The Sustainability of Population Health

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The study of population health encompasses analysis of the fundamental influences on human health, the consequences of such influences for societies and individuals, and the ways in which people and institutions respond to these consequences. A theme lacking from the present discourse is that of the sustainability of population health. To be sustainable, societies must respect the boundaries of natural systems and scorn disparities in standards of living. Preliminary analysis of data from 152 countries reveals an inverse relation between measures of population health and sustainability, although there are examples of societies where this inverse relation does not hold. Future research in population health should begin to question the sustainability of improving the health of some populations at the expense of others, and investigate how some societies appear to be able to achieve population health without compromising the health of the biosphere.

KEY WORDS: population health; sustainable development; ecological integrity; life expectancy.

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INTRODUCTION

We live in an era of unprecedented global change characterized by marked population growth, increasing gaps between rich and poor, rapid technological advance and diverging consumption patterns. Global environmental assessments indicate that human activities, partially driven by an impractical vision of progress, are eroding the environmental conditions required to sustain our species (NRC, 1999). Recent estimations conclude that humans appropriate between one-third and one-half of the present net primary production of the biosphere (Pauly & Chrisensen, 1995). In addition to these pressures on global life support systems, social and economic inequalities among and within states have increased substantially over the past 40 years (Galbraith, 2002). One implication is that once poorer countries begin to catch up to consumption patterns typical of rich countries, environmental degradation will be yet worse; indeed, China is poised to exert an enormous influence on world resources.

The notion of sustainable development (and sustainability) was articulated at an international level by the World Commission on Environment and Development (1987). It was a noble attempt to argue that neoliberal economic interests could be reconciled with maintaining healthy ecosystems alongside just and equitable societies. More recently, ideas on sustainability have placed greater emphasis on social and economic conditions, regarding human health as a top priority (UNDSD, 2003). Currently, the main tenets of sustainability include a focus on integrating ecological, economic and social considerations into decision making, the improvement of equity between generations, within and among nation states, stability of population growth, and the conservation of natural systems (Dale, 2001).

The concept of population health is being increasingly adopted by many western industrialized countries; it aspires to improve the health of whole societies and especially to reduce health inequalities among population groups (Health Canada, 2003). On the surface, sustainability and population health share common objectives of reducing inequalities and improving the well-being of humanity. Nevertheless, the theme of sustainability has been given limited attention in population health frameworks. The emerging paradigm of population health (like that of epidemiology before it) has failed to incorporate the growing awareness that individuals cannot achieve and sustain health in an unhealthy environment. Nor do models acknowledge that improvements in health indicators such as longevity or improved quality of life may imply further resource depletion, especially in a world that perpetuates unequal power relations. Many population health models portray health as a continuum or process subject to an array of influences; among physical determinants they acknowledge the public health role of access to clean air and water, secure and nutritious food supplies, and protection from the natural elements as requirements to health (Nadakavukaren, 2000). Beyond this, however, the World Health Organization defines health in terms of harmony—within our bodies, between each other, and with our environment—and in terms of resiliency. Nevertheless, population health frameworks, in general, omit an explicit acknowledgement that human health is ultimately dependent on the health of natural systems and must respect the limitations imposed by the biocapacity of the planet.

Acknowledgement of our dependency on healthy natural systems should be of central concern to population health. The natural systems that provide for our requirements must be shared equitably with all species in a symbiotic social system. From this perspective, the discourse of sustainability provides an appropriate forum to situate a broader conceptual framework for population health.

WHAT IS POPULATION HEALTH?

The academic study of population health identifies systematic variations in patterns of occurrence of (mostly adverse) health states within and between populations, and applies the resulting knowledge to develop policies and actions to improve the health and well-being of those populations (FPTACPH, 1996). The population health approach transcends the traditional biomedical perspective on health and focuses on the interrelated social, economic and environmental conditions that influence the health of populations over the life course. In addition to biological endowment, health is conditioned by a complex of factors related to a person's social and physical environments, and income situated in the context of national wealth and prosperity (Evans & Stoddart, 1990). Many authors have demonstrated the power of social and economic determinants of differences in health (Black, Morris, Smith, & Townsend, 1982; Marmot, 1986, 2003; McKeown, 1979; Wilkinson, 1996), and the capacity of the contextual milieu to modify associations between individual characteristics and health (Evans & Stoddart, 2003; Kawachi & Berkman, 2000).

