

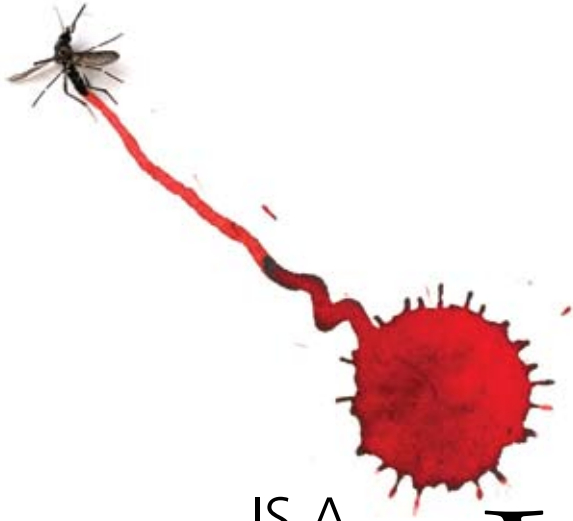
In the late 1990s, a set of alarming maps created a stir in the scientific community. Based on predictions by a team of Dutch and Australian researchers and initially published in the journal *Environmental Health Perspectives*, the maps charted how global warming could increase the risk of malaria in seemingly unlikely locales: northern countries such as Poland, the Netherlands, and Russia.

Over the next several years, versions of the maps continued to appear in journals and at scientific meetings as researchers raised the disquieting possibility that climate change could trigger an expansion of disease. An article in *Scientific American* reprinted one iteration of the maps and declared that “by the end of the 21st century, ongoing warming will have enlarged the zone of potential malaria transmission from an area containing 45 percent of the world’s population to an area containing about 60 percent.” Statements like these added to the popular perception that a warmer world will automatically be a sicker one.

But what if this isn’t true, or is only partially true? Kevin Lafferty, an ecologist at the U.S. Geological Survey, is among a handful of scientists now raising these questions and rethinking conventional wisdom. Lafferty recently published a controversial article in the journal *Ecology* suggesting that, while climate change may shift the ranges of certain diseases, it won’t necessarily increase the total amount of territory they affect. (1) And Sarah Randolph, a parasite ecologist at the University of Oxford, has reviewed recent disease outbreaks—some of which have been attributed to global warming—and concluded that human actions and other factors may have played a larger role than climate.

Lafferty’s and Randolph’s opinions have stirred intense debate. While there are credible arguments on both sides, the overriding point is that some scientists are beginning to see the ecology of disease as far too complicated to support simple declarations about the impact of global warming. It turns out that disease ecology is made up of a multitude of moving parts, ranging from precipitation patterns to animal migrations, that constantly shift and adjust in relation to each other. And when climate changes, the end result may be an increase in disease—or not.

As scientists piece together how climate impacts disease, strange patterns are emerging: mosquito outbreaks can follow drought, shorter migrations can make butterflies sick, and more birds (not fewer) can ward off West Nile virus.



IS A
Warmer World
A Sicker World?

By Roberta Kwok



Nature vs. Nurture

When tick-borne encephalitis spread throughout the Baltics, was the culprit climate change or the fall of the Soviet Union?

Sarah Randolph has spent more than 30 years studying vector-borne diseases (diseases transmitted to hosts by insects and other animals). She's also a maverick who has devoted the latest chapter in her career to digging beneath what she calls "seductive mindsets." As she wrote in a response to Lafferty's *Ecology* article, one of these mindsets is that recent disease outbreaks are caused by climate change, "adding fuel to the fire of predicted impending doom." (2)

Take tick-borne encephalitis (TBE), a nasty viral disease that can cause inflammation of the brain. Beginning in the 1980s and 1990s, a rise in temperature appeared to correspond with a TBE surge in several European countries, where thousands of people were stricken with headaches, fever, and other unpleasant symptoms. In Sweden, some scientists suggested that warming had triggered the rise in TBE cases and that future climate change would exacerbate the scourge.

Randolph decided to conduct her own investigation. In a 2007 study, her team examined county-level TBE trends in the Baltic countries of Estonia, Latvia, and Lithuania; they found patterns that couldn't be explained solely by climate. While temperatures rose in 1989 across the Baltics, TBE cases in individual counties began spiking anytime between 1990 and 1998.

