

# Chapter 4

## Behavioral Mediators of the Human Population Effect on Global Biodiversity Losses

Jeffrey K. McKee and Erica N. Chambers

### 4.1 Introduction

Despite our understandings of sound and tested ecological principles over vast time scales, interpretations of occurrences in the natural world during our modern human slice of geological time is fraught with uncertainty. Yet if we combine time depth from the fossil and archeological records with contemporary data of global reach, we can begin to dissect out the most relevant factors that threaten the future of all levels of biodiversity on this planet. It is our contention that the size of the human population and the scale of the human endeavor led to a dramatic rise in extinctions over the past 10,000 years. Continued exponential growth in the human population and our resultant environmental dominance, due to cultural development and ecological contingencies, is rapidly leading to a global mass extinction.

The fossil record of Earth's distant past is instructive, as it is littered with species that have dwindled into extinction. The reasons for past extinctions are many and comprise the topics of rigorous debates among paleontologists and evolutionary biologists. Climatic and environmental changes constantly challenge species of plants, animals, and microbes to find new niches. Novel adaptations to new or altered modes of existence are necessary components of survival. Some groups successfully evolve into new species, involving a "transitional extinction" of the parent species. But more often, the inability to adapt leads to a "terminal extinction", literally a dead end. The complex causes of terminal extinctions are not always easy to discern.

It is not unusual in nature for the rise and success of one species to lead to the downfall of another. Competition can be "red in tooth and claw", as often envisioned. However, it is more common for the effects of a competitor to be profoundly subtle – the product of intricate ecological systems that have developed with evolving components over long periods of time, some on the order of thousands, others millions, of years. The entry of humans or their predecessors into these ecosystems, like that of any other competitor, can thus be expected to have led to a pattern of extinction among certain organisms. Humans were in competition for the finite resources afforded by varied ecosystems – our ancestors' successes in each environment left little for our competitors, and many were vanquished.

Our analysis of the past and present states of global ecological affairs is premised and tested upon the hypothesis that human population density is a major factor in both the losses and threats to other species. Research at the species level of biodiversity can be viewed as a scientific convenience based on widespread availability of data. Research indicates that species are disappearing at a pace possibly 1,000 times that of historic background rates (Pimm et al. 1995). In addition, it should be made clear that also there have been real losses of biodiversity at the genetic level of many species, as surviving populations lessen in numbers. This is an important consideration because the resilience and long-term adaptive capacity of a population is dependent on the genetic variability upon which natural selection can act. Many allelic variations of the species' genes have already gone extinct, even if the species survives. Terminal extinctions become more likely than transitional extinctions, and thus we have already incurred an "extinction debt" for the future (Cowlshaw 1999). As long as our population continues to grow and exert pressure on the natural world, that debt will increase.

A further caveat to species-level studies of biodiversity is that higher levels of biological organization do not automatically get considered. The sustainability of our biosphere also depends on the survival of diverse ecosystems, each of which harbors endemic species as well as key population variants of more widespread species. Yet a study of species, past and present, can still serve as a useful barometer of "biospheric pressure".

## 4.2 Past Human Population Impacts on Species Biodiversity

The effects of human population growth on species biodiversity may have had a substantial time depth, depending on which of our ancestors one can comfortably call "human". Following the origin and spread of *Homo erectus* circa 1.8 million years ago (mya), there was a substantial decline in mammalian biodiversity in Africa (Behrensmeyer et al. 1997; McKee 2001). From a scientific perspective, it is difficult to attribute these mid-Pleistocene extinctions to *H. erectus*, let alone to the population growth of this species. Yet the coincidence of the increased rate of mammalian extinctions with "human" geographic incursions independently spans across four geographical regions (Klein 2000). Furthermore, our increased body size and the metabolically demanding brain size required greater demand for natural food resources. Thus, the features that allowed our ancestors to compete successfully, and thereby expand their populations, played into the likelihood of a more profound ecological impact on their competitors and prey.