There have been remarkable improvements in many indicators of health status over the past century. The decline in rates of infant mortality

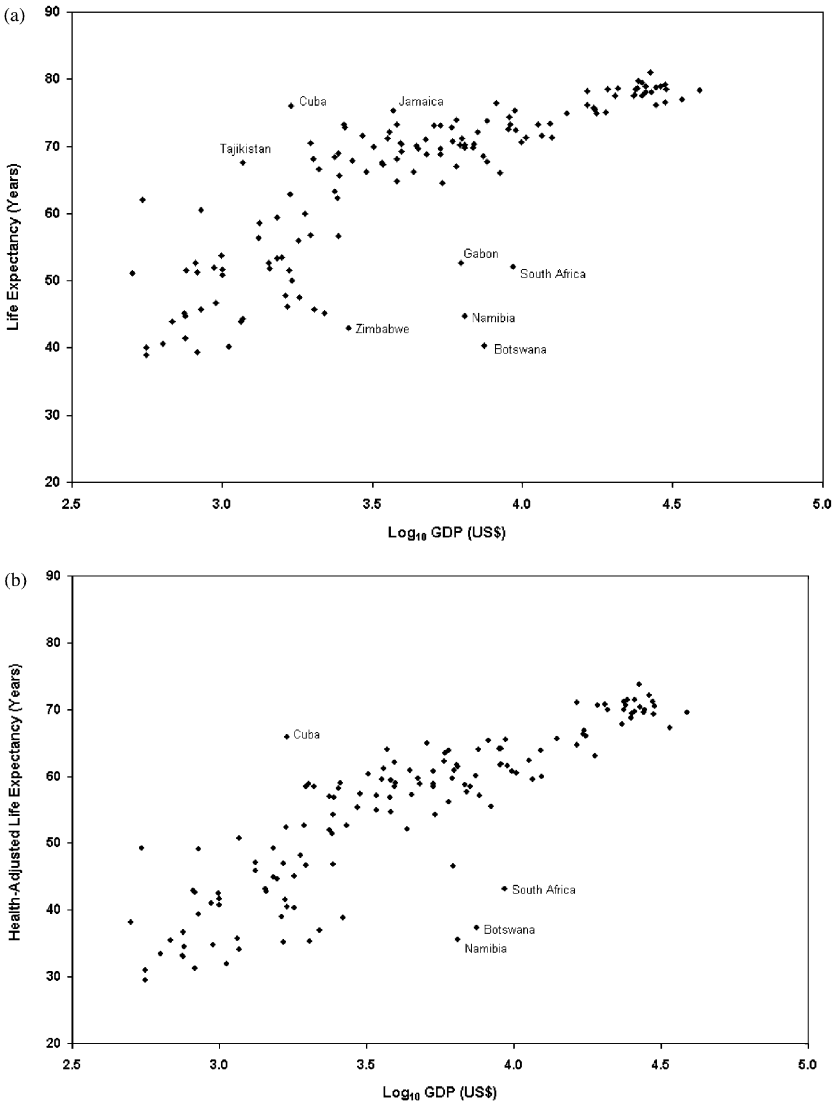

FIGURE 1. The relationship between $\log_{10}$ GDP per capita and (a) life expectancy and (b) health-adjusted life expectancy for 148 countries and a population of 5.7 billion. (*Source:* World Bank, World Development Indicators, 2001; UNDP, Human Development Indicators, 2002).

and many victories over infectious disease have allowed some populations to more than double their life expectancy, but this progress has often accentuated health disparities. Neoliberal economic approaches have adopted the theme that, ultimately, economic prosperity produces health—a wealthy society is a healthy society. The relationship, however, is complex, and there are many exceptions. Figure 1 illustrates the association between life expectancy (and health-adjusted life expectancy) and logarithmically transformed per capita gross domestic product (GDP) for 148 countries. Similar-shaped relationships hold for infant mortality rates and low birth weight (Hertzman, 1996).

While there is a strong positive correlation, there are outliers and the association with health-adjusted life expectancy is more clearly log-linear than that with life expectancy alone, suggesting that after the beneficial effect of GDP on life expectancy declines, there can still be an advantage for health. There are presumably biological limits to the extent to which growing GDP can benefit life expectancy. Despite the complex form of the relationship between wealth and health, a naïve interpretation of the wealth-health link has driven international health policy discussions (Williamson, 1990) and has prompted advocates to highlight the commensurate health benefits to society from wealth-generating activities (WHO, 2002).

There have been critics, however Szreter's (2003) analysis of the historical relation between health and wealth reveals a more ambivalent and contingent association, in which the process by which wealth is created may also be responsible for rising social inequalities and the deterioration of state capacity to maintain and protect population health (Labonte, 1998; Rocheleau, 1999). Materialist conceptions of population health may also underestimate the contribution of health care and other social forces such as power relations within societies (Poland, Coburn, Robertson, & Eakin, 1998).

