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Review

Climate change, human health, and epidemiological transition

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ABSTRACT

The health of populations depends on the availability of clean air, water, food, and sanitation, exposure to pathogens, toxins and environmental hazards, and numerous genetic, behavioral and social factors. For many thousands of years, human life expectancy was low, and population growth was slow. The development of technology-based civilizations facilitated what Abdel Omran called “epidemiological transition,” with increasing life expectancy and rapid population growth. To a large extent, the spectacular growth of human populations during the past two centuries was made possible by the energy extracted from fossil fuels. We have now learned, however, that greenhouse gases from fossil fuel combustion are warming the planet's surface, causing changes in oceanic and atmospheric systems, and disrupting weather and hydrological patterns. Climate change poses unprecedented threats to human health by impacts on food and water security, heat waves and droughts, violent storms, infectious disease, and rising sea levels. Whether or not humanity can reduce greenhouse gas emissions quickly enough to slow climate change to a rate that will allow societies to successfully adapt is not yet known. This essay reviews the current state of relevant knowledge, and points in a few directions that those interested in human health may wish to consider.

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In his seminal 1971 paper “The epidemiological transition,” Abdel Omran put forth a conceptual framework linking the many facets of epidemiology with the forces behind population dynamics, emphasizing the changing nature of structural influence (Omran, 1971). At that point in human history, clear and convincing evidence had emerged documenting a “transition in which degenerative and man-made diseases displace pandemics of infection as the primary causes of morbidity and mortality.” Around the same time, scientists were beginning to report that human emissions of greenhouse gases were causing global warming and climate change (Benton, 1970; Gast, 1971; Manabe and Wetherald, 1975).

Omran divided human history into three major epidemiological epochs. The first, or “Age of Pestilence and Famine,” lasted for thousands of years and was characterized by cyclic patterns of localized population growth ended by major die-offs, often precipitated by war, civilization collapse, and/or epidemic infection. In the second “Age of Receding Pandemics” Omran wrote that “mortality declines progressively; and the rate of decline accelerates as epidemic peaks become less frequent or disappear.” In Omran's third epoch, the “Age of Degenerative and Man-Made Diseases,” “mortality continues to decline and eventually approaches stability at a relatively low level. The average life expectancy at birth rises gradually until it exceeds 50 years. It is during this stage that fertility becomes the crucial factor in population growth.”

For more than a century, knowledge regarding “degenerative and man-made diseases” has increased at a dizzying pace. The era of using science to identify and respond to human-engendered disease arguably began when John Snow in 1854 traced the source of a London cholera epidemic and then removed the Broad Street pump handle to limit further contagion (Koch and Denike, 2009; Paneth, 2004; Tulchinsky, 2010). Not long afterwards, work by Louis Pasteur (Bordenave, 2003) and others led to a remarkably broad and detailed understanding of infectious disease, much of which was caused or exacerbated by population growth, urbanization, and crowding. These discoveries provided rationale for large scale potable water, sanitation and public health

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systems, which in turn facilitated even more rapid population growth in the world's emerging urban centers (Szreter, 2003).

More recently, the cardiovascular disease epidemic has been investigated and addressed at multiple levels, with several proven strategies to normalize blood pressure, prevent clots, and reduce cholesterol. For several cancers, useful screening and/or effective treatments are now available. Environmental, occupational and behavioral strategies have been even more effective. Science demonstrating tobacco's ill effects was followed by widespread and effective smoking cessation campaigns. Seat belts, safer automobiles and better roadways have greatly reduced motor vehicle casualties. Water and air pollution have improved in many locales, with measurable improvements in cardiorespiratory morbidity and mortality. Mostly missing from the medicine and public health discourse, however, has been the realization that massive-scale human activity is radically altering the atmosphere and surface of the planet, and that the basic functionality of our life-sustaining ecosystem can no longer be taken for granted.

It took several million years for anthropoid apes to evolve to anatomically modern human form, and then another 400 centuries before our *Homo sapiens sapiens* ancestors began to show their prowess. Following the advent of agriculture around 10,000 years ago, populations began to increase substantively, spreading out across the globe, forming cities, kingdoms, and civilizations. By 1800, there were approximately a billion (1,000,000,000) people on the planet. This doubled to around 2 billion by 1922, 4 billion by 1974, and 7 billion today. New technologies and systems of production led to rapid and widespread developments in agriculture, transportation and sanitation, with ever-increasing numbers of people living longer, more productive, and more consumptive lives.

The past two centuries of explosive population growth were facilitated in large part by the burning of fossil fuels. Mechanization of agriculture, combined with increasing agrochemical inputs, not only fertilizers, but also pesticides, allowed huge increases in crop productivity, which in turn fueled population growth. Exploitation of coal, oil, and natural gas yielded vast and rapid systems of transport, electrical power, and a globalized economy of relatively inexpensive and widely available products, services, and information exchange. This modern era of explosive growth, however, cannot continue unabated, given the finite nature of the resources and the ecological threats that unrestrained consumption poses. Having survived (so far) the specter of nuclear war, humanity is now facing the fundamental contradiction of continued growth trajectories in the face of resource and ecosystem limitations. If we successfully respond to these challenges and transition to a sustainable future, humanity may enter a new age, characterized by much more prudent use of energy, among other things. These ideas are not entirely new. In 1798, Reverend Thomas Robert Malthus noted that finite resources, such as arable land, would eventually be overcome by sustained population growth: “The power of population is indefinitely greater than the power in the earth to produce subsistence for man (Malthus, 1798).”