It is reasonable to suggest that by the time our own species, *Homo sapiens*, spread to the new world toward the end of the Pleistocene, human population growth could at least partially account for the overkill of North American megafauna (Alroy 2001). These continental effects of humans on biodiversity took time as human populations slowly reached a critical mass before their impact was great enough to cause extinctions. Islands such as Madagascar, New Zealand, and Hawai'i had

elevated levels of species richness combined with smaller habitat sizes such that critical masses were reached more quickly and extinctions followed with greater rapidity (Holdaway and Jacomb 2000; Mlot 1995; Pimm et al. 1995). These global patterns of biodiversity loss led McKee (2003) to attribute many past extinctions to the effects of the growth and spread of human and prehuman populations. Population growth was argued to be a primary *cause*, mediated by aspects of human biology and behavior, as opposed to a spurious correlate of incidental effects.

The impact of human population growth on continental biodiversity accelerated with the origin and spread of agriculture over the past 10,000 years (Redman 1999; McKee 2003), but not without a cost. This lifestyle shift, from nomadic foraging by small bands of people to a group-based sedentary lifestyle, was based on primary food production utilizing monocropping and herding techniques (Armelagos 1990; Barrett et al. 1998). Predictable food supplies altered the birth/death rate equilibrium, resulting in increased population densities (Roberts and Manchester 1997). Although the viability of other species was still impacted by our growing ecological influence, it was mediated in a different way. Rather than directly killing off species through hunting or outcompeting other species for natural food resources, agriculturists promoted wholesale displacement of both plants and animals by utilizing expanses of land for crops and herding. Agricultural lands necessarily became less diverse and less productive in biomass as concentrations of domesticates were grown specifically for human consumption, at the expense of more diverse systems that had evolved to sustain many species.

One of the great bioarcheological ironies is that human health and longevity declined with the origins and spread of agriculture (Larsen 1995). Although reliance on fewer food types decreased nutritional value intake, human populations managed to flourish. Building upon an established base of human “capital”, the exponential nature of population growth – even at a slow growth rate – ensured that our numbers increased (McKee 2003). Meanwhile, large mammal extinctions reached an all-time high. For example, in South Africa, 16 species of large mammals went extinct in the past 10,000 years, including nine in historic times. This is in contrast to the general pattern, prior to the emergence of the genus *Homo*, of an extinction rate of about four large mammal species every 100,000 years (McKee 1995).

The ineluctable conclusion is that the growth of our population and the extinction of other species have long been closely related and accentuated with the origins of sedentism and agriculture. Our analysis of contemporary data further demonstrates that population densities and agricultural practices still play a critical role in understanding patterns of extinction.

### 4.3 Biodiversity and Human Population Density Today

The human population grew past six billion people in 1999 and has reached over 6.7 billion by 2009 (US Bureau of the Census 2009a). Our numbers continue to grow such that there will probably be seven billion people by 2013 (US Bureau of the

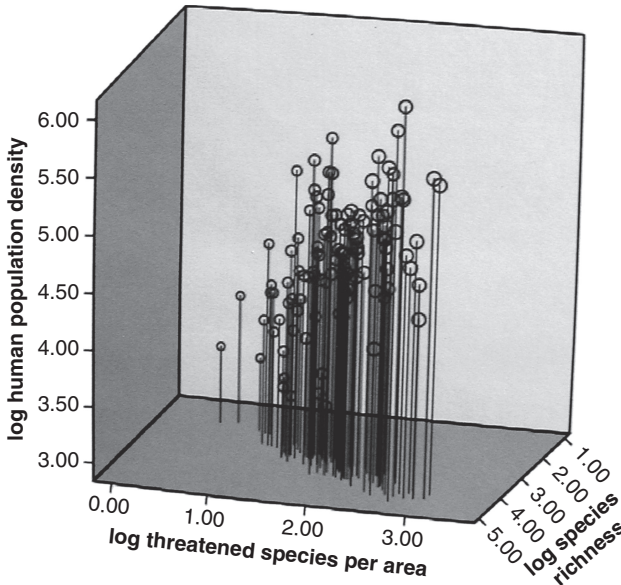
Census 2009b) and nearly nine billion by 2050 (UNFPA State of World Population 2004). Meanwhile, 11% of known mammal and bird species are threatened (Stork 1997), compounded by immeasurable effects on species yet to be documented by the scientific community. Are these figures directly connected?

