cases steadily growing, indicates that biodiversity conservation in the hotspots will have to occur in the context of considerable human occupation. With growing demand for limited resources, understanding key dimensions of human occupation in the hotspots is essential to developing conservation strategies that benefit people as well as nature and contribute to the long-term maintenance of biodiversity. One such dimension is human health, an essential component of the human condition.

Data on two health indicators have been compiled at a sub-national level for most of the areas covered by hotspots—infant mortality and percent of children underweight (CIESIN 2005). These sub-national estimates are particularly valuable for present purposes, providing a direct means of calculating their values for each hotspot through the use of geographic information system (GIS) technology. Infant mortality rate is the number of children who die in their first year for every 1,000 live births, with the global data analyzed generally associated with the year 2000 (base data spanning 1990 to 2002). Figure 35.3a shows infant mortality for the hotspots; the resulting values vary widely, from about 1 for Japan to nearly 110 for the coastal forests of East Africa.[2] A closer examination of these results reveals a pattern generally repeated by the other health indicators considered in this study, namely a broad range of values from more desirable levels in hotspots located in developed countries to levels much less desirable in hotspots located in less-developed countries. In the case of infant mortality,

2 For infant mortality rate, no data existed for infant deaths in New Caledonia. Because the hotspot corresponds to the entire nation, I inserted the 2000 infant mortality rate of 7.0 to complete the bar chart summarizing regional data (World Bank 2002).

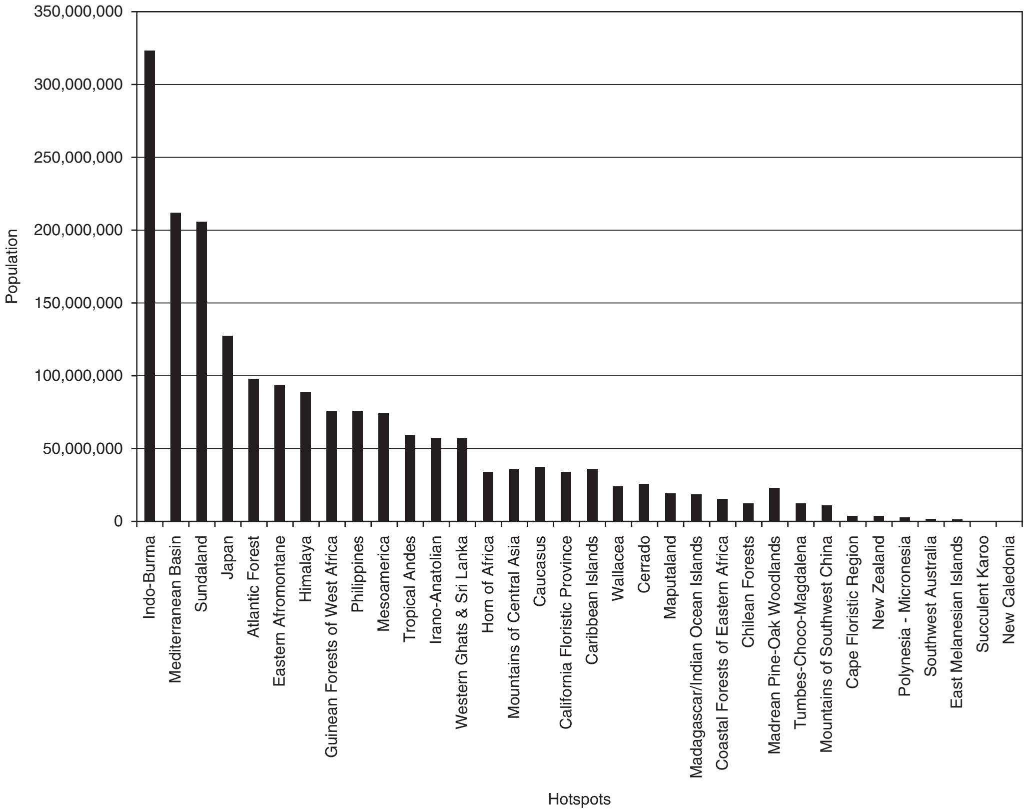


Figure 35.2:
Population in the biodiversity hotspots, 2000.

extremely low rates in the developed world contrast markedly with high rates in the less-developed world, the latter including two sub-Saharan Africa hotspots that lose 10% or more of their children in the first year of life.

Children underweight represents the percentage of children aged five years or less whose weight is two standard deviations or more below the median weights established for an international reference population by the U.S. National Center for Health Statistics, U.S. Centers for Disease Control and Prevention, and the World Health Organization (CIESIN 2005). Data again are generally for 2000 (base data covering the years 1990 to 2002). Though focusing on a subset of total population, children underweight is a major risk factor leading to death, particularly in low- and middle-income countries (Skolnik 2008). Figure 35.3b presents the results of this analysis for 25 of the 34 hotspots, with estimates of number of underweight children, number of children aged five years or less, or both lacking in at least part of the areas covered by the remaining nine hotspots. Once again, we see a broad range of values, from less than 1% of children in the California Floristic Province underweight to more than 40% of the children in the Himalaya hotspot. The contrast between developed and less-developed country continues: hotspots featuring high infant mortality rates also contain higher percentages of children underweight, and vice versa.

