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Mosquitos in Constructed Wetlands: A Management Bugaboo?

Urban planners considering constructed wetlands for stormwater treatment might be concerned that mosquitos could become a major nuisance. Some observations in the field indicate that mosquitos are not a problem in constructed wetlands (Adams, 1983; Bennett, 1983). In general, functioning stormwater wetlands are less likely to produce mosquitos than are nutrient-laden secondary sewage and agricultural wastewater ponds or ponds that do not have frequent turnover. Even so, strong preconceptions exist, and building a wetland without first gauging public opinion could result in a major public relations headache. Those involved in the decision to build a wetland and the wetland designer can familiarize themselves with the breeding requirements of prevalent mosquito species to determine whether they feed on humans or carry disease and the likelihood that a wetland will be a high producer of mosquitos. Public opinion surveys and good information dispersal are important to avoid setbacks or negative impressions of wetlands and stormwater practices. Preventive measures can be incorporated in the site selection and design. In general, the basic design and maintenance of a good stormwater pond deters mosquito production (Table 1). If, indeed, mosquitos emerge, various biological controls can be used to subdue larval and adult populations.

An anti-mosquito strategy is as follows:

1. Assess the probable mosquito nuisance level of the area. Inform the public of the differences between stormwater and wastewater treatment.
2. After obvious high-risk sites have been ruled out (the local riding stable!) and there is still a moderate risk, modify the wetland design (e.g., maintenance of base flow, choice of vegetation) to deter mosquito breeding.
3. Choose and implement appropriate controls (Table 2) and monitor production levels.

Consult Biologists Familiar With the Locality at Each Stage

Some form of public involvement could be incorporated into the technical process. It cannot be assumed that residents will accept different designs equally. It might be worth considering inviting interested residents to participate in the planning well before designs are finalized and resources committed to the project.

Mosquito Risk

Where and when are mosquitos a concern? Wherever there is standing water, there may be mosquitos. Depending on the species, eggs are laid directly in standing water or in dry cavities (ground depressions, old tires) that later receive water. The larvae feed on algae and organic particles and take in oxygen by floating at the surface. Larvae develop into pupae, which emerge from the water as winged adults. The females of most species feed on the blood of animals although not all feed on humans. Many species of *Culex* do indeed feed on humans and these are the major nuisance species of North America. Some species of *Culex* carry encephalitis. Only species of *Anopheles* may potentially carry malaria and while there are such mosquitos in North America, the disease itself has not recently occurred here.

Mosquito production is sensitive to water level fluctuations. For the majority of species, production

Table 1: How Well-Designed Stormwater Wetlands Deter Mosquito Production

Mosquito breeding requirements	Stormwater pond design
■ Shallow, stagnant water; anaerobic condition ■ Egg rafts of permanent-pool species float on the water	■ In a well-constructed and maintained stormwater pond the water is kept moving; residence time is only a few days.
■ Adult females choose environments of high nutrition (anaerobic, high nutrients and bacteria) in which to lay their eggs.	■ Urban stormwater ponds are in non-agricultural settings and do not have high nutrient loads or animal waste.
■ Temporary-pool species require periodic drying (as in containers, puddles, tidal marshes)	■ Well-designed on-line systems are not expected to dry out.

increases with duration of standing water. However, there is an important exception in the case of “temporary pool” mosquitos. Impounding and flooding marshes is a way of controlling mosquitos in mainly coastal areas, where the prevalent nuisance species is one that depends on dry periods for egg development. In some localities, this approach could backfire if permanent-pool mosquitos also occur in the area where temporary-pool species are being controlled. One could inadvertently trade one nuisance species for another! It is important to know which species one is dealing with and what their breeding requirements are before implementing controls.

Being bit by a mosquito near a wetland does not necessarily mean that the mosquito came from the wetland. Female freshwater mosquitos range over half a mile (WRRI, 1989). Saltwater marsh species may range as far as 40 miles away from the site of emergence and be a nuisance in urban centers (R. Wolfe, personal communication). Therefore, mosquitos in an urban area could be coming from a number of sources, not necessarily the nearest wetland.

Designs for Deterrence

Which wetland designs contribute to and which deter mosquito production? Some factors that make wetlands good water treatment devices also make them more likely to be breeding areas for mosquitos:

- Dense vegetation is desired to better filter incoming water, stabilize the pond bottom, provide microbe substrate, and take up excess nutrients. Unfortunately, dense submerged vegetation can be correlated with high mosquito larvae production (WRRI, 1989), probably because the foliage provides refuge from predators and particles of plant detritus are food for larvae. Trees could be planted to shade out herbaceous aquatics but this would be counterproductive for water treatment.
- Low oxygen content and the presence of partially decomposed organic matter makes wetlands good immobilizers of trace metals. Mosquito larvae also thrive in these conditions.
- High surface area-to-volume ratio of the pond is generally recommended to achieve sheetflow and maximize the area of substrate for pollutant adsorption. Unfortunately, these large areas of shallow water are conducive to mosquito production. Deeper and steep-sided ponds will probably produce fewer mosquitos.
- A gradual bank slope increases vigor, diversity, and efficacy of the vegetation and lessens erosion (article 92). This design might also lead to higher mosquito production.

Certainly these basic design principles need not be abandoned, so long as it is understood that post-construction mosquito controls might be needed.