There are sound theoretical reasons and considerable evidence suggesting that a close relationship between human population size and biodiversity losses, as in the past, continues today in an alarming manner. Increases in population size and density have caused rapid cultural and ecological changes initiated by human endeavors. Our analysis in this contribution is based on known “threats” to extant species as opposed to documented terminal extinctions, such as those confirmed by our research on the fossil record. Again, the species is a convenient unit of analysis, though genetic and ecosystem biodiversity are also important variables to consider.

Ironically, there are of many examples of human-introduced species that result in biodiversity loss. Globalization of our population, born of necessity as more of us require “unearned resources” from other parts of the world, inevitably globalizes other species, usually considered to be “weed species”. Humans may be one such species.

Examples of plant and animal biodiversity loss do not always paint a clear picture of global biodiversity threats. In order to explore a broader view of current trends, McKee et al. (2004) analyzed data on threatened species per nation, comprising critically endangered, endangered, and vulnerable species of mammals and birds from the IUCN Red List (2000). Data from 114 continental nations, excluding exceptionally small nations, was also compiled on human population densities and “species richness” – defined for analysis as the number of known mammal and bird species per unit area. A stepwise multiple regression analysis of log-transformed data defined a statistical model that explained 88% of the variability in current threats to mammal and bird species per country on the basis of just two variables: human population density and species richness (Fig. 4.1). Clearly, “species richness” is not the root cause of the threats – these diverse ecosystems persisted through climatic changes and ecosystem shifts over many thousands of years. That leaves the other variable in the equation, human population density, as the likely culprit leading to globally increased species threats. In essence, a greater concentration of species sets the stage for the human impact to be more devastating.

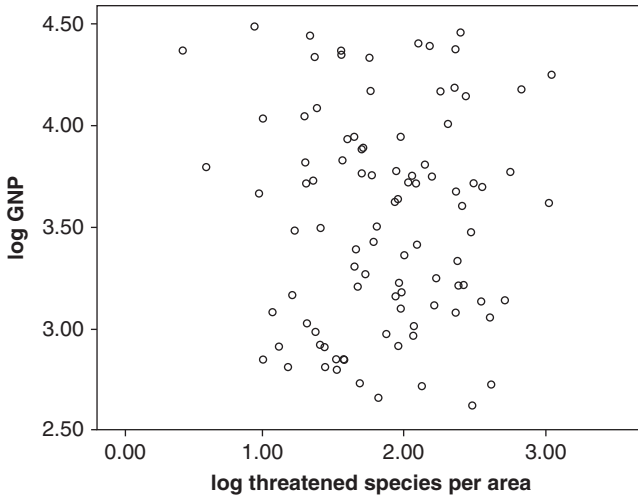
The human population impact on biodiversity has empirical support from both past and present – it is more than an assumption. On the other hand, correlation does not necessarily mean causation. One must ask if our increased population density is the root cause or a spurious correlation that masks the more direct effects of human behavior. Certainly, one can assume, there must be some effect from what many ecologists now refer to as the “ecological footprint” – the effect each individual or group has in terms of resource consumption (Wackernagel and Rees 1996; Chambers et al. 2000). This is manifested in many ways – fuel consumption, deforestation, fresh water usage, global warming, or even the household dynamics of urban sprawl (Liu et al. 2003). There are direct correlates of the “ecological footprint” with depletion of both renewable and nonrenewable resources. Is this extraction of resources also related to biodiversity losses?



**Fig. 4.1** Relationship of threatened species per unit area, population density, and species richness. A multiple regression model,  $\log \text{ threatened species per } 10^6 \text{ km}^2 = -1.534 + (0.691 \times \log [\text{species richness}] + (0.259 \times \text{human population density})$ , accounts for 88% of the variation in species threats

Such questions can be teased from the global data by adding variables to the model and testing hypotheses. One measure of some aspects of the “ecological footprint”, for which data are generally available, is per capita Gross National Product (GNP). Previously, McKee (2003) found that whereas there is a strong correlation between species threats and human density, the threat has virtually no correlation with per capita GNP. Figure 4.2 shows the relationship between log-transformed currency-adjusted per capita GNP (Purchasing Power Parity) and the number of species threats for mammals and birds among 101 nations (for which all data were available). The effects of affluence on threatened species originally appeared to be overshadowed by our sheer numbers.

