THE POTENTIAL OF MOSQUITO-INDIGESTIBLE PHYTOPLANKTON FOR MOSQUITO CONTROL[1]

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Biological control usually brings to mind the introduction of natural enemies, but another form of biological control, based on biological introductions that eliminate a pest's food supply, may also be of use for controlling disease vectors. In the case of mosquitoes, phytoplankton deserve particular attention since phytoplankton are the principal food for larvae of many species. Mosquito larvae can digest most kinds of phytoplankton, but a recent study (Marten 1986) suggests there are at least 200 species of planktonic green algae that can kill *Aedes*, *Anopheles*, and *Culex* larvae because the larvae are unable to digest them. The cell walls of these algae contain a thin layer of sporopollenin, a carotenoid that protects them from digestive enzymes (Atkinson et al. 1972). These algae are digestible to animals that can break their cell walls mechanically, but mosquito larvae are unable to do so. Since mosquito larvae do not discriminate between these algae and other phytoplankton, wherever these algae are more abundant than other phytoplankton the larvae simply feed upon the indigestible algae until they starve to death.

I first became aware of the significance of mosquito-indigestible phytoplankton when I noticed that *Aedes albopictus* (Skuse) larvae in Hawaii were dying of starvation in container-breeding habitats where the green algae *Kirchneriella irregularis* had taken over the phytoplankton (Marten 1984). Moreover, if I introduced a small quantity of *K. irregularis* to a container habitat where it was not already present, it often took over and rendered the water unsuitable for *Ae. albopictus* larvae. These observations stimulated me to screen a broad taxonomic range of algae in laboratory tests to see if other species have the same effect (Marten 1986).

The results showed that most species of algae are good food for mosquito larvae, but many species of *Kirchneriella*, *Scenedesmus*, *Coelastrum*, *Selenastrum*, *Dactylococcus*, *Elakotothrix*, *Tetrallantos* and *Tetradesmus* are virtually indigestible for mosquito larvae. At least some species in additional genera (e.g., *Dictyosphaerium*) also possess this property. All of these genera are in the order Chlorococcales (Philipose 1967) and are closely related to one another. There are other genera in the Chlorococcales (e.g., *Chlorella*, *Ankistrodesmus*, *Pediastrum*, *Micractinium*, *Gloenkinia* and *Tetraedron*) that can be abundant where mosquitoes breed and appear to have no significant detrimental effect on mosquito larvae. These genera are not fully digestible to the larvae, but they are digestible enough to satisfy the larva's nutritional needs.

The significance of mosquito-indigestible algae has not generally been recognized because, even when these algae are abundant, their occurrence in nature is usually in combination with other kinds of algae that provide sufficient nutrition. However, they sometimes do have an impact in nature. *Culex quinquefasciatus* Say larvae starved to death in water dominated by *Kirchneriella* that I collected in Hawaii from a sewage treatment pond and from an aquaculture pond, and the same happened with water dominated by *Scenedesmus* that I collected from a roadside ditch. Barr (1985) observed that *Culiseta incidens* (Thomson) larvae failed to develop in a rain barrel where *Scenedesmus* dominated the phytoplankton.

A number of species of *Scenedesmus* are known to thrive in sewage treatments ponds (Gloyna et al. 1976). It might be feasible to reduce mosquito problems by managing the ponds to encourage *Scenedesmus* instead of other algae (e.g., *Chlorella*, *Chlamydomonas* and *Euglena*) that often prevail.

A key question for mosquito control is how to assist mosquito-indigestible algae to take over in situations where that does not happen naturally. The algae need not be highly abundant to kill mosquito larvae; they only need to be more abundant than other phytoplankton so the larvae consume them to the exclusion of other food. It will not work to dump massive quantities of algae indiscriminately into the water wherever mosquitoes are breeding. If ecological conditions are not suitable, the introduced algae will quickly diminish in numbers or even disappear.

Nonetheless, experiments in Hawaii (Marten 1986) have shown that mosquito-indigestible algae can take over the phytoplankton and maintain that position even when introduced in very small quantities—provided the algae are local strains highly competitive in the particular habitat to which they are introduced. Such intro-

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ductions are greatly facilitated by the simultaneous introduction of filter-feeding zooplankton. The grazing pressure of zooplankton on digestible algae gives indigestible algae a competitive advantage. Best results come from introducing a mixture of several promising algae species and several promising zooplankton species. When I introduced a mixture of several specis of *Kirchneriella* and *Scenedesmus* in combination with *Daphnia* to water from a pig farm stabilization pond, one or two of the introduced algae species consistently displaced *Chlorella* already in the water and rendered the water unsuitable for *Culex quinquefasciatus* larvae. *Ceriodaphnia*, *Diaphanosoma*, *Sida*, *Bosmina* and *Diaptomus* are examples of zooplankton that could also be useful in this regard.

Mosquito-indigestible phytoplankton do not appear to have undesirable environmental side effects. They are not toxic to fish or any other animals, nor are they particularly associated with the kinds of algae blooms that lead to oxygen depletion or fish kills. Numerous kinds of aquatic animals are associated with these phytoplankton in nature, even when mosquito larvae cannot survive.

We do not know whether mosquito-indigestible phytoplankton will prove practical for large-scale mosquito control, but they are worth exploring further. A significant advantage of indigestible phytoplankton is that mosquitoes should not be able to evolve a resistance to them. However, indigestible phytoplankton can be effective only for mosquito species that are primarily filter-feeders, and only where they can predominate over other food in the water. We do not know for how many different kinds of breeding habitats, or for how many species of mosquitoes, this can actually be the case. Nor do we know how long these phytoplankton, once established, will in fact maintain themselves under various field conditions, though they sometimes have persisted for as much as a year after introductions in small-scale field experiments in Hawaii.

The next logical step is to culture local strains of these phytoplankton, introduce them in coordination with mutually reinforcing organisms to a variety of mosquito breeding habitats, and observe the consequences. Only in this way can we realistically evaluate the potential of indigestible phytoplankton for mosquito control.

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