Apart from the above two indicators, global data on human health unfortunately tend to be available only at national levels for many of the countries that are partially or totally in the hotspots. However, by using GIS software and global datasets of population in 5-km grid cells (CIESIN and CIAT 2005) to calculate the percentage of each hotspot population contributed by individual countries, one can estimate the value of several indicators of human health in the

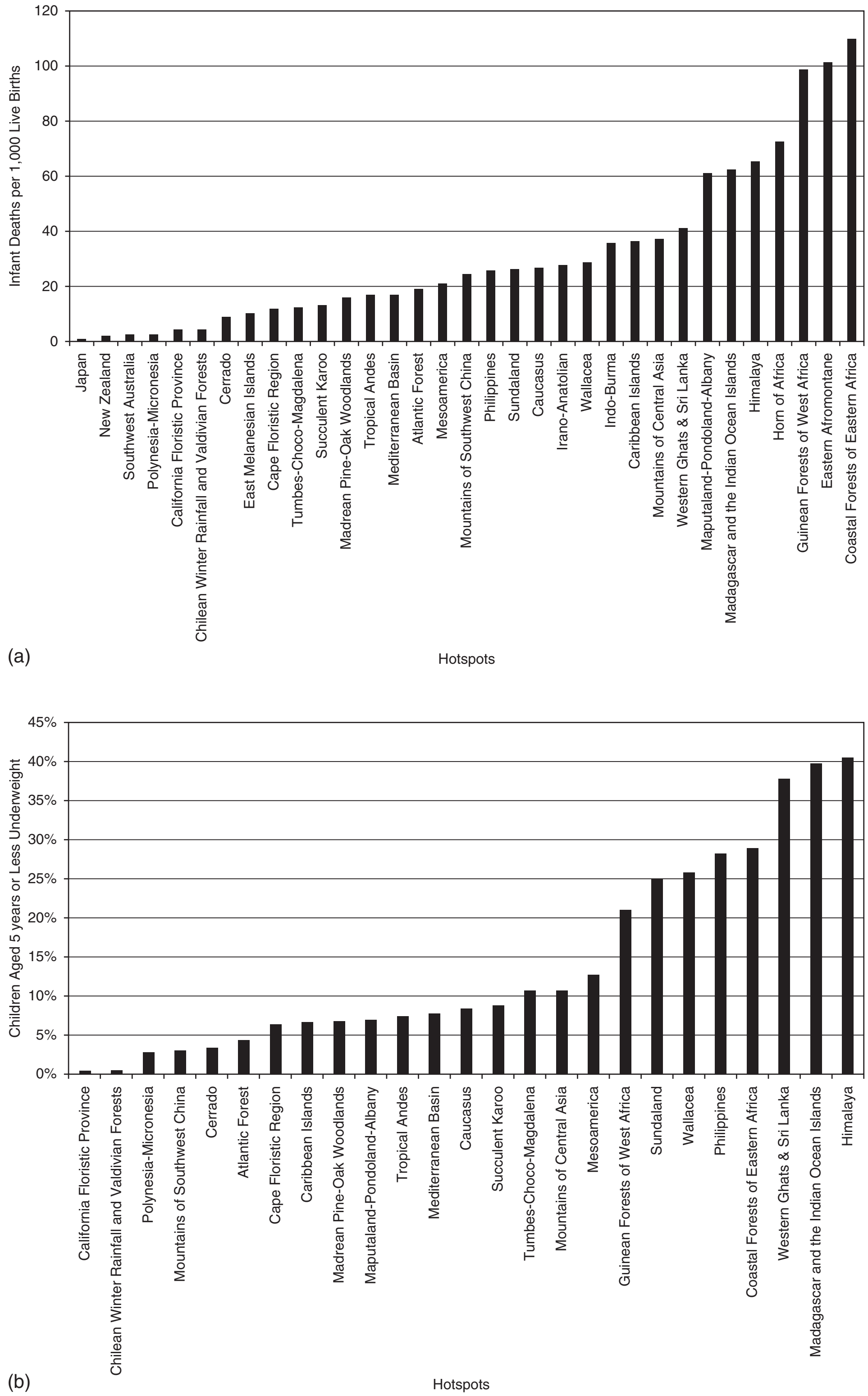


Figure 35.3:
Infant mortality rate (a) and children underweight (b) in the biodiversity hotspots, approximately 2000.