It was somewhat surprising to find virtually no correlation. Kerr and Currie (1995) found a correlation between threatened mammal species and per capita GNP with a different global data set and different methods ( $N = 82$  nations), but this was not borne out by our data (which unlike their study excluded small and island nations, perhaps accounting for some of the differences). The reasons behind this counter-intuitive lack of correlation, or the *negative* correlation found by Kerr and Currie, no doubt are complex. But it is clear that the effects of our large population are mediated through a variety of means – just as in the past when the hunting effect was supplanted by the agricultural effect. Kerr and Currie *did*, like us, find a strong population effect on threatened bird species, and other independent tests have also



**Fig. 4.2** The lack of a close relationship between GNP and threatened species per unit area is evident in this scattergram

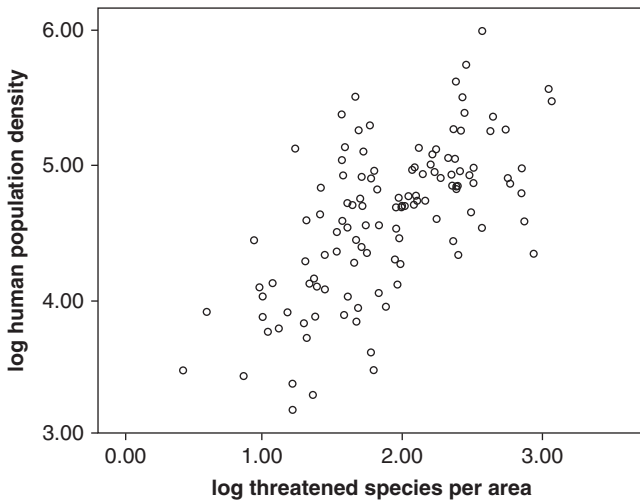
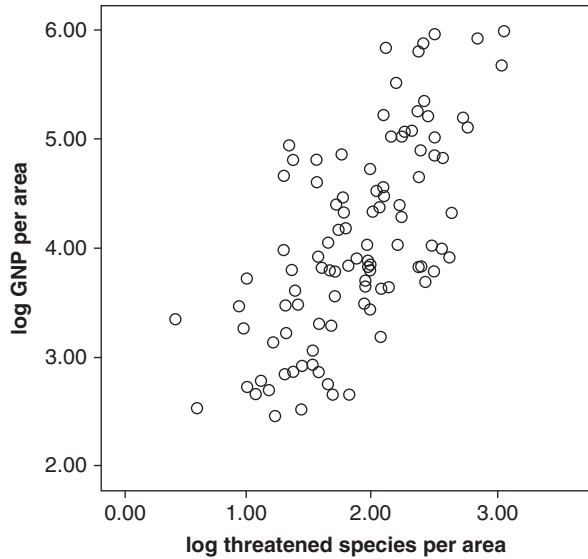
highlighted the effects of human population numbers (Kirkland and Ostfeld 1999; Thompson and Jones 1999; Brushares et al. 2001). Large numbers of people in nations rich and poor invariably put pressures on other species that rely upon the same resources.

In order to address these issues further, we reanalyzed the data, looking at GNP per unit area. An interesting, albeit complex, picture emerged. A strong and statistically significant *positive* correlation (Pearson's) between log-transformed GNP and threatened species came into focus ( $r^2 = 0.443$ ,  $p < 0.001$ ). This correlation is evident in the scattergram of Fig. 4.3. By comparison, human population density alone was a slightly lesser predictor of species threats ( $r^2 = 0.402$ ,  $p < 0.001$ , both variables again log-transformed; Fig. 4.4).

On the other hand, a stepwise multiple regression analysis in which GNP per unit area was added to the variables of the McKee et al. (2004) model left us with the same model: human population density and species richness were the better predictors, to the exclusion of GNP. Part of the reason for this counterintuitive result is that GNP is positively correlated with species richness ( $r^2 = 0.445$ ,  $p < 0.001$ ). Perhaps the high primary productivity of these areas drives diversity as well as economics – but from a statistical perspective, the overlap of GNP and species richness explains some of the same variability in contemporary threats to species of mammals and birds.