Whatever the impact of economic growth on improving health, it is evident that continued initiatives to improve prosperity exert considerable stress on the planetary biosphere and its ecological integrity (Brown, Manno, Westra, Pimentel, & Crabbé, 2000). Global annual energy consumption has increased almost twofold since 1970 to 400×10^3 petajoules (1 PJ = 32,500 tonnes of coal or 20,000 tonnes of oil), and per capita energy consumption increased from approximately 50–65 gigajoules (1 GJ = 27.6 L of gasoline) in the same period (NRC, 1999; World Resources Institute, 2001). Global forest area has decreased by 6%, irrigated area has increased by almost 40%, the number of cattle has increased by 25%, and the use of chemical fertilizers and pesticides has doubled (World Resources Institute, 2001). The 600 million automobiles and 15 million commercial vehicles around the world (McMichael, 2001) are also linked to a wide range of health impacts (Buckeridge et al., 2002). For example, approximately 1 out of every 12 non-accidental deaths in Canada is attributable to air pollution (Burnett, Çakmak, & Brook, 1998). Approximately 23% of preventable ill health at the global level is due to environmental risk factors (Murray & Lopez, 1996), and this result is likely to underestimate of the true health impact (Smith, Corvalan, & Kjellstrom, 1999). Human threats to the biosphere, to the chemistry of the Earth's atmosphere and to the physio-chemical properties of terrestrial and aquatic ecosystems have resulted in measurable changes to the basic life-giving processes required for the long-term sustenance of population health (cf. McMichael, 2002).

EVALUATING THE SUSTAINABILITY OF POPULATION HEALTH

This discussion holds implications for the way we evaluate population health. The carrying capacity of the planet has limits, so health gains that are achieved at the expense of environmental degradation and resource depletion may not be sustainable. And unless sustainability is considered, our conception of population health can become meaningless. Just as future forecasts affect a company's share prices, so we cannot view two populations as being equally healthy if they share the same mortality patterns and quality of life, but if one of them has achieved this at the expense of environmental degradation that will lead to future declines in health. Eastern European countries of the former Soviet bloc offer examples: their improvements in health masked a series of environmental problems that increased the risk of future disease. Thus, the sustainability of population health has to be considered with a time-dimension. Similarly, it must also have a geographic dimension, and should be viewed from a global perspective. Health gains for one group that are achieved at the expense of increasing inequities through compromising health in other populations cannot morally be judged equal to gains that form part of a broader gain for all groups. One example would be the health benefits of eating farmed fish in North America, when those fish are fed using meal processed from fish caught in poorer countries of Latin America, where the population thereby is deprived of a traditional source of nutrition. And yet, population health theory has largely neglected the importance of non-human natural systems in health-generating activities. This is perhaps a consequence of its evolutionary origins rooted in the social and economic determinants of health, grounded in epistemological stances associated with materialist political economy (Hayes, 1994). The exclusion of natural systems as paramount to health generating activities is also well-established in exemptionalist beliefs

(Myers & Simon, 1993) and anthropocentric values. Anthropocentricism is even evident in the language of sustainable development from the 1992 UN Rio Conference on the Environment which stated that human beings are at the *centre* of concerns for sustainable development (UN General Assembly, 1992, Principle 1). The following sections will illustrate the relationship between measures of sustainability and population health and discuss the challenge of improving population health while respecting the limits of Earth's biocapacity.

Ecosystems provide the necessary requirements for population health. Ecosystems are functional units that result from interactions of abiotic, biotic, and anthropogenic components, and comprise interacting parts that form a unitary whole (Eblen & Eblen, 1994). The concern here is whether an ecosystem is healthy or can function in a state that is able to support the activities of all species (including humans). Broadening the theme of "population", ecological integrity subsumes the notion of health; thus a healthy ecosystem is one that retains structure, function and resilience to perturbation (Ulanowicz, 2000). We argue that improvements in population health that come at the expense of damaging ecological integrity are illusory and unsustainable. However, it is difficult to operationalize the notion of ecological integrity since ecosystems are dynamic and complex, self-organizing and unpredictable; measuring the health of ecosystems is difficult due to inherent complexity and chaotic tendencies (Kay, 2000).

Several indicators of ecological integrity have been proposed, and applied to national parks (Woodley, 1997), freshwater aquatic systems (Schindler, 1997), or boreal forest systems (Boutin, 2002). Ecological integrity measures include the Index of Mean Function Integrity (Loucks et al., 1999), the Index of Biological Integrity (Karr & Chu, 1999), and Original Integrity (Miller, 2000). The last index was applied in assessing the relationship between integrity and life expectancy (Sieswerda, Soskolne, Newman, Schopflocher, & Smoyer, 2001). It was found that GDP confounds the relationship between life expectancy and ecological integrity, and analyses showed that the effect of declines in ecological integrity may be reduced through further exploitation of natural capital. We present an analysis of the relationship between population health and sustainability for 152 countries for which data are available.