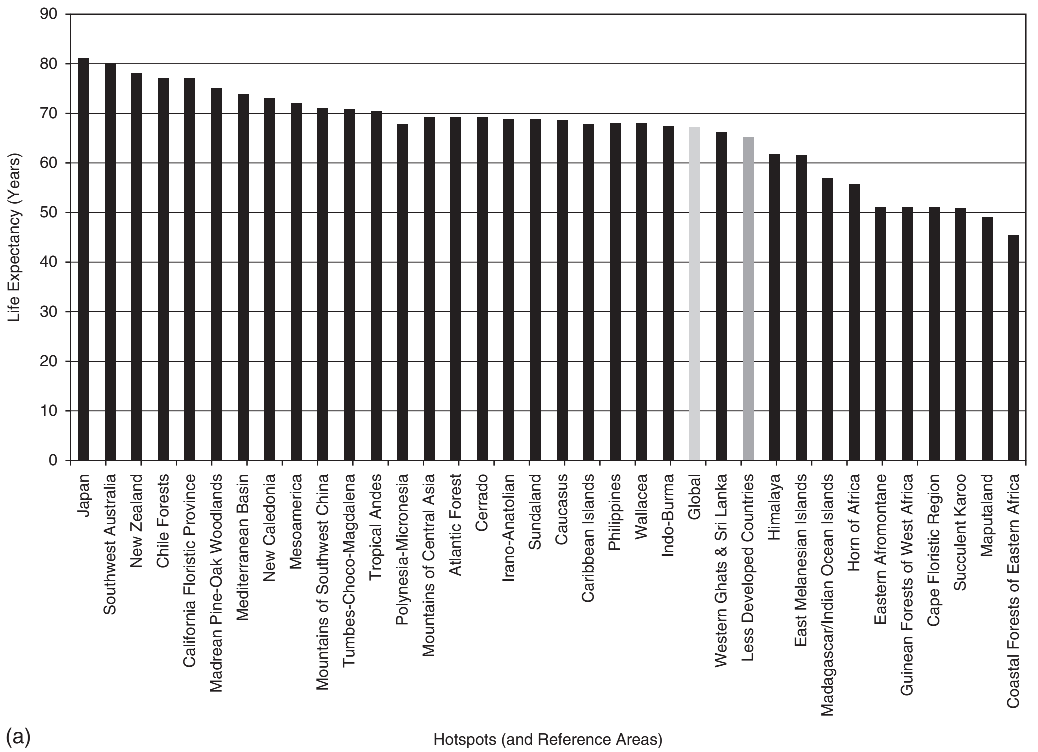
34 hotspots—the proportion of an indicator that a given country contributes to a particular hotspot commensurate with the proportion of total hotspot population contributed by that country. This approach is not ideal—it assumes that values of a given health indicator are uniform across an entire nation—but it provides a systematic means of estimation based on the socioeconomic (demographic) presence of individual countries in each hotspot.[3] This method enables use of national-level data compiled by the World Bank (2002) to develop estimates for life expectancy at birth by hotspot in 2000 (Fig 35.4a). Once again, values of this broad indicator of human health vary greatly among the regions, maintaining the contrast between hotspots composed of developed and less-developed countries.

The strong similarities in analytical results for the three health indicators thus far considered—notably the persisting distinction between developed and less-developed regions—suggest that health status in the hotspots is greatly influenced by poverty. Public health has long recognized a central role for poverty in human health (McMichael 2001; MacDonald 2005; Holtz et al. 2008; Skolnik 2008). Inadequate food, poor sanitation, limited access to vaccination and other components of modern medical technology, and insufficient public health programs contribute to health problems in poor nations. Using data compiled at a national level, one can show differences in poverty in the hotpots through estimating per capita gross national income purchasing power parity, a measure expressed in hypothetical international dollars as a common currency available to purchase goods and services at U.S. prices in a given year (in this case, 2000). The resulting graph is consistent with those showing health indicators presented above (Fig. 35.4b). Statistical analyses confirm links between poverty and life expectancy, infant mortality, and percentages of underweight children, the association among these variables borne out by generally strong, significant correlations (Table 35.1).

Using remaining original habitat as a proxy, conservation at a regional scale seems to be much less important to human health in the hotspots. Recall that, by definition, all hotspots have lost minimally 70% of their original habitat (Mittermeier et al. 2004a), thereby likely compromising many of their ecosystem services. But human health in these regions varies widely, and low (and often insignificant) statistical correlations reveal the tenuous connection that health has with the percentage of original habitat remaining in the hotspots (Table 35.1). Characterizing hotspots not solely in terms of original habitat, but also in terms of habitat that had not been converted to human use for settlement, intensive agriculture, or agriculture mixed with other land use (as defined in the Global Land Cover 2000 database, discussed further below; see European Commission, Joint Research Centre 2003), enables further consideration of the contribution of habitat to human health—assuming land cover that may be *natural* though not necessarily *original* provides more ecosystem services than land cover characterized by human use. Again, the statistical association between health and habitat is weak, here lacking statistical significance as well (Table 35.1).

