A WORLD WITHOUT MOSQUITOES

Eradicating any organism would have serious consequences for ecosystems — wouldn't it? Not when it comes to mosquitoes, finds **Janet Fang**.

M. BOWLER AMAZON-IMAGES/ALAMY

Every day, Jittawadee Murphy unlocks a hot, padlocked room at the Walter Reed Army Institute of Research in Silver Spring, Maryland, to a swarm of malaria-carrying mosquitoes (*Anopheles stephensi*). She gives millions of larvae a diet of ground-up fish food, and offers the gravid females blood to suck from the bellies of unconscious mice — they drain 24 of the rodents a month. Murphy has been studying mosquitoes for 20 years, working on ways to limit the spread of the parasites they carry. Still, she says, she would rather they were wiped off the Earth.

That sentiment is widely shared. Malaria infects some 247 million people worldwide each year, and kills nearly one million. Mosquitoes cause a huge further medical and financial burden by spreading yellow fever, dengue fever, Japanese encephalitis, Rift Valley fever, Chikungunya virus and West Nile virus. Then there's the pest factor: they form swarms thick enough to asphyxiate caribou in Alaska and now, as their numbers reach a seasonal peak, their proboscises are plunged into human flesh across the Northern Hemisphere.

So what would happen if there were none? Would anyone or anything miss them? *Nature* put this question to scientists who explore aspects of mosquito biology and ecology, and unearthed some surprising answers.

There are 3,500 named species of mosquito, of which only a couple of hundred bite or bother humans. They live on almost every continent and habitat, and serve important functions in numerous ecosystems. "Mosquitoes have been on Earth for more than 100 million years," says Murphy, "and they have co-evolved with so many species along the way." Wiping out a species of mosquito could leave a predator without prey, or a plant without a pollinator. And exploring a world without mosquitoes is more than an exercise in imagination: intense efforts are under way to develop methods that might rid the world of the most pernicious, disease-carrying species (see 'War against the winged').

Yet in many cases, scientists acknowledge that the ecological scar left by a missing mosquito would heal quickly as the niche was filled by other organisms. Life would continue as before — or even better. When it comes to the major disease vectors, "it's difficult to see what the downside would be to removal, except for collateral damage", says insect ecologist Steven Juliano, of Illinois State University in Normal. A world without mosquitoes would be "more secure for us", says medical entomologist Carlos Brisola Marcondes from the Federal University of Santa Catarina in Brazil. "The elimination of *Anopheles* would be very significant for mankind."

WILD WONDERS OF EUROPE/SMIT/NATUREPL.COM

Wish you were gone: mosquito clouds can be thick enough to choke caribou in the Arctic.

Arctic pests

Elimination of mosquitoes might make the biggest ecological difference in the Arctic tundra, home to mosquito species including *Aedes impiger* and *Aedes nigripes*. Eggs laid by the insects hatch the next year after the snow melts, and development to adults takes only 3–4 weeks. From northern Canada to Russia, there is a brief period in which they are extraordinarily abundant, in some areas forming thick clouds. "That's an exceptionally rare situation worldwide," says entomologist Daniel Strickman, programme leader for medical and urban entomology at the US Department of Agriculture in Beltsville, Maryland. "There is no other place in the world where they are that much biomass."

Views differ on what would happen if that biomass vanished. Bruce Harrison, an entomologist at the North Carolina Department of Environment and Natural Resources in Winston-Salem estimates that the number of migratory birds that nest in the tundra could drop by more than 50% without mosquitoes to eat. Other researchers disagree. Cathy Curby, a wildlife biologist at the US Fish and Wildlife Service

in Fairbanks, Alaska, says that Arctic mosquitoes don't show up in bird stomach samples in high numbers, and that midges are a more important source of food. "We (as humans) may overestimate the number of mosquitoes in the Arctic because they are selectively attracted to us," she says.

Mosquitoes consume up to 300 millilitres of blood a day from each animal in a caribou herd, which are thought to select paths facing into the wind to escape the swarm. A small change in path can have major consequences in an Arctic valley through which thousands of caribou migrate, trampling the ground, eating lichens, transporting nutrients, feeding wolves, and generally altering the ecology. Taken all together, then, mosquitoes would be missed in the Arctic — but is the same true elsewhere?

Food on the wing

"Mosquitoes are delectable things to eat and they're easy to catch," says aquatic entomologist Richard Merritt, at Michigan State University in East Lansing. In the absence of their larvae, hundreds of species of fish would have to change their diet to survive. "This may sound simple, but traits such as feeding behaviour are deeply imprinted, genetically, in those fish," says Harrison. The mosquitofish (*Gambusia affinis*), for example, is a specialized predator — so effective at killing mosquitoes that it is stocked in rice fields and swimming pools as pest control — that could go extinct. And the loss of these or other fish could have major effects up and down the food chain.

