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# Calling for an ecological approach to studying climate change and infectious diseases

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My Concepts and Synthesis paper (Lafferty 2009), which inspired this Forum, echoed the premise that early reviews about climate change exaggerated claims that infectious diseases will increase in the future (Randolph 2009). The paper sparked five well-reasoned commentaries from ecologists with considerable expertise in infectious diseases (Dobson 2009, Harvell et al. 2009, Ostfeld 2009, Pascual and Bouma 2009, Randolph 2009). These reviews illustrate several examples and case studies which correlate increases in infectious disease with existing climate variation, though alternative explanations exist for many of these patterns (Dobson 2009, Harvell et al. 2009, Ostfeld 2009, Pascual and Bouma 2009, Randolph 2009). A common message is that an ecological approach is increasingly relevant to the challenging topic of infectious disease.

Although we need to focus control efforts on areas where diseases may expand with climate change (Dobson 2009, Pascual and Bouma 2009), it would not be appropriate to then build a general theory of climate change and infectious disease around the one-tailed prediction that climate change will increase the problem of infectious diseases (Randolph 2009). A neutral starting hypothesis is that the ranges of infectious diseases will likely shift with climate change, but not necessarily expand or contract (Lafferty 2009). While public health officials might view this as callous, conservation biologists might find it overly generous. Estimates for free-living species suggest that shifts in climate suitability will tend to decrease the size of occupied ranges and, in some cases, lead to extinction (Parmesan and Yohe 2003). High-altitude and high-latitude species will see the greatest reductions in the size of their fundamental niche and species with limited dispersal ability will see a spatial decrease in their realized niche. Ectotherms (including insect vectors and the free-living stages of infectious organisms) will be more affected by climate change than endotherms. Current estimates of extinctions due to climate change are 15–37% of Earth's free-living species (Thomas et al. 2004). The sensitivity of parasites to host extinction suggests parasite extinctions might outnumber free-living extinctions (Hechinger and Lafferty 2005, Dobson et al. 2008; Lafferty and Kuris, *in press*).

While predictions of mass extinctions apply globally, it is less clear how biodiversity will respond to climate change at smaller spatial scales. This is an important distinction because health officials focus on infectious disease at the local or regional level (Pascual and Bouma 2009). For instance, given the high biodiversity of the tropics, local increases in temperature and precipitation could result in a net increase in local biodiversity, including parasites (Ostfeld 2009). Uncertainty in projections of precipitation (Easterling et al. 2000), however, makes it difficult to know whether global warming leads to rainforests with many diseases or deserts with few.

The shift in the habitat suitability for malaria illustrates the rich set of interacting factors that make it difficult to predict net outcomes in the geographic range of disease and the number of infected humans. Exposure to malaria induces temporary immunity (Dobson 2009) and, over evolutionary time scales, has led to adaptations to reduce infection or increase tolerance (e.g., sickle-cell trait; Allison 1954). If the range of climate suitability for malaria transmission shifts, newly exposed human populations will be more susceptible to infection and likely suffer greater morbidity (Dobson 2009, Pascual and Bouma 2009). This is particularly relevant for moderate-scale shifts in transmission that could occur within the present poverty-prone areas where malaria is endemic (Ostfeld 2009). Whether malaria will disappear from areas where it becomes too hot or arid may depend on how human societies respond to climate change, particularly with respect to damming and irrigation practices to compensate for drought (Pascual and Bouma 2009). In contrast, larger-scale shifts in habitat suitability into wealthier nations at higher latitudes are likely to be countered by control efforts, urbanization, and lack of suitable habitat for vectors (Randolph 2009). (Notably, such impediments to disease may not apply to the spread of wildlife diseases [Harvell et al. 2009].) If climate change

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results in fewer non-host species suitable for vector blood meals, transmission could increase because vectors would concentrate their bites on humans (Dobson 2009). Knowing where malaria may increase and where it may decrease will clearly aid public health officials prepare for the future and properly distribute resources (Ostfeld 2009, Pascual and Bouma 2009).

Ecologists have the luxury of being able to step back from human health and economic concerns to consider infectious organisms in the broader context of biodiversity and ecological interactions. Will this happen? For many ecologists, interest stops at the surface of the organism they study. This is not to say that infectious organisms are not studied, only that ecologists have largely ceded this area to the medical and veterinary community. Most ecology texts represent a traditional perspective with few examples of infectious organisms; fewer lectures in ecology courses mention the word "parasite"; still fewer ecology graduate students take a parasitology course in their career (Windsor 1998). But there is an increasing appreciation that most species on earth have a parasitic life style (Toft 1986, Windsor 1998, Dobson et al. 2008) and that parasites comprise a substantial proportion of biomass on earth (Kuris et al. 2008). Furthermore, many studies indicate infectious organisms can play important roles in the ecology and evolution of free-living species (Dobson and Hudson 1986) and some published food webs now list ubiquitous parasites among their nodes (Lafferty et al. 2008). The ecology of infectious disease is increasingly fashionable and a considerable fraction of ecology graduate students are showing general interest in infectious organisms.

This Forum is indication that ecologists can contribute substantially to the general theory of climate and infectious disease. Challenges include dealing with multiple hosts and parasite species (Dobson 2009), nonhuman hosts (Harvell et al. 2009), accounting for the effects of immunity (Dobson 2009, Harvell et al. 2009, Ostfeld 2009, Pascual and Bouma 2009), quality and details of climatic data and appropriate measures of disease response (Ostfeld 2009, Pascual and Bouma 2009, Randolph 2009), complex analyses to account for multiple, interdependent covariates (Dobson 2009, Ostfeld 2009, Pascual and Bouma 2009, Randolph 2009), host movement in response to climate change (Harvell et al. 2009), and geographic tools to account for distinctions between fundamental and realized niches (Ostfeld 2009, Randolph 2009). With a firmer ecological understanding of how infectious organisms may respond to climate change, we will be better able to deal with those cases where diseases will increase or expand.

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