In the case of human health in the biodiversity hotspots, it appears that the penalties of sacrificing natural habitat and functioning ecosystems currently depend to a large extent on poverty. At a regional scale, both percentage of original habitat and percentage of habitat unconverted to human use show little association with any of the three health indicators considered in this study. In contrast, the relationships between poverty and infant mortality rate, children underweight, and life expectancy at birth are strong and statistically significant for three different measures of correlation. These results convey a sense of *decoupling* people from natural systems, suggesting that human health depends primarily on access to modern technology, including improved living conditions, food security, and medical care (McMichael 2001). However, analyses to this point have focused on health indicators measured at a regional scale. Although global studies inevitably encounter constraints of data availability, let us revisit patterns of infant mortality rate in terms of current habitat, using two global datasets whose spatially explicit characteristics enable more precise, sub-regional inquiries.

3 The approach used here differs from a recent effort to estimate poverty in the hotspots (Fisher and Christopher 2006). I opted for the present method because it ties estimates of indicators of human well-being to a socioeconomic weighting factor, namely population.



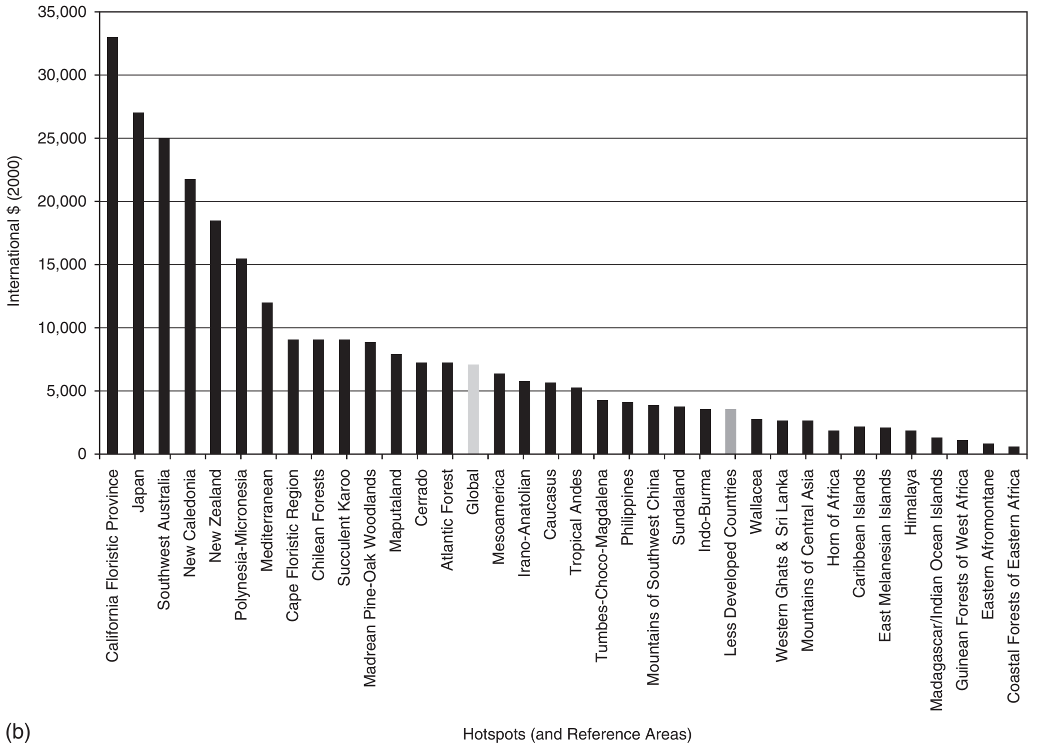


Figure 35.4:
Life expectancy at birth (a) and gross national income purchasing power parity (b) in the biodiversity hotspots, approximately 2000 (note the inclusion of overall global values, and values for less-developed countries, of each indicator for reference).

Table 35.1 Correlations Between Selected Human Health, Income, and Environmental Indicators in the Biodiversity Hotspots

	Correlation Measure (if significant, value given in parentheses)		
Variables	**Pearson's r**	**Kendall's tau**	**Spearman's rho**
IMR × GNI	−0.59 (0.01)	−0.72 (0.01)	−0.86 (0.01)
CUW × GNI	−0.54 (0.01)	−0.55 (0.01)	−0.73 (0.01)
LEX × GNI	0.57 (0.01)	0.55 (0.01)	0.65 (0.01)
IMR × OHAB	−0.35 (0.05)	−0.26 (0.05)	−0.38 (0.05)
CUW × OHAB	−0.26	−0.17	−0.22
LEX × OHAB	0.13	0.07	0.11
IMR × CHAB	0.06	0.00	0.01
CUW × CHAB	−0.14	−0.10	−0.12
LEX × CHAB	−0.22	−0.06	−0.08

IMR, infant mortality rate; CUW, percentage children aged five or less underweight; LEX, life expectancy at birth; GNI, gross national income per capita purchasing power parity; OHAB, percentage of original habitat remaining in hotspot; CHAB, percentage of habitat unconverted for human use currently in hotspot.