METHODS

We used two composite indices to assess the sustainability of population health. The first, developed by the World Wildlife Fund for Nature

(WWF), is called the Living Planet Index (LPI). The LPI is an average of three indices that monitor the fluctuation in populations of several hundred species in forest, freshwater, and marine ecosystems over time (WWF, 2002). LPI data for a 30-year period were taken from Table 1 of WWF's Living Planet Report. The second index is the ecological footprint (EF), a measure of human impact designed to assess the area of biologically productive land and water required to produce the resources consumed in human activity and to assimilate wastes (Wackernagel et al., 2002). The calculation of the EF is too detailed to repeat here, but it is based on six assumptions: (1) it is possible to keep track of most of the resources humanity consumes and the wastes humanity generates; (2) most resource and waste flows can be measured in terms of the biologically productive area necessary to maintain these flows; (3) by weighting each area in proportion to its usable biomass productivity, the different areas can be expressed in standardized hectares; (4) because these areas stand for mutually exclusive uses (they are independent), and each standardized hectare represents the same amount of usable biomass production for any given year, they can be added to a total representing aggregate human demand; (5) ecological services can also be expressed in global hectares of biologically productive space; and, (6) area demand can exceed supply leading to ecological overshoot (Catton, 1980; Wackernagel, Lewan, & Borgström Hansson, 1999). Ecological footprint data for 1961 through 1999 for 152 countries were obtained from the Redefining Progress (Wackernagel et al., 2000).

Indicators of population health were abstracted from electronic databases freely available on the Internet from the World Bank's World Development Indicators report (1999), the United Nations Development Program's Human Development Report (1997), and the World Resources Institute's Earth Trends report (2001). Population health has traditionally been represented using indicators such as life expectancy, health-adjusted

TABLE 1

Summary statistics for health-adjusted life expectancy (HALE), gross domestic product (GDP) and ecological footprint (EF) for 1996

	Minimum	Maximum	Mean (SD)
HALE (years)	29.5	73.8	54.5 (12.0)
GDP (US$)	501.0	38714.0	8135.6 (9044.4)
EF (hectares)	0.4	16.0	3.1 (2.8)

life expectancy, infant mortality, or low infant birthweight. More recent measures such as social cohesion, well-being, and measures of quality of life, are not available for less industrialized states. Per capita gross domestic product and population were selected to crudely represent progress and prosperity (Table 1).

We analyzed the relationship between population health and sustainability in two phases. In the first, we assessed the relationship among all sustainability indices, averaged across all countries, over a 30-year period from 1961 to 1999. The analysis is intended to show the trends in relevant indices as they relate to the carrying capacity of the planet. Recent research suggests that human ecological demand exceeded the Earth's carrying capacity (the available biocapacity) in 1978 and would require more than 1.2 planets to maintain current progress (Wackernagel et al., 2002). To allow comparison of the indices in relation to each other, we assigned a value of 1.0 to each index for the 1978 year and adjusted values for all indices before and after 1978. For example, if the global GDP in 1978 was $12,000 and $10,400 in 1977, then the 1978 value would become 1.0 and the value for 1977 would become $10,400/$12,000 or 0.87. Thus for each year since 1961 it is possible to compare humanity's progress—in terms of the amount of space required to maintain consumption and improve population health—and impacts on materials and other species that constitute biocapacity or natural capital.

In the second phase we investigated the relationship between the ecological footprint measure of sustainability and measures of health and wealth. The ecological footprint and per capita (pc) GDP were chosen for analysis since data were available for 152 countries. Log_{10} transformation of both variables was deemed most appropriate from inspection of scatterplot results. Scatterplots were used to examine the cross-sectional relationship of the ecological footprint with GDP and measures of population health. Correlation coefficients indicated the strength and direction of the relationships. In addition, we examined the relationship between indicators of population health and predictors of population health using bivariate regression analysis. Models were fit using the *glm* function in S-Plus version 6 (Insightful Corporation, 2001) (Table 2).

RESULTS

Figure 2 shows the 30-year trend for six measures related to population health, prosperity, and sustainability for 152 countries comprising a population of approximately 5.8 billion people. The horizontal line across the

TABLE 2

Regression coefficients of two bivariate models predicting health-adjusted life expectancy (*n* = 148)

Variable	Model 1	Model 2
Log_{10} Ecological footprint (hectares)	11.704	
Log_{10} GDP per capita (US$)		20.165
Constant	45.420	−18.392
R^2	0.664	0.734