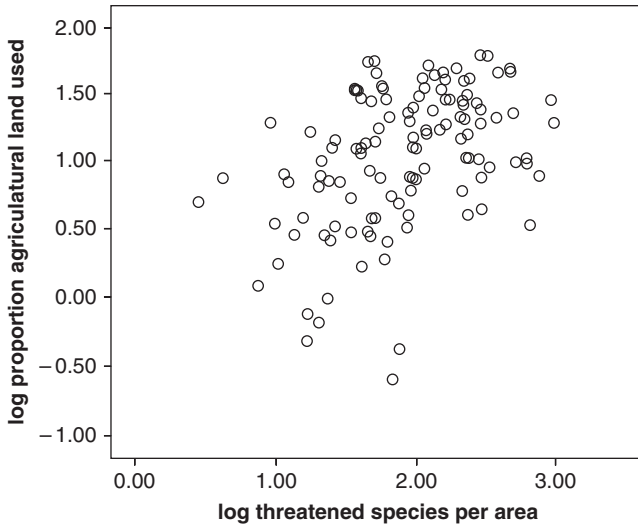
Given the archeological association of the origins of agriculture and extinctions of many mammalian species, it is also instructive to look at contemporary correlations between agricultural land use and species threats. We found a statistically significant positive correlation ( $r^2 = 0.187$ ,  $p < 0.001$ , using log-transformed variables; Fig. 4.5). This correlation is weaker than that of either GNP or

**Fig. 4.3** Once GNP is considered per unit area, the relationship to threatened species becomes more apparent. Compare to Fig. 4.2



**Fig. 4.4** Scattergram of relationship between human population density and threatened species per area

population density. Then again, population density and percentage of land devoted to agriculture are correlated as well ( $r^2 = 0.654, p < 0.001$ ). Thus, the question arises as to whether the correlation reflects the direct effect of agriculture usurping the resources of other species or is agriculture simply a mediator of the human population density effect.



**Fig. 4.5** Scattergram of relationship between proportion of active agricultural land use and threatened species per area

Adding agricultural land use into the stepwise multiple regression analysis, we find that it does add a small but statistically significant component to the model predicting nation-by-nation species threats. It explains some of the variability that other variables, including GNP, do not, thereby increasing the predictability of the model from 88% to 89%.

In summary, numerically speaking, once all of the variables used in this analysis are taken into account, species richness, human population density, and agricultural land use are the best combined predictors of threats to species of mammals and birds. GNP – a measure of economic activity that counts residents’ income from economic activity abroad, as well as at home – while strongly correlated with species threats, does not add to the predictive ability of the model. These results, combined with long-term observations of the human impact on mammal species, lead us to argue that human population density is a primary cause of biodiversity losses, in a large part mediated by agricultural land use, and thus is a key factor that must be addressed to reduce future threats to Earth’s biodiversity.

#### 4.4 Discussion

The results of our analyses bear on debates as to whether human consumption or population density is more relevant in efforts to thwart a mass extinction and its detrimental ecological consequences. Polarized perspectives have emerged. One can take the adamant position of Smail: “*Population stabilization and subsequent*



*reduction is undoubtedly the primary issue facing humanity; all other matters are subordinate*” (2003: 297, italics his). Alternatively, Chambers et al. (2000: 59) exclaim “Don’t count the heads – measure the size of their feet”. We conclude that such debates are specious, and that a better mantra would be “Count heads, mind your feet”. Our research demonstrates that both considerations are relevant, and both must be considered in a comprehensive conservation plan.

For example, one of the complexities not sufficiently addressed in our nation-by-nation statistical analysis is that behavior in one nation can affect biodiversity in another. McKee et al. (2004) noted that Brazil stood out in the analysis as not fitting the trend of greater human population density in species-rich nations leading to biodiversity threats – their threat levels were in excess of those predicted by our model. Such a country may be the exception that proves the rule regarding the importance of global human population growth – economic factors due to population demands in countries with which Brazil does business necessarily influence the rate of habitat destruction and hence the number of threatened species.