INFANT MORTALITY AND HABITAT IN THE HOTSPOTS: POTENTIAL HEALTH BENEFITS OF UNCONVERTED LAND

Global datasets provide important opportunities to conduct large-scale inquiries, and gain new insights, on many key issues across the face of our planet. Unfortunately, as noted, most data on health and related development indicators are available only at national levels. Although one can develop and apply methods to estimate values of these indicators for areas composed of portions of countries, studies based on such estimates are limited when they involve phenomena that require consideration of more precise spatial relationships of co-occurrence or proximity. This is certainly the case with the analyses discussed above. Although at a regional scale health in the hotspots appears unrelated to more natural types of habitat, health status in particular areas with specific habitat conditions, for example, remains unknown. More spatially precise data enable analyses that consider such sub-regional questions. In the present research setting, sub-national datasets on infant mortality and land cover, examined above in regional contexts, support further examination of the relationship between human health and habitat in the biodiversity hotspots.

Sub-national data on infant mortality were generated by a project at the Center for International Earth Science Information Network (CIESIN) at Columbia University to map selected poverty indicators at sub-national levels (CIESIN 2005). Using data for more than 10,000 national and sub-national geographic units, that project developed global datasets on infant deaths (deaths in the first year of life) and live births generally for the year 2000. Data are in the form of a 0.25-degree global grid, each grid cell measuring roughly 28 km to a side at the equator, becoming slightly smaller towards the poles. These data provide information on the locations of births and infant deaths globally—allowing the calculation of infant mortality for entire hotspots, as discussed above, as well as for specific locations within the hotspots, with the exception of New Caledonia (which lacks sub-national data).

Sub-national data on land use and land cover, essential to understanding global environment at the onset of the new millennium, were generated by the European Commission's Global Land Cover 2000 Project (Fritz et al. 2003; European Commission Joint Research Centre 2003). That project used satellite imagery from two brief periods in the year 2000—primarily SPOT-4 Vegetation Vega2000 data, augmented by Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Very High Resolution Radiometer (AVHRR) data to fill in certain gaps—and employed the Food and Agriculture Organization's Land Cover Classification System to categorize the imagery (DiGregorio and Jansen 2000). Project organization consisted of more than 30 teams of regional specialists who examined one or more of 19 regions where they had expertise, yielding a global database that integrates considerable local knowledge. Resulting data consisted of a 30 arc-second global grid, each cell measuring about 1 km to a side at the equator (slightly smaller towards the poles) and classified as one of 22 types of land cover. These data enable identification of land cover and land use for each grid cell within the biodiversity hotspots.

Using GIS software and the Global Land Cover 2000 database enabled definition of areas within the biodiversity hotspots that had been converted to human use, here comprising land cover categorized as artificial surfaces and associated areas (e.g., human settlements), cultivated and managed areas (primarily intensive agriculture), mosaics of cropland and tree cover, and mosaics of cropland and shrub or grass cover. GIS analysis of the sub-national data on births and infant deaths, in turn, enabled calculation of infant mortality in each hotspot for areas converted to human use and for areas that have not been converted (Fig. 35.5). Of the 33 hotspots for which sub-regional infant mortality data exist, 21 have lower infant mortality rates in areas that have not been converted to human use. Among the hotspots where infant mortality is lower in unconverted habitat are the majority of biodiversity regions with high poverty, the main