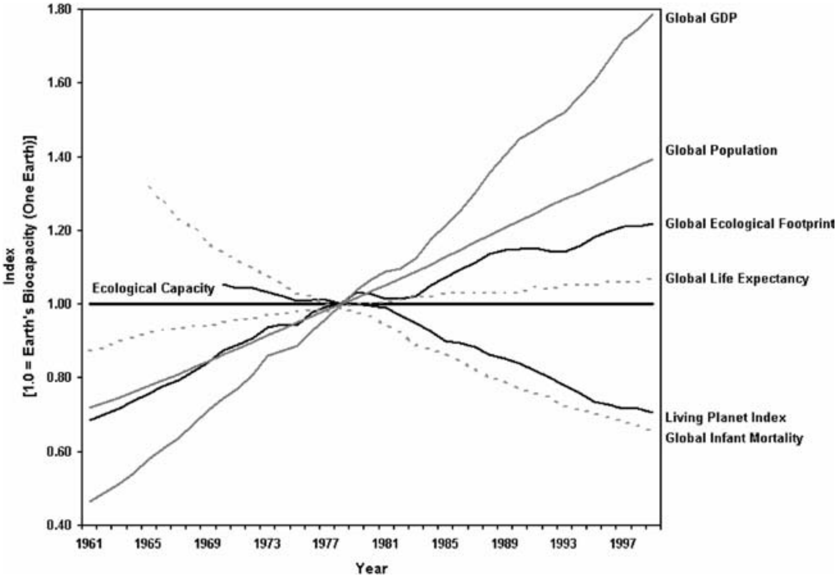

FIGURE 2. Trends of indices related to population health, wealth, and sustainability for 152 countries and a population of 5.8 billion. (*Sources:* World Bank, World Development Indicators, 2001; UNDP, World Population Prospects: The 2000 Revision; World Wildlife Fund, Living Planet Report, 2002).

figure (value = 1.0) indicates Earth's total ecological capacity. Based on analysis of global consumption, the planetary demand on natural capital from all human beings rose to equal the supply of natural capital in about 1978, i.e., the limit for our species living sustainably. This does not mean that resources were shared equitably, however. For each year since 1961 it is possible to compare humanity's demands—in terms of the amount of space required to maintain consumption—and impacts on other species that constitute supplies of biodiversity. The living planet index has decreased by approximately 37% since 1970 and the global human ecological footprint has exceeded the carrying capacity of the planet since 1978. These figures are staggering when one considers that we share the planet with between 7 and 14 million other species (Wackernagel et al., 2002). Values for the living planet index and average human life expectancy are highly-negatively correlated ($r = -0.94$) indicating a loss in species diversity may be related to increases in human life expectancy. Global per capita GDP was almost four times greater in 1999 than in 1961 and global population has doubled. Global average life expectancy has changed very little over the 40-year period, although progress has certainly been made in the reduction of infant mortality.

Theoretically, if we assume that 1978 represents the year in which humanity had reached a globally maximal carrying capacity, it is possible to determine the values for other measures that could be considered sustainable. For example, in 1978 the global GDP (US$) was approximately $17.8 trillion ($4144 per person), global population was 4.3 billion, life expectancy was 62 years, and infant mortality rates were 90 deaths per 1000 births. So far we have relied on technology to maintain the productivity of land to sustain our present population of more than 6 billion and, because we are living 5 years longer, will have to become yet more efficient to offset an ecological overshoot. There are alternatives, however. We could consider the impact of reducing our consumption. Or we could maintain our current course and face the inevitable consequence of ecological collapse. Indices like the ecological footprint are useful in this context since they can be used to develop scenarios of future human development.

How sustainable are continuing improvements in wealth and population health indicators? The relationship between per capita GDP and ecological footprint for 1996 is shown in Figure 3; the correlation is 0.83, although the association becomes more dispersed as per capita wealth increases. More crucially, among many countries with higher per capita GDP, the land area required to support standard of living far exceeds available biocapacity. Thus, incomes above a certain level are generally associated with unsustainable consumption patterns. The more industrialized and rich countries are appropriating more biologically productive land than is available for everyone to share and there is thus an imposed ecological limit for less industrialized and poorer nations to increase their own appropriation of resources.

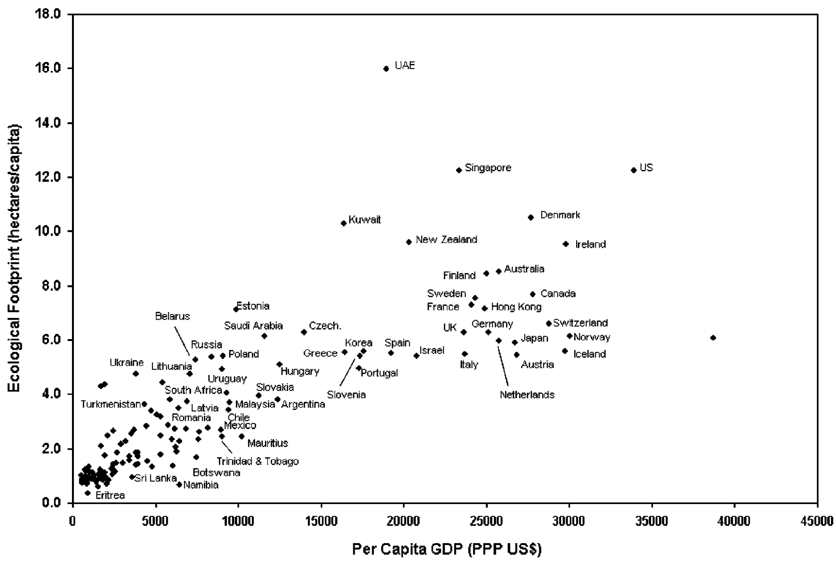

FIGURE 3. The relationship between GDP per capita and ecological footprint for 152 countries. (*Sources:* Wackernagel et al., 2000; World Bank, World Development Indicators, 2001).

