AFTERWORD

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Mosquitoes and their survival instincts fascinate. Yet, in matters of mosquitoes, one gets caught in a dilemma. Mosquitoes do both good and bad to humanity. One must consider whether nature could do without these blood seekers and disease agents? Not really—for not all mosquito species are disease vectors! Shall we or shall we not let them go? Have we not tried enough and failed? Have we learned our lessons yet or not? These are some of the questions that come to mind when considering the lessons of Mosquitopia.

Our knowledge about mosquitoes is not new. In ancient India, Susruta the author of *Susruta Samhita* in the second century AD described five kinds of mosquitoes (or “Mashakah”) in Sanskrit, namely, *Samudrah* (marine or coastal mosquito), *Parimandalah* (very small mosquito), *Hastimashakah* (elephant mosquito), *Krishnah* (black mosquito) and *Parawatiyah* (hill/foothill mosquito). Rao (1984) mentions that from these divisions of mosquito taxa, knowledge about mosquitoes in India is at least 1,800 years old.

The destruction that mosquitoes cause!

Historically, mosquitoes were perceived as the agents of disruption and havoc of various human civilizations. Together with their pathogens and parasites, mosquitoes colluded in killing more people than all the wars fought on the earth. Even the mightiest of warriors, the likes of “Alexander the Great,” fell to a bite of a mosquito laden with *Plasmodium*. Mosquitoes showed no mercy on the Vatican clergy either. In August 1590, Pope Sixtus V and, a month later, his successor Urban VII, died of malignant fever (Celli 1925). In a disastrous Vatican conclave of 1632, eight cardinals and 30 secretaries succumbed to the deadly *Plasmodium*. Mosquitoes were certainly not God-fearing.

Hate at first sight

The very sight of a mosquito annoys and irks. The immediate and voluntary response is to squash it before it syringes out the “red fluid” from the vein. Terrified humans have called mosquitoes “pesky bastards,” “agents of doom,” “flying syringes,” “nasty and evil” and all else. Ranting frustration against a fellow species, however justified, is morally and ethically misplaced as we are informed by *Mosquitopia*. After all, it’s simply the game of survival that species play in nature.

From sledge hammer to resurrection

From an evolutionary perspective, mosquitoes are far superior to humans. Mosquitoes display a remarkable instinct for survival through plasticity in their behaviour which is intimately attuned to their immediate environs. Perfecting life strategies seem to be their constant endeavour. It is in the greatest interest of humankind to preserve mosquitoes for the good they do by way of their ecosystem services in the food web and pollination of plants. They are the objects of scientific curiosity as one of nature’s supreme manifestations of millions of years of evolution.

To start off this volume, Marcus Hall and Dan Tamir make a compelling case for a balanced approach while dealing with these wonderful creatures. The sledge hammer approach to eliminating mosquitoes has only led to their greater fitness, in their opinion. They conclude: In the end, rather than pushing an ultimatum that it must be us or them, can humans promote and practice a kind of “Mosquitopia” with these little humming creatures, humanity’s most dangerous companions? Could we develop a relationship with this insect that will allow healthy cohabitation?

A manifestation of fascinating evolution

In Chapter 2, we have Hawkes and Hopkins’s excellent descriptions of the mosquito’s powerful sensors; its ability to match wingbeats as nuptial strategy; the variety of host-seeking cues; the advanced blood-sucking armature or proboscis; its blood-feeding strategies of piercing and locating the vein; the properties of its saliva that are angiogenic, inflammatory and anaesthetic; and its fecundity and breeding choices. Their indomitable survival instincts only raise one’s inquisitiveness about the innumerable classical features of these amazing creatures and are a powerful reminder of how far mosquitoes have come in their evolutionary journey. By appearance, so beautiful are some of the mosquito species that they will give high-fashion models a run for their money! A look at the shiny and the multi-hued *Sabethes cyaneus* will leave no doubts in one’s mind (Figure 18.1).

The discovery of an amber fossil of a mosquito in Canada resembling *Paleoculicis minutus* suggests that today’s mosquito personifies a refined biological system by

FIGURE 18.1 *Sabethes cyaneus*, mosquito (photo: Paul). Source: <https://featuredcreature.com/now-this-is-buzzworthy-species-of-mosquito-is-worlds-most-beautiful/>

taking advantage of at least 79 million years of evolution. It then becomes obvious that a mere 300,000-year-old hominid, *Homo sapiens*, may be no match for this sophisticated bio-machine that has been engineered, shaped and perfected for millions of years.