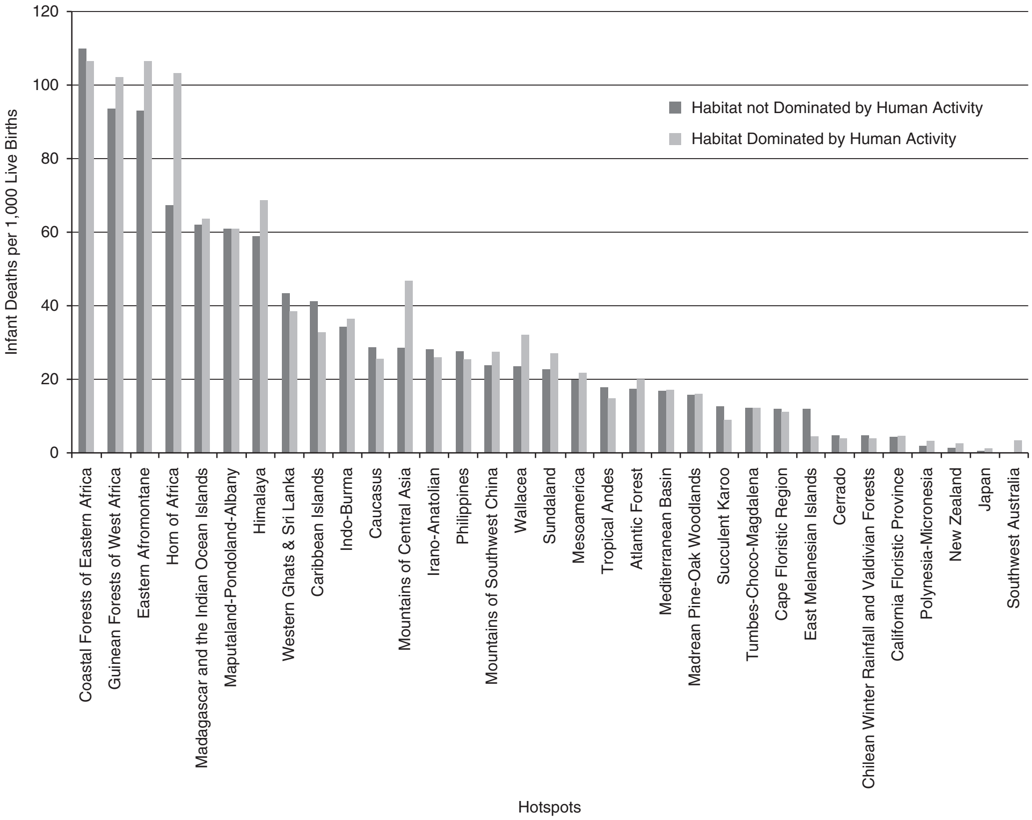


Figure 35.5:
Infant mortality rate in areas converted for human use and areas not converted for human use, approximately 2000.

exception being the Coastal Forests of Eastern Africa; ironically, this region also features the highest infant mortality rate of all the hotspots.

The results shown in figure 35.5 reveal a tendency for infant mortality rate in the biodiversity hotspots to be lower in areas characterized by some form of natural habitat. Given the correlation between infant mortality and other health indicators estimated for the hotspots at a regional level (Table 35.2), this pattern might be the case for human health in general, though as those other indicators are unavailable sub-nationally on a global scale, this proposition is impossible to confirm. Localities that have not been converted to human use likely provide more ecosystem services than areas of converted habitat, and lower infant mortality may represent benefits of these services. Of course, one cannot rely on a simple explanation of these results. For instance, as a prime example of areas converted to human use, cities tend to have fewer functioning ecosystem services than areas of unconverted habitat. However, throughout much of human prehistory and history, concentrations of people in urban settings frequently experienced poorer health conditions than their counterparts living elsewhere for a range of reasons, often due to the generally poor conditions that accompany large numbers of humans living in close proximity and the increased ease with which communicable diseases are transmitted in such settings (M.N. Cohen 1989; Paine and Storey 2006). This pattern continues in many cities today, particularly in less-developed countries where conditions are poor due to cramped living conditions, accumulation of human and other forms of waste, and inadequate access to safe water (McMichael 2000; Stephens and Stair 2007). However, cities also often provide improved access to better healthcare and other services than rural localities, thereby at least partially countering the tendency for this type of converted habitat to be less healthy. Based on the data available, it is impossible to explain precisely what processes underlie the results shown in Figure 35.5. Nevertheless, those outcomes indicate a clear tendency for localities with natural habitat to have lower infant mortality than localities where habitat has been converted.

Is it reasonable to expect that natural habitat might lead to lower infant mortality in some hotspots? Part of the answer to this question may lie in the maladies that account for many infant deaths, and in the ecosystem components associated with them. Infant mortality is a complex phenomenon with several causes. Historically, diarrheal diseases have been a major cause of infant death (Hall and Drake 2006).

Table 35.2 Correlations Between Selected Human Health and Development Indicators in the Biodiversity Hotspots

	Correlation Measure (if significant, value given in parentheses)		
Variables	**Pearson's r**	**Kendall's tau**	**Spearman's rho**
IMR × CUW	0.62 (0.01)	0.57 (0.01)	0.75 (0.01)
IMR × LEX	−0.75 (0.01)	−0.59 (0.01)	−0.69 (0.01)
DDIAR × IMR	0.90 (0.01)	0.68 (0.01)	0.80 (0.01)
DDIAR × H_2O	−0.81 (0.01)	−0.55 (0.01)	−0.71 (0.01)
DDIAR × GNI	−0.50 (0.01)	−0.61 (0.01)	−0.76 (0.01)
IMR × H_2O	−0.77 (0.01)	−0.54 (0.01)	−0.71 (0.01)
CUW × H_2O	−0.52 (0.01)	−0.44 (0.01)	−0.55 (0.01)
LEX × H_2O	0.67 (0.01)	0.51 (0.01)	0.67 (0.01)
GNI × H_2O	0.68 (0.01)	0.66 (0.01)	0.83 (0.01)

IMR, infant mortality rate; CUW, percentage children aged five or less underweight; LEX, life expectancy at birth; DDIAR, age-adjusted death rate due to diarrheal disease; IMR, infant mortality rate; H_2O, percentage population with access to improved water; GNI, gross national income per capita purchasing power parity.