The shape of the relationship between ecological footprint and two measures of population health in Figure 4 is similar to the associations between wealth and health shown in Figure 1. The correlation between ecological footprint and health-adjusted life expectancy was 0.82, and with infant mortality was −0.75.

The relationship between the appropriation of biologically productive land and improvements in both IMR and HALE are strong until about 3.1 hectares/capita beyond which there is little improvement in health. When this result is taken alongside the fact that there are only 1.91 hectares of bioproductive land per capita worldwide, the consumption of biocapacity to sustain or improve population health can no longer be seen as benign since it comes, ultimately, at the expense of those countries with less available biocapacity, or those countries unable to afford the appropriation of resources from another country.

Table 1 shows the summary statistics for the variables used in the regression analysis. To assess the relation between sustainability and life expectancy we regressed ecological footprint on health-adjusted life expectancy (HALE) as shown in Model 1 of Table 2.

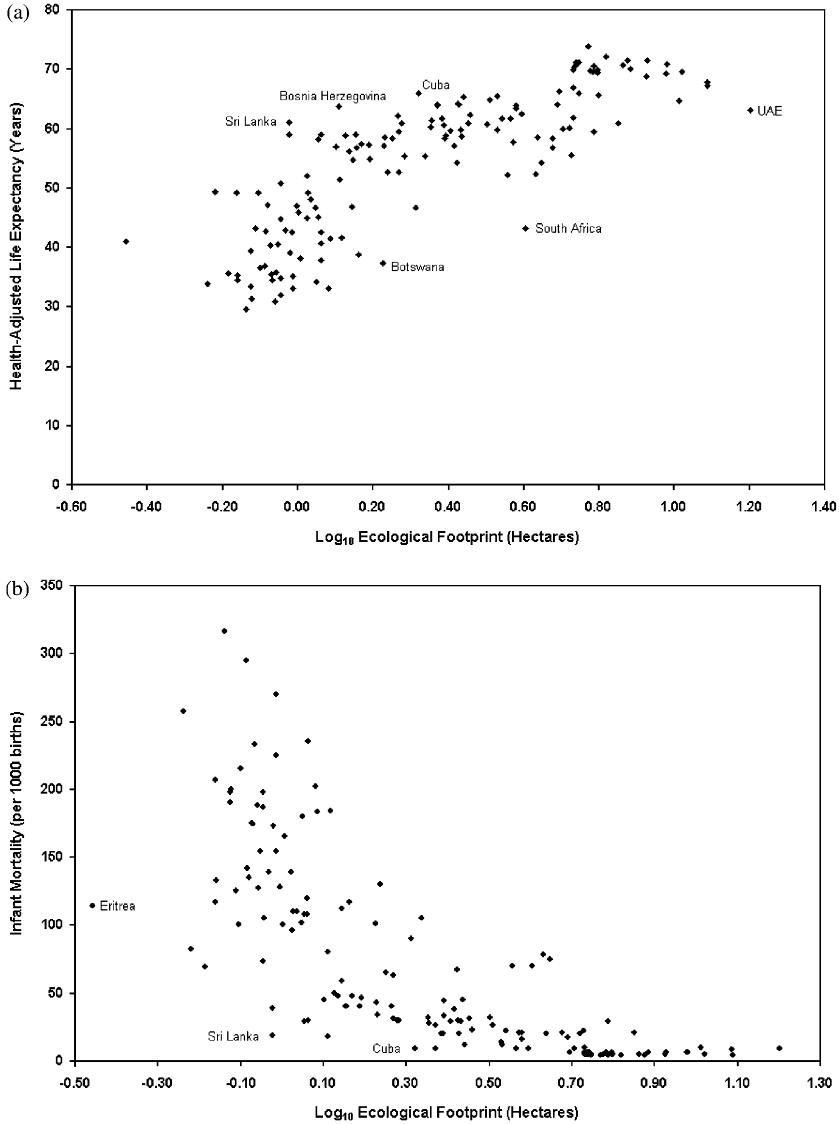

FIGURE 4. The association between $\log_{10}$ ecological footprint and (a) health-adjusted life expectancy and (b) infant mortality for 152 countries and a population of 5.8 billion. (*Sources:* Wackernagel et al., 2000; UNDP, Human Development Indicators, 2002).

