Climate Change and Infectious Disease: Stormy Weather Ahead?

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Extreme weather events are becoming more intense, and are likely to become more frequent as the world climate changes.[1,2] For epidemiologists, one important aspect of these trends is their impact on infectious disease.

In this issue of EPIDEMIOLOGY, Woodruff *et al.*[3] demonstrate a strong association between heavy rainfall and outbreaks of Ross River virus disease. Ross River virus is mosquito borne, and, although the disease is little known outside of Australia, is found in nearly all parts of the continent. Infection can produce disabling polyarthritis, and there is no specific treatment. In southeast Australia, Ross River virus disease poses a threat not just to local populations, but also to tourism—Australia's largest industry.

The work of Woodruff *et al.*[3] adds to a growing body of studies[4] that explore the impact of weather on infectious disease. Beginning in the mid-1970s, there has been a worldwide emergence, resurgence, and redistribution of infectious diseases.[5] Although the spread of infectious diseases is multicausal,[6] global climate change may be a major contributor. Weather and climate can influence host defenses, vectors, pathogens, and habitat. Studying climate effects requires integration of information from many sources. For example, by mapping multiple datasets into geographic information systems (GIS), researchers can detect emerging patterns, and these spatial and temporal associations can lead to new hypotheses regarding causality.

The findings of Woodruff *et al.*[3] are plausible. Although Ross River virus disease can spread even without excessive rain, extreme rainfall increases the likelihood of large outbreaks (via the mosquito *Culex australicus*). As floodwaters abate, oxbow lakes are pinched off at river bends, creating "billabongs"—ideal sites for breeding mosquitoes. With alert public health monitoring, preventive measures can be taken to avoid spread of the disease.

But a larger question is, can we predict the conditions that lead to the spread of the disease? Our capacity for long-term weather forecasting has greatly improved, with monitoring of Pacific Sea surface temperatures and the state of the El Niño/Southern Oscillation. Such forecasts have helped predict weather patterns that may lead to infectious disease outbreaks.[7–9] There are longer trends that must also be considered in making weather projections—which brings us to the issue of climate change.

Climate Change

> *"As important as. . .global warming may be to human health, the effects of the extreme. . .weather that accompany it may be even more profound."*

In the study of global climate change, the field is an N of 1, an experiment that cannot be repeated.[10] For the past 420,000 years, atmospheric CO_2 levels (which parallel average global temperatures) have remained within a range of 180 to 280 parts per million.[11] CO_2 is now close to 370 parts per million and rising.[2] Taken as a whole, the Holocene Age—the past 10,000 years—has been one of the most stable periods in climate records.[12] Even so, warming this century has been rapid, and it is not occurring uniformly. Although the overall rate of maximum temperature increase since 1950 is approximately 1°C per century, minimum (nighttime and winter) temperatures have increased at twice that rate (~2°C per century),[13] and winter temperatures are rising even faster near the poles.[2] In global change research,

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models are used to project what might be expected with warming, and data are examined for consistency with the projections. The accumulating number of such "fingerprint" studies forms the basis for the conclusion that human-induced climate change has indeed begun.

Global warming has implications for the spread of infectious disease. Small arthropods are highly temperature sensitive,[14] and temperature constrains the range of vector-borne diseases like Ross River virus disease.[15–17] Ticks have been moving northward in Sweden as winters warm.[18] Mosquitoes are appearing in mountainous regions where plant communities and freezing levels have shifted upward and glaciers are rapidly retreating.[19] Changes in mountain ecosystems are consistent with projections,[20] and the biological and physical observations are consistent with one another.

In addition, extreme weather events can be associated with "clusters" of vector-, rodent-, and water-borne diseases.[21] Flash floods leave behind mosquito breeding grounds, drive rodents from burrows, and seed the waterways with toxic chemicals, microorganisms (such as *E. Coli*, Cryptosporidium, and *Vibrio cholerae*), and nutrients that can trigger red tides. Sequential extremes can be particularly destabilizing. Droughts reduce predators, whereas heavy rains boost food for their opportunistic prey.

Other emerging climate-related health concerns that require further investigation include: the role of increased variability in heat and cold mortality;[22] synergies with air pollution, including CO_2 fertilization, ragweed pollen, and asthma;[23] travel hazards associated with unstable winter weather;[24] and genetic shifts in arthropods induced by warming.[25]

Climate Destabilization

As important as the overall tendency toward global warming may be to human health, the effects of the extreme and anomalous weather that accompany it may be even more profound.[12] The rate of warming has recently increased, and anomalies and wide swings away from norms have become more frequent.[2] This increased variance raises the possibility that natural corrective mechanisms are being overwhelmed. Increased variability may also be characteristic of transitions in climate. Ice core records from near the end of the last ice age (about 10,000 years ago) indicate that increased variability was associated with a rapid change in state.[12]

Further evidence for instability comes from an increase in temperature gradients in the world ocean. Whereas the ocean has warmed overall, a large region of the North Atlantic has cooled in the past several decades, perhaps from melting and thinning of Arctic ice[26–28] and from increased rain at high latitudes.[29] The North Atlantic is where deep-water formation drives thermohaline circulation, the "ocean conveyor belt" that is regarded as key to climate stabilization.[30]

Warming is accelerating the hydrological (water) cycle. As heat builds up in the deep ocean—down to 2 miles[31]—more water evaporates and sea ice melts.[2] Over the past century, droughts have lasted longer and heavy rainfall events (defined as more than 5 cm, or 2 inches, per day) have become more frequent.[32] Enhanced evapotranspiration dries out soils in some regions, whereas the warmer atmosphere holds more water vapor, fueling more intense, tropical-like downpours elsewhere.[33] Prolonged droughts and intense precipitation have been especially punishing for developing nations.

The Forecast

The resurgence of infectious diseases in the late 20th century has brought infectious disease back into the mainstream of epidemiology. Investigating weather variables associated with Ross River virus disease and other infectious diseases can help anticipate future epidemics, and can focus our efforts at surveillance and interventions. Early warning systems can have direct health and economic benefits.

"Volatility of infectious diseases may be one of the earliest biological expressions of climate instability."

But the epidemiologic monitoring of infectious diseases may have even more fundamental utility. We have already underestimated the rate at which climate would change. So, also, we have underestimated the sensitivity of biological systems to this change.[34,35] Volatility of infectious diseases may be one of the earliest biological expressions of climate instability. Close monitoring of the spread of infectious disease can thus contribute to the evidence that will be needed to motivate strong precautionary policies.[36] Pollutants from fossil fuel combustion are the primary drivers of climate change. The environmental, health,[37] and security reasons for weaning ourselves from these buried carbon stores are mounting. Although the costs of changing our patterns of energy production and consumption would be high in the short run, we may also be underestimating the economic and social benefits from developing clean energy technologies and greater energy efficiency. The alternative of continuing our present course may cost more in the long run than any society would choose to pay.

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