Many species of insect, spider, salamander, lizard and frog would also lose a primary food source. In one study published last month, researchers tracked insect-eating house martins at a park in Camargue, France, after the area was sprayed with a microbial mosquito-control agent[1]. They found that the birds produced on average two chicks per nest after spraying, compared with three for birds at control sites.

Most mosquito-eating birds would probably switch to other insects that, post-mosquitoes, might emerge in large numbers to take their place. Other insectivores might not miss them at all: bats feed mostly on moths, and less than 2% of their gut content is mosquitoes. "If you're expending energy," says medical entomologist Janet McAllister of the Centers for Disease Control and Prevention in Fort Collins, Colorado, "are you going to eat the 22-ounce filet-mignon moth or the 6-ounce hamburger mosquito?"

With many options on the menu, it seems that most insect-eaters would not go hungry in a mosquito-free world. There is not enough evidence of ecosystem disruption here to give the eradicators pause for thought.

At your service

As larvae, mosquitoes make up substantial biomass in aquatic ecosystems globally. They abound in bodies of water ranging from ephemeral ponds to tree holes[2] to old tyres, and the density of larvae on flooded plains can be so high that their writhing sends out ripples across the surface. They feed on decaying leaves, organic detritus and microorganisms. The question is whether, without mosquitoes, other filter feeders would step in. "Lots of organisms process detritus. Mosquitoes aren't the only ones involved or the most important," says Juliano. "If you pop one rivet out of an airplane's wing, it's unlikely that the plane will cease to fly."

Mosquito larvae form a substantial part of the biomass in water pools worldwide.

M. & P. FOGDEN/MINDEN PICTURES/FLPA

"If there was a benefit to having them around, we would have found a way to exploit them. We haven't wanted anything from mosquitoes except for them to go away."

The effects might depend on the body of water in question. Mosquito larvae are important members of the tight-knit communities in the 25–100-millilitre pools inside pitcher plants[3,4] (*Sarracenia purpurea*) on the east coast of North America. Species of mosquito (*Wyeomyia smithii*) and midge (*Metriocnemus knabi*) are the only insects that live there, along with microorganisms such as rotifers, bacteria and protozoa. When other insects drown in the water, the midges chew up their carcasses and the mosquito larvae feed on the waste products, making nutrients such as nitrogen available for the plant. In this case, eliminating mosquitoes might affect plant growth.

In 1974, ecologist John Addicott, now at the University of Calgary in Alberta, Canada, published findings on the predator and prey structure within pitcher plants, noting more protozoan diversity in the presence of mosquito larvae[5]. He proposed that as the larvae feed, they keep down the numbers of the dominant species of protozoa, letting others persist. The broader consequences for the plant are not known.

A stronger argument for keeping mosquitoes might be found if they provide 'ecosystem services' — the benefits that humans derive from nature. Evolutionary ecologist Dina Fonseca at Rutgers University in New Brunswick, New Jersey, points as a comparison to the biting midges of the family Ceratopogonidae, sometimes known as no-see-ums. "People being bitten by no-see-ums or being infected through them with viruses, protozoa and filarial worms would love to eradicate them," she says. But because some ceratopogonids are pollinators of tropical crops such as cacao, "that would result in a world without chocolate".

Without mosquitoes, thousands of plant species would lose a group of pollinators. Adults depend on nectar for energy (only females of some species need a meal of blood to get the proteins necessary to lay eggs). Yet McAllister says that their pollination isn't crucial for crops on which humans depend. "If there was a benefit to having them around, we would have found a way to exploit them," she says. "We haven't wanted anything from mosquitoes except for them to go away."

War against the winged

Humans have made many concerted, if not always effective, efforts to eliminate mosquitoes. The more successful attempts include the eradication campaign against *Aedes aegypti* in the early 1900s, which relieved yellow fever enough to allow the completion of the Panama Canal; and the use of the larvicide Paris Green to rid Brazil of the malaria vector *Anopheles gambiae* by 1940. Application of the adulticide DDT allowed the United States to be declared free of malaria in 1949.

But the chemicals sprayed then are banned in many countries now. "We can't mount those top-down, military-style efforts today," says Roger Nasci, an entomologist at the Centers for Disease Control and Prevention in Fort Collins, Colorado. "And we don't have DDT any more. It came with a lot of baggage but was an outstanding product for mosquito reduction."