A unit $\log_{10}$ increase in ecological footprint is associated with a gain of 12 years of health-adjusted life expectancy (adj. R^2 = 0.66). Model 2 shows the stronger relation between GDP per capita and HALE, with GDP accounting for 73% of the variance in life expectancy. We chose to limit our results to bivariate models since the purpose of our analysis was to estimate the contributions of the individual predictors to the production of life expectancy. Furthermore, the high level of correlation between ecological footprint and GDP would complicate the derivation of reliable regression estimates if both terms were included into a single model.

DISCUSSION

The attractiveness of population health is that it shifted the discourse away from individual health toward examining health as an ecological characteristic of populations; it helped us to identify, promote, and intervene with forces that operate beyond the level of the individual. Ultimately, population health concepts help to complete the causal picture of the full range of factors that influence health. However, as has been shown here, the discourse of population health must also recognize and integrate an assessment of its sustainability. Our analysis reveals that current trends in improvements to prosperity and population health are associated with the unsustainable appropriation of resources and declines in global biodiversity. It has also demonstrated strong associations among the ecological footprint, wealth, and health-adjusted life expectancy. For example, each unit increase in $\log_{10}$ per capita GDP corresponds to another 20.2 years of health-adjusted life expectancy. However, the logarithmic relation shows this to be a relationship of diminishing returns, while the growing GDP consumes ever more ecological resources. The ecological footprint (as well as declines in planetary biodiversity) is also strongly related to improvements in life expectancy and with declines in infant mortality. So we have a dilemma: growing wealth supports improved health (on average), but implies exponentially greater consumption of resources. It is uncertain as to how much of the relation between wealth and health is predicated on the unsustainable appropriation of Earth's biological capacity.

Our analysis addresses important questions concerning the articulation of population health determinants, including the following issues. First, many countries with the best population health are the most dependent on external resources and the least sustainable. The shape of the curve indicates a slight decline in health status associated with extension along the flat of the curve (see Figure 4a). Countries such as the United States, Singapore, and the United Arab Emirates, for example, have lower life expectancies than countries like Japan or Iceland which require only half the amount of per capita bioproductive land to maintain their standard of living (Table 3). Perhaps this reflects the development of diseases of over-consumption—diabetes, obesity, and cardiovascular disease.

Second, our results have significant implications for the arguments that support wealth as a determinant of a population's health. The log-linear relationship between wealth and population health, as well as the steep slope of the regression lines, underscore both the inequalities and the inefficiency of higher levels of wealth in producing commensurate gains in health. The profit motive of modern economic philosophy militates against sustainability. From an ecological health perspective, Hertzman (1996) raised the question of whether wealthy societies could preserve their health status if they were to consume less of the world's resources. Labonte (1995) used Japan as an example of how wealth creates health, arguing that Japan's economic growth was attained at great environmental expense in the rest of Asia. The concentration of production in Japan, built on imported raw materials, yields marginal gains in health that are dependent on a resource-intensive economy. Blomley (1994) showed the importance of acknowledging this role of ''distant strangers'' in supplying the resources required to shape the health status of populations.

Third, the analyses lead to the question of whether it is possible to maintain population health improvements, and reduce health inequalities, if we choose to reduce our ecological footprints to live within Earth's bio-

TABLE 3

Selected country-level summaries of health-adjusted life expectancy (HALE), gross domestic product (GDP) and ecological footprint (EF) for 1996

Country	HALE (years)	GDP ($US)	EF (ha)
Costa Rica	65	8 193	2.1
Cuba	66	1 700	2.1
Chile	66	9 417	3.4
Iceland	71	29 000	5.6
Japan	74	26 707	5.9
Canada	70	27 834	7.7
United States of America	67	33 939	12.2
Singapore	68	23 356	12.2
United Arab Emirates	63	18 941	15.9

capacity. Current population health measures reveal nothing about the prospects of sustaining those measures in the future. It is unwise to conclude from Figure 1 that health is improving because we have more wealth, and that long-term health is improving because we are living longer, if at the same time we have exceeded the carrying capacity of the planet. It is more likely that many of our health gains have been realized by trading off the potential for further gains in the future. Moreover, as research in population dynamics has also shown, rapid population growth coupled with technological tactics that enable us to exceed Earth's carrying capacity will ultimately lead to negative health consequences (King, 1990). It is unknown as to how long this will take or whether we are able prevent such an event.

Inequalities in the ecological footprint hold adverse implications for population health. Just as Wilkinson (1992) stressed the relevance of income inequality in a society for health, so Wackernagel and Rees (1995) suggested that the size of the ecological footprint for families varies greatly with income. Larger families with higher incomes could have a footprint two to three times greater than a family considered to be deprived. Available data suggest that reducing the footprints of the wealthy would not necessarily drive the health status of the population down. Considering the monumental inequalities between those who have much and those who have nothing in this world, a reduction of the ecological footprint for those in more wealthy countries may be better for us all in the long term.