Such different time scales suggest that human evolution is on a hopelessly slow track when it comes to accumulating and transferring useful mutational changes and genetic recombinations to future generations. Thus, it takes about 6,570 days (or 18 years) for humans to become biologically productive and start one new generation. During the same time, with 40 days of maximum life, a typical mosquito would pass through some 164 generations. Even adjusting for the several months spent in hibernating eggs (in inclement weather) and overlapping generations, the mosquito's wheel of life turns much faster than that of humans to provide these insects with much faster natural selection advantages.

An entangled destiny of mosquitoes and humans

Mosquitoes and humans are companions. Uli Beisel and Carsten Wergin (Chapter 3) remind us that mosquito–human entanglements can be “infra-structuring environments.” Loss of biodiversity, global warming, and heightening trade and travel provide new opportunities for sharing environments for resources and habitats so that humans actively promote mosquito expansion with

their mobility and create feeding, resting, and breeding opportunities for mosquitoes. Citing the expanding distribution of *Aedes aegypti* and *Aedes albopictus* in Europe and Americas with used car tyres, and with lucky bamboo in Germany, they point out that “Just as humans and goods move, disease vectors and pathogens utilize global connectivities to expand their habitat.”

Elaborating on human–pathogen–mosquito entanglements, together with global warming and accelerating inter-country connectivity, Beisel and Wergin predict that several mosquito species will find new ways to expand. The One Belt One Road (OBOR) initiative is just one ongoing infrastructural project for enhancing maritime trade and overland travel between Asia, Europe and Africa that will bring the world ever closer together. Vigilance of these networks may also provide insights into better ways for hindering vector movement, especially at the points of entry. The International Health Regulations division of WHO remind us that movement and expansion of invasive species is real.

The mosquito surge and human response

In Chapter 5, Urmi Engineer Willoughby argues that humans domesticated vectors by promoting anthropophilic behaviour and mosquito companionship when human settlers and slaves cultivated sugarcane in the Americas during the nineteenth century. Tenacious mosquito behaviour led to their evolutionary success, and their ability to pose an ongoing threat to humanity. Bill Gates calls them “the deadliest animal in the world” (Gates 2006).

Our early shot at a mosquito

Mosquito control campaigns in the last two centuries have been focused on water drainage and marsh reclamation resulting in a significant impact on vector populations and in reducing malaria burden (James Webb, Chapter 4). This was followed by the use of Paris Green, as in the project of eliminating *Anopheles arabiensis* from Northeast Brazil, and *Anopheles gambiae* from Egypt during one of the most meticulous anti-mosquito campaigns that led to the successful eradication of these two invasive malaria vectors. Buoyed by these successes led by Fred L. Soper, the Rockefeller Foundation sought to eradicate *Anopheles labranchiae* from the island of Sardinia in Italy with DDT as larvicide and adulticide. Although mosquito numbers were drastically reduced, thereby eliminating malaria, complete eradication of the vector proved elusive, with *An. labranchiae* returning to occupy its lost ground in later decades. Similar projects were carried out against *Aedes aegypti* in Brazil starting in 1947. Although highly successful in its initial years, *Aedes aegypti* numbers in South America would return by the 1960s. Moreover, the collateral damage of DDT was showing greater manifestations around the globe, leading to the destruction of non-target fauna. Rachel Carson’s famous *Silent Spring* (1962), which painted a picture of a world without birdsong, evoked

a strong response. Subsequent environmentalism and activism led to restricting DDT in agriculture and public health. Webb reminds us that only a few mosquito species are vectors, and that removing other species of mosquitoes and non-target organisms could prove perilous to humanity.

One sees that the battle of survival and superiority between humans and mosquitoes has been raging for centuries. And for the most part, mosquitoes have been holding the upper hand. One wonders who will have “the last laugh.” Can humans achieve the Sisyphean task of exterminating mosquitoes even if they wished to? Could we or should we accept the inevitable and halt our fight for environmental, biological and mechanical reasons so that we can settle for something less than elimination of the invincible mosquito? Fred L. Soper’s fight-to-finish strategy to William Gorgas’ calibrated and selective approaches provide us with lessons to guide our future course as explained by Nancy L. Stepan (Chapter 6). The very thought of eradication appears to be misplaced and in a quagmire: the goal should remain that of reduction, not complete elimination, of vector populations.