To investigate further, Randolph's team studied the region's social and economic history. After the Baltics broke from Soviet rule in the early 1990s, unemployment rates—and poverty—surged. Poorer people were less likely to be vaccinated, the researchers found, and more likely to forage for food in tick-filled forests. This suggested to Randolph that, contrary to popular assumptions, the disease surge probably had far more to do with human actions than planetary changes.

The TBE case isn't unique. "In the last two decades," Randolph argues, "there's practically no examples where a vector-borne disease can be pinned on climate change."

Of course, Randolph is only one player in a contentious debate, and other scientists say they have found links between climate and diseases such as malaria, dengue, and cholera. Just because disease is influenced by a myriad of factors doesn't mean we should ignore climate, warns Richard Ostfeld of the Cary Institute of Ecosystem Studies. "To me, that's kind of like saying because we know that obesity is also a risk factor for heart disease, we don't need to worry about smoking," he says.



Dry and High

Why did mosquito populations surge after drought dried up their habitat?

As researchers piece together the disease puzzle, some of the most complicated variables revolve around the mosquito. Notorious for transmitting malaria, West Nile virus, and other pathogens, mosquitos are expected to develop faster at higher temperatures, raising concerns that global warming could spur disease outbreaks. But as researchers like Jonathan Chase unravel how mosquitos respond to key climate conditions, they're reaching surprising new conclusions.

An ecologist at Washington University in St. Louis, Chase didn't set out to discover anything about mosquitos. He wanted to know how droughts affected biodiversity, so his team built artificial wetlands by filling outdoor tanks with dirt and water. To simulate different wetland drying patterns, they left some tanks full year-round, while others were drained annually. A third type of tank was drained only once in three years, mimicking wetlands that generally retain water but go dry during a drought.

You might think periodic droughts would diminish mosquito populations by drying up habitat. But the number of mosquitos in the third group of tanks skyrocketed to more than 20 times the amount in the other tanks.

Chase thought back to figure out what might have happened. He knew that, since those tanks usually held water, they housed mosquito predators and competitors that were poorly suited to dry conditions. When the “drought” killed many of them off, mosquitos likely seized the opportunity to multiply. With their fast breeding times, Chase reasoned, mosquitos could quickly recolonize the area before their predators rebounded, resulting in the population boom.

To see whether the idea held up in nature, Chase turned to data from a survey of Pennsylvania wetlands. Sure enough, ponds that dried out only during a drought showed a spike in mosquito larvae the following year. The results confirmed what Chase had suspected—the drought had opened a “giant habitat for a small window of time,” he says, allowing mosquitos to flourish.

Chase’s team took the research a step further to see how this might affect the spread of disease. They analyzed data on human West Nile virus cases in the United States between 2002 and 2004, comparing the trends to changes in precipitation. In the western United States, the number of cases increased after dry years, as expected. But in the eastern part of the country, the pattern was the opposite: outbreaks happened after rainy years.

The variation might arise from a difference in mosquito species, says Chase. Mosquitos that spread the virus in the western United States tend to dwell in wetlands and thus would benefit if a drought wiped out fellow inhabitants. But mosquito species on the other side of the country prefer to breed in puddles and water-filled containers, so they could take advantage of higher rainfall.

Chase’s mosquito findings illustrate how much scientists still have to learn before they can accurately forecast the effects of climate change on disease. “You have these simple no-

tions that one factor will work in one way,” says Andrew Read, an infectious-disease researcher at Pennsylvania State University who was not involved in Chase’s work. “But in the context of community ecology and food chains, anything can happen.”



Photo courtesy of Sonia Altizer, University of Georgia



Canceled Flights

Do long migrations keep butterflies healthy?

It has long been feared that climate change will enable disease to run rampant through animal populations. A warming world could alter the borders of suitable habitats, leading migratory species to new territory and exposing them to diseases they haven’t encountered before. But scientists are only beginning to get their arms around the mechanisms that might allow disease to weaken some populations while others emerge unscathed.

Karen Oberhauser, an ecologist at the University of Minnesota, has been pursuing answers to questions about how climate change might



Remote Diagnosis

Satellite data can suggest when and where epidemics will strike next

In December 1997, large numbers of cattle, goats, and sheep began dying in the Garissa district of northeastern Kenya. A month later, people started dying, too. It was, at the time, the biggest recorded outbreak of Rift Valley fever in East Africa. Some 100,000 stock animals succumbed, and about 90,000 people were infected—hundreds fatally—in five countries.