Compared to the amount of literature written on conservation to limit biodiversity loss through reduced consumption, nature reserves, and even valuable new ideas such as reconciliation ecology (Rosenzweig 2001, 2003), there is a relative dearth in the wildlife conservation literature on the need to reduce human population density. Here, we want to emphasize the importance of both traditional and novel conservation measures, but concentrate this discussion on population issues as they relate to biodiversity.

Cincotta and Engelman (2000) did present a strong case for the need to address population issues in biologically diverse “hotspots”. Our global analysis, which uses country-level data, comes to a similar conclusion – that greater human population has been accumulating in regions associated with higher levels of species endemism – despite our analysis having excluded the islands that comprise many of the hotspots. Clearly, human population growth with the hotspots should be addressed quickly as part of a complete conservation plan. Yet it is our assessment that in order to preserve biodiversity at all levels, we need to go beyond a focus on hotspots, valuable though they may be, to a more global effort in which conservation and human population reduction are both paramount to the survival of the planet.

By way of illustration, the state of Ohio can serve as a case study, for its problems are a microcosm of general global trends. Although it is not a biodiversity hotspot, within its political boundary are at least 175 endangered and threatened species, by state government accounts (Hunt 2005). There is a concentration of public discussion on balancing economic development with preserving Ohio’s natural heritage, and many conservation projects have succeeded. On the other hand, of the 2000 or so development projects reviewed each year by the US Fish and Wildlife Service, none have been turned down. Similarly, the Ohio Environmental Protection Agency issued 336 environmental permits for construction and development (e.g., waste water discharge, drilling, and water quality maintenance permits), covering 97.5 ha of wetlands in fiscal year 2004 (Hunt 2005).

Part of the pressure on Ohio for development is the growth of our population, but population issues are rarely considered. There is a general perception in the state,

often repeated by various news agencies, that Ohio's human population has remained steady at "about" 11 million people. In very round figures, that may be true, but from 1990 to 2000, Ohio's human population grew 4.7% – by more than half a million people, from roughly 10.8 million to 11.4 million (US Bureau of the Census 2009c). Ohio's rate of population growth is slower than the country as a whole, which grew 13.1% during the same time period. But in a state already saturated with people, it is highly significant. Ohio has the seventh largest population of states in the USA as of 2000, despite being 34th in land area.

So part of the problem is that the general public and policy-makers do not recognize the relevance of our rapidly growing human family. A further component of the problem is that population issues are politically unpopular. There was nearly no mention of population issues in the US presidential election campaigns of 2004 and 2008. This is symptomatic of a larger problem. For example, at the 2002 World Summit on Sustainable Development in Johannesburg, South Africa, population was virtually a taboo subject, despite their goal of reducing the rate of biodiversity loss by 2010.

The complexity of population issues stymies those who should know better from even broaching the subject. Controversial and complex issues concerning human rights and racism, for example, are integral components of the dialog on population growth abatement. But difficulties in addressing such issues should not prevent the conversation from taking place.

Another key component to public diffidence toward population problems is that our rate of growth is slowing. Thus, there is a perception that as developing nations follow the theorized pattern of the demographic transition, our population will naturally peak at 10 or 11 billion, depending on estimates of fertility as the transition occurs (Lutz et al. 2001). There are a number of problems with this logic.

The demographic transition typically involves economic growth and increased consumption, hence increasing the "footprint". In economics, there is no equivalent of the "demographic transition", in which growth slows naturally. It could be argued that affluent societies have more modern technological developments, which represent, at least in theory, progress toward a more efficient, less environmentally draining mode of production. But that is not what we see. For example, as China becomes more industrialized, it is on course to overtake the United States as the most voracious consumer of resources (Favin and Gardner 2006).

Moreover, the underlying assumptions of the demographic transition are not borne out by the data. McKee (2003) argued that many countries did not fit the traditional model. To test this idea, we used our data to compare national growth rates to GNP. Whereas there is indeed a statistically significant correlation ( $p < 0.01$ ), only 52% of the variation in growth rate can be explained by GNP (Fig. 4.5). In other words, we cannot automatically count on the demographic transition through economic development to abate human population growth.