The mosquito as art

What an inspiring and fascinating impression that artists Kerry Morrison and Helmut Lemke (Chapter 10) create in the minds of the wetland visitors and the readers from their mobile carrier, Wetlands on Wheels (WoW)! Viewing the world from the eyes of an artist adds another dimension to the nature of complexities. Fantasizing about mosquitoes to awaken human sensitivities through the medium of art brings together science and culture on the single canvas of life.

Mosquito and human rights

Do mosquitoes have rights as individuals and as species? Anna Wienhues (Chapter 13) questions the very morality of humans in killing an individual mosquito and also in trying to eliminate and eradicate mosquito species. It becomes apparent that the principle of hubris and risk applies to *Homo sapiens* in their quest to dominate all life forms on the planet in the sense of ownership. Wienhues points out that even if some mosquitoes act as vehicles for disease agents, they are, themselves, innocent victims. In defending their action for preventing infection and suffering, making a case for the extinction of an entire species is totally unjustified both morally and ethically, even though it may not be physically and biologically plausible. Also, can a few humans who venture to exterminate mosquitoes assume the moral and ethical responsibility of all humanity? Is moral, political, financial and informed consent crucial for such responsibility? Even if killing disease agents and vectors is justified as a matter of human rights, the talk of eradicating mosquitoes may be against a mosquito’s natural rights.

Mosquito management

Management of pestiferous mosquitoes, and drainage of wetlands in the early twentieth century proved a practical and sustainable control strategy on Hayling Island, in South West England, and in the New Jersey marshlands. How mosquitoes harassed the guests of John F. Marshall, including Ronald Ross in 1922, is a telling story (Chapter 7, Peter Coates). The successes of the British Mosquito Control institute (BMCI) in draining the Hayling island marshlands in three years using tropical wisdom was an astonishing feat. During a subsequent visit to the same island in 1925, not a single bite was experienced by Ross and other guests. This points to the fact that today's highly chemical-dependent approach is short-term, never-ending and unsustainable. The integration of decades of gathered wisdom must shape the future of mosquito control. Suffice to mention that humans often live close to marshlands for food and livelihood, as emphasized by Ford, Gearey and Acott (Chapter 9).

In present times, William Takken (Chapter 8), advocates community engagement and implementing an integrated approach, that of combining environmental management (e.g. effective drainage) with housing improvements (mosquito-proofing and screening), biological control (with larvivorous fish and *Bacillus thuringiensis israelensis*), bio-rational methods (insect growth regulators and attractive toxic sugar baits), chemical control (indoor residual spray and long-lasting insecticide nets) and behavioural control (repellents/attractants). All of these methods form the backbone of the Global Vector Control Response of the WHO which stresses operational research and global entomological capacity-building as a foundation for judicious interventions in a sustainable control strategy.

Alex Nading (Chapter 12) raises an interesting issue of ambivalence while dealing with mosquitoes. On the one hand, there is talk of extermination of mosquitoes, and on the other, the same insects are modified and propagated for human welfare. As an example of this ambivalence, *Wolbachia* is a gram-negative endosymbiont bacterium naturally present in about 60% of insect species and has the ability to check dengue, chikungunya, and Zika viruses. However, *Wolbachia* infection in *Aedes aegypti* (the vector of these viruses) is rare. This observation has convinced the World Mosquito Programme (WMP) to advocate the release of *Wolbachia*-infected *Aedes aegypti* from the laboratory for curbing these viruses. Interestingly, the mating of a *Wolbachia*-infected male *Aedes aegypti* with an uninfected wild female will cause cytoplasmic incompatibility, resulting in sterile eggs. Over a period of time, this mating process will eliminate the local wild *Aedes aegypti* population, thereby diminishing the associated vector-borne diseases.

Isabelle Dusfour and Sarah Cunard Chaney (Chapter 14) list various methods employed to control mosquitoes and feel that most such methods have reached the end of their chemical life since mosquitoes have become quite resistant to most insecticides. Biological control agent *Bacillus thuringiensis israelensis* has, by

and large, proved itself to be safer and more effective than the larvicide temephos. Newer tools and techniques have become available such as releasing genetically modified insects with a dominant lethal gene (RIDL), sterile insect technique (SIT), insect incompatibilities with *Wolbachia*-modified mosquitoes (IIT) and gene drive. These methods are, however, at an early stage of experimentation as explained by Ramya Rajagopalan (Chapter 15). Paradoxically, many of the above techniques require mass production of mosquitoes in the laboratory for release in the field to control or replace wild populations. In the ongoing scrutiny of the safety and desirability of these latest control techniques, the authors conclude that it is more critical than ever to search for a sustainable and acceptable equilibrium that simultaneously preserves human health and protects the environment. One must aim to integrate the social aspects of mosquito-borne diseases with the ecological habits of the mosquitoes that transmit those diseases.