Mosquito control using less-toxic chemicals is key to keeping the insects in Florida and parts of southeast Asia and Latin America at tolerable levels. Worldwide malaria control in 2010 requires about US$1,880 million for indoor residual spraying and $2,090 million for insecticidal nets.

"It's a complicated business, and that's why we still have mosquitoes," Nasci says. "They're not going anywhere."

Researchers are developing alternative mosquito-control methods; some are outlined below.

RNA interference

● RNA-based insecticides kill female *A. aegypti* by promoting cell suicide[6]. "It basically tells the mosquito to go kill itself," says Stanton Cope, director of the US Armed Forces Pest Management Board, Washington DC.
● Formulation not yet developed to spray it in large quantities.

Male sterilization

● Introduced in large-enough numbers, sterile males can slow reproduction. Screw worms were eradicated in the United States in the early 1980s in this way: irradiated pupae grew into sterile males that were released until the species bred itself out of existence.
● Hasn't been widely field tested for mosquitoes.

Improved chemicals

● Mosquitoes are becoming resistant to current adulticides, which target the nervous system. Researchers are seeking agents with new mechanisms, including natural products such as cedar oil.
● Basic research to be done to find compounds and modes of action.

Mosquito traps

● In 2003, *Aedes taeniorhynchus* was mostly eliminated from an island in Florida by researchers at the US Department of Agriculture, using traps that generate carbon dioxide to lure mosquitoes.
● Good for gardens or small islands, but probably not feasible on a larger scale. **J.F.**

Battle to the death: fumigating the streets of Calcutta, India.

D. WYLIE/MAGNUM PHOTOS

Ultimately, there seem to be few things that mosquitoes do that other organisms can't do just as well — except perhaps for one. They are lethally efficient at sucking blood from one individual and mainlining it into another, providing an ideal route for the spread of pathogenic microbes.

"The ecological effect of eliminating harmful mosquitoes is that you have more people. That's the consequence," says Strickman. Many lives would be saved; many more would no longer be sapped by disease. Countries freed of their high malaria burden, for example in sub-Saharan Africa, might recover the 1.3% of growth in gross domestic product that the World Health Organization estimates they are cost by the disease each year, potentially accelerating their development. There would be "less burden on the health system and hospitals, redirection of public-health expenditure for vector-borne diseases control to other priority health issues, less absenteeism from schools", says Jeffrey Hii, malaria scientist for the World Health Organization in Manila.

Phil Lounibos, an ecologist at the Florida Medical Entomology Laboratory in Vero Beach says that "eliminating mosquitoes would temporarily relieve human suffering". His work suggests that efforts to eradicate one vector species would be futile, as its niche would quickly be filled by another. His team collected female yellow-fever mosquitoes (*Aedes aegypti*) from scrap yards in Florida, and found that some had been inseminated by Asian tiger mosquitoes (*Aedes albopictus*), which carry multiple human diseases. The insemination sterilizes the female yellow-fever mosquitoes — showing how one insect can overtake another.

D. ALLEN/ISTOCKPHOTO.COM

Given the huge humanitarian and economic consequences of mosquito-spread disease, few scientists would suggest that the costs of an increased human population would outweigh the benefits of a healthier one. And the 'collateral damage' felt elsewhere in ecosystems doesn't buy much sympathy either. The romantic notion of every creature having a vital place in nature may not be enough to plead the mosquito's case. It is the limitations of mosquito-killing methods, not the limitations of intent, that make a world without mosquitoes unlikely.

And so, while humans inadvertently drive beneficial species, from tuna to corals, to the edge of extinction, their best efforts can't seriously threaten an insect with few redeeming features. "They don't occupy an unassailable niche in the environment," says entomologist Joe Conlon, of the American Mosquito Control Association in Jacksonville, Florida. "If we eradicated them tomorrow, the ecosystems where they are active will hiccup and then get on with life. Something better or worse would take over." ■

Janet Fang is an intern in *Nature*'s Washington DC office.

1. Poulin, B., Lefebvre, G. & Paz, L. *J. Appl. Ecol.* **47,** 884–889 (2010).
2. Daugherty, M. P. & Juliano, S. A. *Am. Midl. Nat.* **150,** 181–184 (2003).
3. Daugherty, M. P., Alto, B. W. & Juliano, S. A. *J. Med. Entomol.* **37,** 364–372 (2000).
4. Heard, S. B. *Ecology* **75,** 1647–1660 (1994).
5. Addicott, J. F. *Ecology* **55,** 475–492 (1974).
6. Pridgeon, J. W., Zhao, L., Becnel, J. J., Strickman, D. A., Clark, G. G. & Linthicum, K. J. *J. Med. Entomol.* **45,** 414–420 (2008).