The point we want to make here is that population issues and policy initiatives must move to the top of the political and policy agenda. There is no guarantee that the human population growth will continue to slow naturally through the demographic transition, the alleged economic catalyst of the transition involves increased

consumption, and even if our population *does* peak at 10 or 11 billion, that is far too many for sustainability of biodiversity (McKee 2003). Whereas we agree that conservation policies are vitally important to sustaining the ecological health of the planet, they will be all for naught unless we find a way to close the floodgates of human population growth.

The evidence is in the statistics. As we demonstrated with prehistoric and contemporary data, there is a strong and important correlation between human population growth and biodiversity losses. Using our mathematical model (see Fig. 4.1) to forecast future species threats based upon demographic projections per country, all else being equal, it was found that we can expect a 7% increase in the global number of threatened species of mammals and birds by 2020, and a 14% increase by 2050, based upon growth in human numbers alone (McKee et al. 2004). It is difficult to translate these calculations into predicted numbers of extinctions, but as we noted earlier, the very nature of the threat involves extinctions of genetic variability, thereby creating an extinction debt. Without intervention toward abating and halting human population growth, future extinctions are assured.

## 4.5 Conclusion

Human population growth has resulted in changes in Earth's biodiversity for thousands of years. Competition within global ecosystems has produced evolutionary changes resulting in the rise and fall of species. Although the extinction of a species is a natural event, the frequency of these extinctions is rising at an unprecedented rate in human history. Increases in human population density have initiated drastic changes in land use strategies and heightened levels of migration causing plant and animal displacement and extinction. We stated earlier that "novel adaptations to new modes of existence are necessary components of survival". That is true for our species now.

Increases in human population growth and environmental dominance and manipulation have set the stage for the global mass extinction that has already begun. However, the extinction rate is not the sole indicator of a compromised ecosystem. Species threats are causing a depletion of genetic biodiversity, which puts species in greater risk of extinction since adaptability to altered environments becomes less likely. Ecosystem diversity is also jeopardized by human expansion, thus compounding the threat.

Our analyses have demonstrated that species richness, human population density, and agricultural land use are the best predictors of species threats. Increases in human population density and concomitant lifestyle practices are the primary cause of biodiversity threats. Malthusian principles, although much maligned for two centuries due to the successes of the human enterprise, have snuck up behind us as the biodiversity on which we rely has continued to quietly dwindle to dangerous levels of vulnerability. We need to overcome the public aversion toward identifying and addressing population issues. With the sustainability of global ecosystems

under threat, the human family needs to realize that addressing the crisis of overpopulation is in everybody's best interest.

**Acknowledgments** We would like to thank Richard Cincotta for the invitation to write this chapter as well as his insights that helped guide our analysis.