Fourth, a valuable population health research agenda might explore how less wealthy but sustainable societies remain healthy. If we examine the sustainability of population health by measuring the ratio of life years produced to the per capita GDP, or ecological footprint, some of the world's healthiest countries would be Costa Rica, Chile and Cuba. The most recent figures for 2002 indicate that average life expectancy in Cuba was 76 years with a per capita GDP of approximately $1700, compared to an average life expectancy of 76.9 years and a mean per capita GDP of $22,630 for 27 of the richest countries in the OECD. Per capita ecological footprint is only 2.1 ha, close to the amount available for the global population if equally distributed. Largely through the application of established public health measures, Cuba has low infant mortality and scores high on the UNDP's Human Development Index, but it is not the only low-consuming, sustainable society with good population health outcomes.

Societies characterized by high levels of government spending on education and welfare, and a high level of literacy and independence for women tend to perform well in assessments of population health status (Caldwell, 2001). Similarly, in a study of child mortality and public spending on health care, Filmer and Pritchett (1997) found that almost 95% of all cross-national variations in infant mortality can be explained by wealth and income distribution, the extent of female education, and differences in religious and linguistic preferences, and are not necessarily attributable to health care sector policy. Studies of the determinants of population health also attribute the power of social and economic determinants, rather than health care systems *per se*, to improvements in health status (Evans & Stoddart, 1990). While these studies help to explain why some societies are more healthy than others, they do not examine whether the wealth required to support the health of human populations was generated in a sustainable manner, that is, without disruption to ecological integrity. This sort of upstream thinking is critical to understanding whether population health can be maintained, or even improved, while respecting the natural limitations of Earth's biocapacity. Currently there is a paucity of research examining these issues.

FINAL COMMENTS

Deterioration of earth's global life-support systems is a paramount health issue. McMichael, Smith, and Corvalan (2000) described the next challenge for population health as the transition to sustainability. The transition involves the protection and maintenance of the planetary systems that support life, an accountability to future generations, and a revised economic regime that is restrained to the carrying capacity of ecological systems. The question is—how can we redesign population health as an evolving paradigm to join this transition? The following ideas may help to answer this question.

1. Research on ecosystems has shown them to be self-organizing dissipative systems that revolve around attractors and exhibit chaotic tendencies (Kay, 2000). It is normal for ecosystem theories to view nature as complex with people as an integral element. Population health research should focus more on the conceptual spaces and interactions between the determinants of health rather than on the determinants themselves. If the processes occurring among determinants are inherently complex then the determinants themselves are no longer static and are subject to alteration. For example, in a WHO sponsored pilot workshop on the relationship between human health and ecological integrity Soskolne and Bertollini (1999) recommend a more extensive examination of the linkages between human health and ecological disintegrity.

2. Population health research should adopt truly transdisciplinary approaches so that the boundaries of health problems can be explored (Albrecht, Higginbotham, & Freeman, 2001). It is likely that while exploring the boundaries of their own disciplines, researchers will forge a common conceptual framework with researchers from other disciplines. The omission of sustainability from many current conceptions of population health shows how important contributions can be overlooked.
3. David Orr (1991) noted that much of the environmental destruction and mismanagement of damaging human activities is not the work of ignorant people, but of highly (but narrowly) trained people. Researchers in population health should strive to become more ecologically literate so that the sustainability implications of population health objectives can be understood. There is also the necessity here for personal change to a less consumptive lifestyle.
4. Population health research should develop indicators and measurements that record sustainability. Much of the population health literature still uses GDP or GNP and other indices to represent wealth and income in societies. There is an expanding literature depicting the pitfalls of using such indicators since they do not incorporate the costs to society from ecological damage and unsustainable practices. Research into other measures such as the Genuine Progress Indicator reveals more realistic estimates economic and social progress in societies (Cobb, Glickman, & Cheslog, 2001). Equivalent innovations are required in population health measurements.
5. Several disciplines related to population health have been quick to embrace ecosystems as a valid conceptual construct. For example, the discipline of ecosystem health has been introduced as a paradigm for dealing with the interconnectedness of many global problems and complexities (Rapport, 1995). Population health models and approaches should refer to developments in this parallel emerging field for insights into the relations between human health and the health of ecosystems.

Certainly a better understanding of the sustainability of population health will not completely alter its goals of improving human well-being. However, thinking about the sustainability of population health forces researchers to question the purpose of their research and may help to better situate population health in the larger context of natural processes. When properly integrated, the concepts associated with striving for sustainability will enhance our understanding of human health. The relationships explored in this paper sound a call for further research into the sustainability of population health. Countries like Cuba and Costa Rica provide settings for exploring alternative approaches to understanding the influences of population health, and to suggest how, in industrialized countries, unsustainable consumption patterns can be altered.

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