Despite recent progress in reducing mortality from these diseases through improved nutrition, better care-seeking, and rehydration therapy, such maladies continue to plague much of the world (Skolnik 2008). Indeed, diarrheal diseases remain the second leading cause of mortality among children globally (accounting for 18% of child deaths worldwide) and tied for the leading cause of death among children in Africa (WHO 2010b). Diarrhea can be caused by bacteria, viruses, and parasites, including *Shigella* sp., *Salmonella* sp., *Vibrio cholera*, *Escherichia coli*, and rotavirus (Friedman 2008; Skolnik 2008), transmitted by contaminated water or food as well as inadequate sanitation. A plot of age-adjusted death rates (per 100,000 people in the population) due to diarrheal disease estimated for the hotspots in 2004, based on WHO (2009) data, indicates high mortality rates due to these diseases in several high biodiversity regions, the resulting distribution reminiscent of the patterns shown above for other health indicators (Fig. 35.6; see also Figs. 35.3 and 35.4). The high statistical correlation between diarrheal death rate and infant mortality rate in the hotspots suggests that many infant deaths in these regions are due to diarrheal illnesses (Table 35.2), consistent with observations throughout much of the world (Sampat 2000; Thapar and Sanderson 2004; WHO 2007; Clasen and Haller 2008; WHO and UNICEF 2010).

High correlations between reduced diarrheal death rate and access to improved water sources in the hotspots lend credence to the public health strategy of providing safe water to reduce mortality from diarrhea (Skolnik 2008; Table 35.2). Improving water sources, along with closely related efforts to improve sanitation, are key development interventions used to help reduce the 2.5 billion instances of diarrhea in children each year, and the 1.5 million child deaths that result (Gleick 2002; WHO 2007, 2010a; WHO and UNICEF

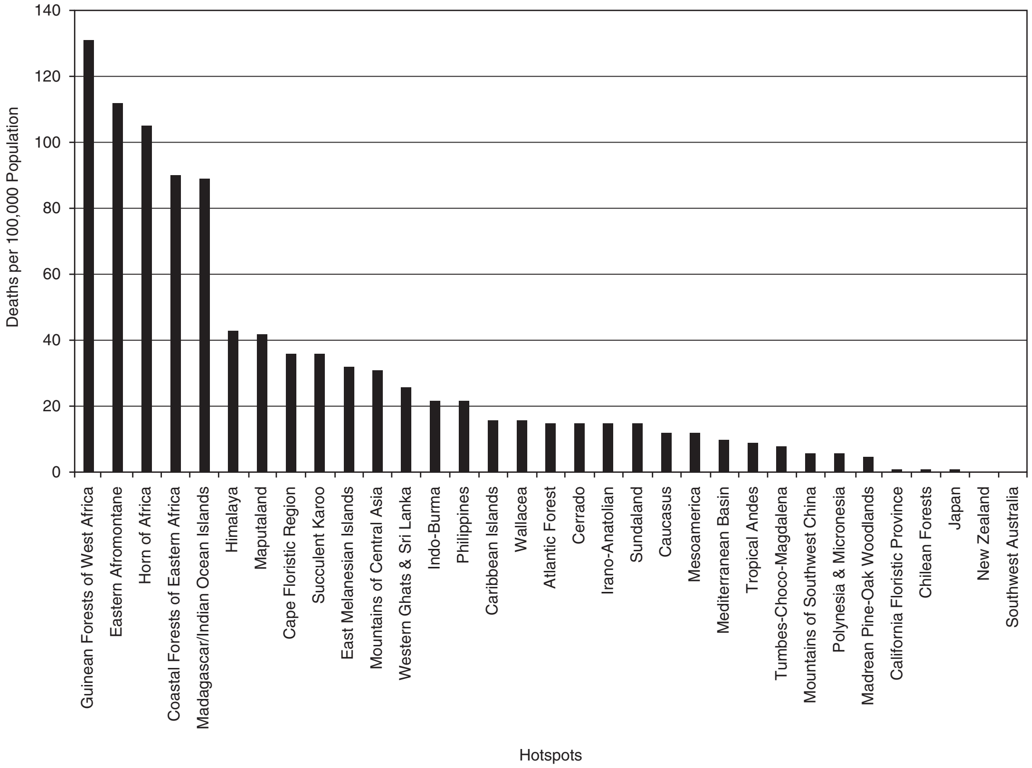


Figure 35.6:
Age-standardized mortality rate due to diarrheal disease in the biodiversity hotspots, 2004.

Children's Fund 2010). As seen in Table 35.2, access to improved water sources also tends to be strongly correlated with poverty. Although treatment of many contaminants in water is not difficult, it requires funds that often are unavailable in poor countries (Friedman 2008). In places lacking adequate financial resources to provide improved water sources through technical means, conservation may in particular contribute to human health by helping to maintain natural processes that purify water (IUCN 2000; Pattanayak and Wendland 2007; Vörösmarty et al. 2010).