## References

- Alroy J (2001) A multispecies overkill simulation of the end-Pleistocene megafaunal mass extinction. *Science* 292:1893–1896
- Armelagos GJ (1990) Health and disease in prehistoric populations in transition. In: Swedlund A (ed) *Disease in populations in transition*. Bergin and Garvey, New York, pp 127–144
- Barrett R, Kuzawa CW, McDade T, Armelagos GJ (1998) Emerging and re-emerging infectious diseases: the third epidemiologic transition. *Annu Rev Anthropol* 27:247–271
- Behrensmeyer AK, Todd NE, Potts R, McBrinn GE (1997) Late Pliocene faunal turnover in the Turkana Basin, Kenya and Ethiopia. *Science* 278:1589–1594
- Brushares JS, Arcese P, Sam MK (2001) Human demography and reserve size predict wildlife extinction in West Africa. *Proc R Soc Lond B* 269:2473–2478
- Chambers N, Simmons C, Wackernagel M (2000) *Sharing nature's interest – Ecological footprints as an indicator of sustainability*. Earthscan, London
- Cincotta RP, Engelman R (2000) *Nature's place: human population and the future of biological diversity*. Population Action International, Washington, DC
- Cowlishaw G (1999) Predicting the pattern of decline of African primate diversity: an extinction debt from historical deforestation. *Conserv Biol* 13:1183–1193
- Favin C, Gardner G (2006) China, India, and the new world order. In: Stark L (ed) *State of the World 2006*. WW Norton, New York, pp 3–23
- Holdaway RN, Jacomb C (2000) Rapid extinction of the moas (*Aves: Dinornithiformes*): model, test, and implications. *Science* 287:2250–2254
- Hunt S (2005) Habitats in danger? Projects usually not. *The Columbus Dispatch* 01/01/2005
- IUCN (2000) *Red list of threatened species*. <http://www.iucnredlist.org/>. Accessed June 2000
- Kerr JT, Currie DJ (1995) Effects of human activity on global extinction risk. *Conserv Biol* 9: 1528–1538
- Kirkland GL, Ostfeld RS (1999) Factors influencing variation among states in the number of federally listed mammals in the United States. *J Mammal* 80:711–719
- Klein RG (2000) Human evolution and large mammal extinctions. In: Vrba ES, Schaller GB (eds) *Antelopes, deer, and relatives, present and future: fossil record, behavioral ecology, systematics, and conservation*. Yale University Press, New Haven, pp 128–139
- Larsen CS (1995) Biological changes in human populations with agriculture. *Annu Rev Anthropol* 24:185–213
- Liu J, Daily GC, Ehrlich PR, Luck GW (2003) Effects of household dynamics on resource consumption and biodiversity. *Nature* 421:530–533
- Lutz W, Sanderson W, Scherbov S (2001) The end of world population growth. *Nature* 412:543–545
- McKee JK (1995) Turnover patterns and species longevity of large mammals from the late Pliocene and Pleistocene of southern Africa: a comparison of simulated and empirical data. *J Theor Biol* 172:141–147
- McKee JK (2001) Faunal turnover rates and mammalian biodiversity of the Late Pliocene and Pleistocene of eastern Africa. *Paleobiology* 27:500–511
- McKee JK (2003) *Sparing nature – the conflict between human population growth and Earth's biodiversity*. Rutgers University Press, Piscataway
- McKee JK, Sciuilli PW, Fooce CD, Waite TA (2004) Forecasting global biodiversity threats associated with human population growth. *Biol Conserv* 115:161–164

- Mlot C (1995) Biological surveys in Hawaii, taking inventory of a biological hot spot. *Science* 269:322–323
- Pimm SL, Russell GJ, Gittleman JL, Brooks TM (1995) The future of biodiversity. *Science* 269: 247–250
- Redman CL (1999) Human impact on ancient environments. The University of Arizona Press, Tucson, Ariz
- Roberts C, Manchester K (1997) The archaeology of disease. Cornell University Press, Ithaca, New York
- Rosenzweig ML (2001) Loss of speciation rate will impoverish future diversity. *Proc Natl Acad Sci* 98:5404–5410
- Rosenzweig ML (2003) Win-win ecology: how the earth's species can survive in the midst of human enterprise. Oxford University Press, Oxford
- Smail JK (2003) Remembering Malthus III: implementing a global population reduction. *Am J Phys Anthropol* 122:295–300
- Stork NE (1997) Measuring global biodiversity and its decline. In: Reaka-Kudla ML, Wilson DE, Wilson EO (eds) *Biodiversity II*. Joseph Henry, Washington, DC, pp 41–68
- Thompson K, Jones A (1999) Human population density and prediction of local plant extinctions in Britain. *Conserv Biol* 13:185–190
- UNFPA State of World Population (2004) <http://www.unfpa.org/swp/>
- US Bureau of the Census (2009a) US and World population clocks. <http://www.census.gov/main/www/popclock.html>. Accessed 1 February 2009
- US Bureau of the Census (2009b) International Data Base. <http://www.census.gov/ipc/www/idb/worldpopgraph.html>. Accessed 1 February 2009
- US Bureau of the Census (2009c) American Factfinder. [http://factfinder.census.gov/home/saff/main.html?\\_lang=en](http://factfinder.census.gov/home/saff/main.html?_lang=en). Accessed 1 February 2009
- Wackernagel M, Rees W (1996) Our ecological footprint – reducing human impact on the earth. New Society, Gabriola Island, British Columbia