In December 2007, the same thing happened. Or rather, it started to happen but was stopped in its tracks. The difference was that the second time around there was ample warning. In September, researchers at the Goddard Space Flight Center in Greenbelt, Maryland—part of NASA, the U.S. space agency—told authorities in Kenya that they had a problem. They told them again in October. And again in November. By the time the epidemic emerged, the Kenyan health ministry had dispatched teams to the area to distribute mosquito nets and urge village leaders and religious authorities to stop people from slaughtering and eating animals. Though the outbreak still killed 300 people in Kenya, Somalia, and Tanzania, it could have been a lot worse. According to Kenneth Linthicum of the

U.S. Department of Agriculture, the number of deaths would probably have been more than twice as high without the warning.

The warning itself was possible because of a model of how disease spreads that Dr. Linthicum helped design. And the data plugged into that model came from satellites.

What the researchers at Goddard had noticed at the time of the first outbreak was that in the months preceding it, surface temperatures in the equatorial part of the Indian Ocean had risen by half a degree. These higher temperatures brought heavy and sustained rains, cloud cover, and warmer air to much of the Horn of Africa. Mosquitos multiplied wildly—and lived long enough for the virus that causes the fever to develop to the point where it is easily transmissible. In September 2007, the researchers saw the same thing happening in the ocean and suspected the same consequences would follow.

Attempts to foresee epidemics such as these have traditionally relied on fieldwork on the ground. This is often slow and expensive. Crunching data from satellites is much-less costly. Satellites transmit



Photo courtesy of NASA

copious information on temperatures, precipitation, vegetation cover—and the health, moisture content, and chlorophyll production of plants.

As David Rogers, an expert in ecology and disease at Oxford University, observes, this is an enormously useful combination of variables. His research has linked levels of photosynthesis, detected from satellites, to the size of a vein in the wings of West African tsetse flies. This vein measurement indicates the health and size of fly populations—and suggests the likelihood of epidemics of sleeping sickness, a tsetse-borne parasitic disease that kills tens of thousands of Africans a year. That means satellite data can be used to predict epidemics without having to collect any flies on the ground.

And it is not only Africa that is benefiting. Satellite research indicates a “significant risk” that dengue fever, malaria, and Rift Valley fever will enter Europe, according to Renaud Lancelot, head of the EDEN project, a group of laboratories and public-health agencies in 24 European and African countries. Indeed, chikungunya, a mosquito-borne virus endemic to tropical Africa and Asia, has already arrived in Albania and Italy. A harbinger of things to come, perhaps? 🐞

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affect the monarch butterfly. Today, eastern North American monarchs can log up to 5200 kilometers on their annual trips to forests in Mexico.

But in a 2003 study, Oberhauser found that global warming might make these forests too wet for monarchs. Instead of flying to Mexico, she says, the butterflies might take a shorter migration route to the Gulf Coast of the United States.

On the face of it, shorter migration flights might not seem alarming. But Sonia Altizer, a former student of Oberhauser’s who is now at the University of Georgia, has been finding surprisingly strong links between the length of monarch migrations and the prevalence of disease.

Altizer examined nearly 15,000 monarchs to determine which were infected with the parasite *Ophryocystis elektroscirrha*, which can cause wing deformities and shorten life spans. Among monarchs that travel long routes to Mexico, less than 8 percent of the butterflies were heavily infected. But for western North American monarchs that take shorter flights to California, the numbers went up to about one-third. And in a Florida population that didn’t migrate at all, more than 70 percent were stricken.

Altizer’s team speculated that migration might weed out infected butterflies, which wouldn’t survive strenuous trips. To investigate, they attached monarchs to the end of a butterfly “treadmill”—a horizontal rod that could spin around a pivot—and let them fly in circles. The researchers found that infected butterflies stopped an average of 14 percent sooner and traveled 10 percent slower than uninfected butterflies. If monarchs start wintering in Texas instead of Mexico, the population might accumulate more diseased butterflies, says Altizer.

Shorter or stalled migrations might pose a threat to other migratory species as well. For instance, reindeer and fall armyworm moths may also shake off parasites through seasonal migrations, either by ridding themselves of sick individuals or leaving contaminated sites. Climate change could even create year-round habitat that encourages migratory species to stay put, Altizer says, strengthening the foothold of infectious diseases.