Natural habitat helps to purify water by supporting natural purification processes (Postel and Richter 2003; Millennium Ecosystem Assessment 2005; Vörösmarty et al. 2005; Postel 2005, 2007). Water quality is particularly susceptible to the benefits of maintaining natural habitat, with certain types, such as forest, found to be especially effective (Bruijnzeel 2000, 2004; Kaimowitz 2004; Scott et al. 2005; Schmoll et al. 2006). Much of water purification as an ecosystem service involves components of the hydrological cycle, slowing runoff (and the erosion and siltation of surface hydrology that often accompanies it) while promoting infiltration that improves the quality of both surface and subsurface water. Although it is impossible to state with certainty based on current data, analysis results presented above augmented by ancillary information on causes of infant death suggest that improved water quality in portions of hotspots where habitat has not been converted to human uses may account for reductions in the infant mortality rates in many of these areas.

CONCLUSIONS

This study has focused on human health in 34 biodiversity hotspots with the dual aims of describing basic health patterns in these regions and identifying any possible roles that conservation might play in improving health status. In principle, functioning natural ecosystems essential for biodiversity conservation provide important services to people, and some of those services should contribute to better health by purifying air and water, improving agricultural production through nutrient replenishment, protection from certain natural hazards, and so on. But analyses conducted at a regional scale point to poverty—a broad indicator of human well-being—as the key determiner of health in the hotspots. Neither total percentage of original habitat nor total percentage of unconverted habitat, as proxies for intact nature and ecosystem function, seems to show a strong relationship with the health indicators considered in this study at a regional scale. In the case of original habitat, essential for maintaining the enormous volume of biological diversity in the hotspots, these results challenge the contribution of biodiversity conservation to human health. However, a sub-regional analysis of infant mortality (the one health indicator available at sub-national levels for nearly all of the hotspots), contrasting areas converted for human use against areas not so converted, provides evidence of nature benefiting human health in most hotspots. Given the close connection between infant mortality rate and diarrheal diseases, the tendency for such diseases to involve contaminated water, and the importance of natural processes in improving water quality, maintaining habitat unconverted for human use may contribute to better health in the biodiversity hotspots by providing safer water.

One issue in this chapter that remains unresolved is the role of *biodiversity conservation* in the context of human health. The analysis of infant mortality with respect to habitat types within the hotspots does not specifically target conserved *original* habitat—that is, habitat characteristic of the hotspots prior to broad human impact where much of the resident biodiversity occurs. Instead, it focuses on habitat that has not been converted for human use—habitat that might not be original and, ultimately, might be of limited importance for the conservation of biodiversity. Examples of such habitat include monoculture forests, planted as commercial sources of pulp or timber, represented in the Global Land Cover 2000 dataset as some type of forest but of little value to maintaining biodiversity. Unfortunately, available global data do not allow one to distinguish between original habitat and other forms of habitat that have not been converted for human use, but might have changed considerably from their original state. As shown in research on specific illnesses, the benefits of nature to human health often are tied to functioning ecosystems through complex sets of relationships that help to contain, dilute, or otherwise reduce the transmission of diseases (Patz et al. 2005; Ostfeld et al. 2005; Molyneaux et al. 2008; Keesing et al. 2010). The benefits of conserving original habitat in the hotspots generally will be greater for human health than maintaining unconverted habitat, because of the likelihood that many ecosystem functions in the former will be more intact. In the hotspots, high biological diversity and endemism make original habitat much more important for conservation. Although unable to distinguish between original and other forms of unconverted habitat, analyses in this chapter indicate that natural habitat, whether original or not, can improve human health. Although improvements, in the form of reduced infant mortality rate, often are modest, such results provide additional impetus for maintaining habitat in the hotspots—including key habitat essential for conserving the considerable (and often unique) biodiversity found in each.

One important outcome of the analyses presented above is a sense of how maintaining unconverted habitat can complement more conventional approaches to improving human health in less-developed countries. In the biodiversity hotspots, poor health often is linked to poverty, and both characterize many of the regions examined. In lieu of increasing national income or growing investments in healthcare, and in recognition that development organizations cannot address health problems everywhere, conservation may provide an alternative to more conventional strategies for improving human health, particularly in rural settings featuring natural habitat but unlikely to attract development interventions. Moreover, as a complement to conventional strategies, maintaining unconverted habitat (and conserving any biodiversity that occurs there) provides a sustainable solution susceptible to policy decisions and regional planning, interventions increasingly important as global population (and the challenge of maintaining the health of that population) grows to levels previously unknown (McMichael 2001).

Based on analyses of global data, health improvements by maintaining habitat in the biodiversity hotspots that has not been converted for human use often are marked but not dramatic. In most cases, more conventional interventions presumably will be essential to achieve large reductions in infant mortality. Decisions about where to focus habitat conservation actions to improve human health will require careful analyses of health conditions and natural characteristics at a small geographic scale for specific localities, both to confirm the relationships between health and conservation and to maximize benefits to people and nature. Such studies should employ detailed data on the human and natural environments that help to identify precise relationships between health and conservation in specific settings. In a world of persisting poverty and rapidly declining biodiversity, actions that potentially benefit both people and nature are certainly actions worth considering.

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