Similar ideas have been put forth many times since, most notably in 1968 by Paul and Ann Ehrlich in *The Population Bomb* (Ehrlich, 1968) and then in 1972 in *The Limits to Growth* (Meadows et al., 1972) by Donella Meadows and colleagues from The Club of Rome, who showed with then state-of-art computer modeling that finite resources are incompatible with unlimited economic and population growth. Similar notions were initially explored in the ecological literature by writers such as Pianka (1970) and MacArthur and Wilson (1967) who showed that reproduction rates and longevity dynamics combined with environmental constraints, such as availability of food and water, lead to “boom and bust” cycles, and, occasionally, to species extinction.

What is relatively new to this discourse, however, is the realization that human-emitted greenhouse gases are warming the planet, melting the ice caps, raising the oceans, and increasing the frequency of droughts, floods and extreme weather events. There is no longer any reasonable doubt that global warming is occurring, and that this is due primarily to human activities (IPCC Working Group 1, 2013; IPCC Working Group 2, 2014; National Academy of Sciences, 2014; National Climate Assessment and Development Advisory Committee, 2014). There is also very little doubt that ensuing changes in climatic patterns will lead to myriad adverse outcomes, including heat waves, droughts, and increased frequency and violence of major weather events (Honda et al., 2014; Kravchenko et al., 2013; Lane et al., 2013; Stanke et al., 2013). These will in turn accelerate the already monumental and tragic loss of biodiversity, (Cardinale et al., 2012; Hooper et al., 2012; Mayhew et al., 2008; Pimm et al., 2014; World Resources Institute, 2005) and will promote the spread of infectious diseases such as malaria and gastrointestinal infections (De Luca and Giraldi, 2011; Murray et al., 2013; Patz and Reisen, 2001; Ramasamy and Surendran, 2011). The billion or so people living on low-lying islands and coastlines will need to immigrate, adapt, or perish (McMichael et al., 2012a). This will place pressure not only on those most directly threatened, but on political and economic systems in neighboring countries, and indeed, on all societies. Health outcomes, psychosocial stresses and behavioral responses cannot be predicted with confidence, but the broad outlines are extremely concerning (Patz et al., 2014).

Since “The epidemiological transition” was first published in 1971, the scientific understanding of anthropogenic global warming has matured. While some details are still emerging, the broad outlines are incontrovertible. The burning of fossil fuels has released hundreds of gigatons of greenhouse gases, most notably carbon dioxide (CO_2), which has increased in atmospheric concentration from pre-industrial levels of 280 parts per million (ppm) to more than 400 ppm today (IPCC Working Group 1, 2014). This has already contributed to a mean surface temperature increase of 0.9 °C, and an average ocean surface rise of more than 20 cm (Intergovernmental Panel on Climate Change, 2007). Current projections suggest that average global temperatures will rise to 2 to 6 °C above the levels in which humanity evolved (IPCC Working Group 1, 2014). Even the most conservative projections conclude that this will constitute the most rapid change of atmospheric composition and global temperature ever occurring in our planet's 4.5 billion year history (National Research Council, 2013a). It will also accelerate what is already by far the worst wave of plant and animal extinctions our planet has experienced, with approximately 3 species disappearing each hour and a third of all vertebrates disappearing in less than 50 years, an extinction rate of approximately 1000 times evolutionary background averages (Cardinale et al., 2012; Hooper et al., 2012; Mayhew et al., 2008; Pimm et al., 2014; World Resources Institute, 2005).

Following the advice of numerous scientific bodies, the 2009 Copenhagen Accord called for policies that would limit average planetary warming to no more than 2.0 °C (Ramanathan and Xu, 2010). Current best estimates conclude that no more than an additional 400 to 800 gigatons of CO_2 can be added to the atmosphere if we are to have a reasonable chance of staying within this limit (IPCC Working Group 1, 2014; Meinshausen et al., 2009). Burning all proven coal, oil and gas reserves, however, would produce around 2800 gigatons, likely leading to temperature rises of 3 to 6 °C (Meinshausen et al., 2009). Warming of this magnitude could trigger positive feedback loops pushing atmospheric and oceanic systems past a series of crucial tipping points (Hansen et al., 2013; National Research Council, 2013a). As the ice cover melts, less of the sun's energy is reflected, increasing heating effects. Melting of the northern tundra would release vast quantities of methane and other greenhouse gases, further accelerating the process. Conservative models project that water from melting of the Greenland and Antartic ice sheets will combine with thermal expansion to yield sea level rises of 200-600 cm by the year 2100 (IPCC Working Group 1, 2014). Adding in tipping points and positive feedback loops, we may be looking at ocean surface rises of 10 m or more by the middle of next century (Hansen et al., 2013; Joughin et al., 2014; Rahmstorf, 2010; Rignot et al., 2014). Thirteen of the world's 20 largest cities are located on a coastline. More than 2 billion people live within 60 miles