Musk ox on Nunivak Island/U.S. Fish and Wildlife Service



Parasites Lost and Found

Why do warmer Arctic summers give musk oxen nosebleeds?

As climate and animal movements are changing, so are the organisms that play a key role in disease ecology: parasites. Often carried by insects or other animals to their hosts, parasites are the infectious agents behind many human and wildlife diseases. And as climate change begins to alter the life cycles and biodiversity of these organisms, scientists say, it could have a powerful impact on disease patterns.

Susan Kutz, a wildlife parasitologist at the University of Calgary, began studying one Arctic parasitic worm in 1994. The worm penetrates the feet of slugs, using them as a growth chamber until the slugs are eaten by musk oxen. The worms then take up residence inside the musk oxen's lungs, causing nosebleeds, weakening the

animals, and making them vulnerable to predators such as grizzly bears.

To investigate how climate change might affect the parasite's life cycle, Kutz spent two summers on the Arctic tundra, tracking the worm's growth. She calculated that a couple of decades ago, the tundra would have been too cold for the worm to develop in one summer. But around 1990, rising temperatures probably allowed the parasite to grow faster, shortening its development time from two years to one.

This finding suggests that small changes in temperature can trigger large jumps in parasite life cycles, says Kutz. Since the faster growth rate would have allowed more worms to survive to maturity and infect the musk oxen, she speculates, it might explain why musk oxen numbers declined in a 1994 survey—although there aren't enough data to say for sure.

The parasite equation is complicated by the fact that, in addition to allowing some parasites to develop faster, climate change could drive others to extinction. Those that can't handle warmer conditions might try to find new hosts to the north or let existing hosts carry them to cooler

regions, Kutz suggests. Once they reach new habitat, they will face competition from other parasite species. If they can't win the struggle for animal hosts, she says, they may run out of places to go.

Parasites could also be in trouble if their hosts become endangered or extinct, the USGS's Kevin Lafferty says. Biodiversity is expected to decline with climate change, and the disappearance of one animal species could threaten multiple parasite species. "Listen, you don't want to be a parasite of a polar bear or a penguin," he says.

As outlined in a recent article in *Proceedings of the Royal Society B*, one possibility is that the disappearance of certain parasites could simply allow remaining parasites to spread. And parasites that lose mammal hosts to extinction might just switch to a different host species—possibly humans. (3)

But Lafferty cautions that it's far too early to leap into crisis mode. Instead of adding to the slew of doom-and-gloom climate predictions, he believes it's first necessary to withhold judgment and construct a more-complete portrait of disease ecology. It's a daunting task, but it's also within reach. Ecologists already have the tools to study intricate systems, Lafferty suggests, and that could allow them to disentangle the contributions of various factors, including climate, to disease. Until this happens, predictions of climate-driven disease spread are likely to be insufficient and incomplete. "The outcome is important enough," Lafferty says, "that we should get it right."



Strength in Numbers

Can biodiversity thwart the spread of disease?

Some scientists are starting to believe biodiversity could act as a powerful repellent to infectious disease. "Biodiversity gives insects a choice of what to bite," says Andy Dobson, an infectious disease ecologist at Princeton Univer-

sity. In other words: If there's a large number of species to choose from, a disease-carrying bug could miss its target and bite a species that isn't susceptible.

Some recent studies have affirmed this. A team led by Brian Allan at Washington University in St. Louis found that West Nile virus infection was more common in areas with low bird diversity, areas which also tend to harbor the species most likely to transmit the virus. In another study, researchers removed small mammals from plots in Panama and observed higher hantavirus infection rates among remaining host species.

But the disease buffer could vary depending on which species are lost or gained. In some low-diversity communities, animals that transmit a particular disease may have already dropped out, says Peter Hudson, an ecologist at Pennsylvania State University. Alternatively, the presence of certain species could help spread the disease.

If some species are a particularly good disease buffer, it could be tempting to try to add more of them to ecosystems. But that's probably infeasible, says Richard Ostfeld of the Cary Institute of Ecosystem Studies. Opossums are known to reduce Lyme disease risk, he says, "but are we going to go out and air-drop opossums into suburban neighborhoods? I don't think so." 🐾

Roberta Kwok is a freelance writer based in Foster City, California.

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