Indra Vythilingam (Chapter 17) highlights the worldwide campaign to eliminate malaria and filariasis with the support of the WHO. She professes how vectors and vector-borne diseases evolved and were addressed with different tools and strategies in Malaysia. Her most striking example shows how deforestation and human settlements led *Anopheles* to infect humans with *Plasmodium knowlesi*, a monkey malaria originating in local macaques. The author cautions against the use of genetically modified mosquitoes, citing the example of Oxitec *Aedes aegypti*. Eighteen months after the release of these GM mosquitoes, observations showed that the wild population which had initially been suppressed began to rebound to pre-release levels (Evans et al. 2019). The cautionary note here is that these releases may end up promoting more robust populations of mosquitoes in the future, with ultimate consequences for the ecosystem remaining unknown. It may also be an unrealistic or uneconomic strategy for many disease-endemic countries to set up sophisticated, GM-mosquito-producing laboratories, and then transport, monitor and evaluate GM- or *Wolbachia*-transinfected vector populations. Vythilingam underscores the paradox of convincing communities to carry out repeated releases of mosquitoes rather than preventing mosquito breeding in the first place.

An enigma of sorts!

From an anthropological perspective and the Brazilian narrations of Jean Segata (Chapter 11), one realizes the complexity of combining existing mosquito populations, patients ailing with yellow fever, and equivocal responses of authorities with yet another *Aedes*-borne outbreak that worsens incidence of dengue, chikungunya and Zika. As the face of disease changes its epidemiological dimensions, human perceptions and disease-detection technologies need to occupy the already crowded space for effective responses from municipalities, health workers, bureaucrats and political leaders. The mosquito, the scientists and their research and the healthcare institutions, alongside the human suffering, when combined with public health measures and job security of mosquito workers, all become nuts and bolts of the same inexorable machine: “the disease.” The very

movement of this machine depends on a disease continuum, its modulations and its dimensions in time and space. What an enigma of sorts!

The Mosquitome

Frederic Simard introduces (in Chapter 16) the intriguing concept of the “Mosquitome,” which by his definition is the assemblage of mosquitoes that thrive where people live. He reminds us that human transformations of the natural environment are responsible for creating opportunities and habitat for mosquitoes, with the Mosquitome being composed of a handful of highly synanthropic mosquito species. This concept helps to separate mosquitoes into disease vectors living in the vicinity of human settlements from those that do not cause us harm—and indeed may carry out important roles in ecosystems. Here, elimination of mosquitoes should not be the goal; rather, the main strategy should focus on methods to reduce longevity and control mosquitoes of the Mosquitome so that they do not transmit their pathogens. Quoting Michalakis and Renaud (2009), Simard mentions that opportunities exist to disentangle vector fitness from pathogen transmission. *Beauveria* and *Wolbachia* are considered good candidates for the late-life control of mosquitoes. In this way, mosquitoes can lay eggs but die before infecting humans with dangerous microbes. Local breeding containers and puddles must be drained; house-screening and insect-proofing will reinforce a methodology that targets the Mosquitome.

Mosquitopia

Mosquitopia is thus a treasure trove in the hands of explorers, nature lovers, entomologists and mosquito managers alike. It is an assemblage of deep insights into the world of mosquitoes, and is as much a philosophical expression of human appreciation of nature as it is a catalogue of the human successes and failures when dealing with mosquitoes. The volume sounds a wake-up call for the human race that stands at the crossroads of the old and the new, still searching for tools and methods to limit mosquitoes. *Mosquitopia* is a timely statement when global warming’s effects are appearing more ominous in a world that is poised to further empower the old foe. Our wise authors implore us to raise human conscience and steer away from the aims of extermination and eradication and towards appreciating the moral and ethical rights of all life forms. Mosquitoes arrived several million years before *Homo sapiens* walked on this planet and will surely continue buzzing much after our species is gone. The sane approach? To “live and let live”.

A mosquito!
Tiny and fascinating
superbly adapted

amazingly powered
 hated and victimized
 facing extinction
 returned emboldened
 Better thee understand
 my rights in thy space
 A shared destiny
 Better humans beware!

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