Some design considerations for mosquito deterrence include the following:

- Get an idea of future nutrient load on the wetland—is any septage or agricultural and animal waste likely? Sites of high nutrient load should be avoided. This is not likely to be a problem in developed settings.
- Attempting to avoid standing water altogether by building wetlands with flow-through gravel bottoms or that operate intermittently is probably unnecessary. Keeping a wetland dry is counterproductive to stormwater treatment processes (for example, the microbial activity in the muck layer). In addition, the degree of water level control appropriate in wastewater treatment or impoundments requires more supervision than can usually be given to a stormwater practice. Wastewater wetlands are built for a different purpose than are stormwater wetlands and function under different circumstances; therefore, their design and operation should not be copied blindly.
- Choose emergent vegetation with minimal submerged growth—dense submerged foliage provides refuge for the larvae and interferes with sampling and control.
- Cover open canals where feasible to cut down on standing water open to the sun; replace open troughs with closed distributor pipes (Tennessen, 1993).
- A properly laid-down parallel pipe system (article 150) will drain away and shouldn’t cause any problems.
- Construct stormwater ponds on-line. Keep inflows and outflows clear of debris to maintain base flow.

Evaluation of Controls

Bacteria

The bacterium *Bacillus thuringiensis israelensis* (Bti) is a common insecticidal control of mosquitos and flies. It is widely available in briquet, powder, or liquid form. Commercial Bti is considered safe enough to add to drinking water (WRRI, 1989). It is active against most mosquitos, but less so against anophelenes. It is also toxic to many flies. There appears to be no evidence as yet that it is harmful to “desired” insects. Bti does not appear to interfere with the activity of larvae-eating fish (Mian, 1986). In addition, the presence of nitrates and phosphates does not interfere with

Table 2: Comparison of Mosquito Controls		
Control	**Efficacy**	**Availability**
Biological controls		
Mesocyclops, a copepod	50-90% larvae consumed every few days	Laboratory reared, not easily obtained
Fish	Live-hatchers tend to do better than egg-layers; native spp. should be chosen, restocking not necessary except after severe winters or in shallow ponds	Non-natives may be prohibited in your areas. State Dept. Natural Resources or Mosquito Control often raise stocks of native fish
Pupfish *(Cyprinodon)*	Egg-layer, good survival in unpolluted water but sensitive to wastewater	Most restricted to desert streams/springs in Southwest, some endangered.
Guppy *(Poecilia reticulata)*	Prolific live-hatchers, high efficacy, sensitive to pH but tolerant of wide range of temperatures and dissolved oxygen	Non-native
Mosquitofish *(Gambusia spp.)*	Live-hatching, does well in non-polluted waters	Wide-ranging native and introduced spp. in US, E. coast, S.E., Missisipi and Colorado R. basins
Killifish *(Fungilis spp.)*	Voracious, very successful in MD and DE coastal programs	Several native spp., hardy overwinterer
Larvicides		
Cyromazine, methoprene (insect hormones)	One-time application good for 30+ days, application time should correspond with larval development	Several US distributors
Organophosphates (e.g. Abate)	Broad spectrum toxin, lethal for many invertebrates	Several US distributors
Bacillus sphaericus	Efficacy depends on injestion by larvae, not as effective as Bti against non-Culex spp.	Product in development, available in some states, not nationwide
Bacillus thuringiensis israeliensus (Bti)	Highly effective if applied at correct time, efficacy depends on injestion by larvae, high turbidity or suspended solids interfere with injestion	Widely used in various forms, several distributors in US

References: Mian, 1986; Castelberry, 1990; Toyama, 1986; Cohen, 1986; Tennessen, 1993; Jones, 1990; Ali, 1989 uptake of *Bacillus* larvicides, as is the case with organophosphates (Tennessen, 1993). The agent is applied as pellets, dust, or slug injection. Bti becomes active upon ingestion by the larvae. It loses its efficacy as the larvae age or as turbidity increases. A newer bacterial strain, *Bacillus sphaericus*, showed longer activity than Bti in one study but was not as effective as Bti against species other than *Culex* (WRRI, 1989). *B. sphaericus* is approved by the U.S. EPA but state registration is pending. At least one American company is developing the product. Tennessen (1993) recommends weekly treatments with Bti before sampling reaches 0.5 larvae/dipper, blower application for small wetlands, and slug injection for large cells.

Chemical Larvicides

Unlike *Bacillus* larvicides, organophosphate larvicides, such as temephos, are non-specific—they kill whatever animal receives a lethal dose. This means that the dose required to kill the mosquito larvae in a pond could do away with many other invertebrates in the wetland and pose a threat to downstream habitats. If these chemical larvicides are overapplied, the dose may be high enough to be a risk to the health of other animals and an irritant to people. This makes organophosphates inappropriate control agents in populated areas. Some non-phosphitic chemicals that are used as larvicides are methoprene, an insect hormone mimic, and cyromazine, an insect growth regulator which purportedly affects only flies and mosquitos. Cyromazine was found effective in one study of a drainage ditch. A one-time application of cyromazine (0.5 g active ingred./m^3), prevented pupation and emergence for about forty days in a drainage ditch (Cohen, 1986).

The chemical Sevin (carbaryl) is toxic to humans and animals and should not be used.

Insect-Eating Fish

The best fish for mosquito control are those species that reproduce quickly and have a wide tolerance of environmental conditions. The more fish in the pond, the fewer mosquitos that emerge. Castleberry (1990) compared three species - pupfish (*Cyprinodon nevadensis amargosae*), mosquitofish (*Gambusia affinis*), and guppies (*Poecilia reticulata*) - in tanks planted with pondweed and containing *Culex* larvae. Guppies became well established, and tanks containing these fish produced the fewest mosquitos. Mosquitofish placed second and pupfish last. The trouble with pupfish may be that they are egg-laying and the eggs have a narrow environmental tolerance. The live-hatchers did better. Mian *et al.* (1986) observed high survival rates for both the guppy and a different species of pupfish (*Cyprinodon macularius*). In another study, guppies began to die when pH fell below 5.5 (Toyama, 1989), indicating that acidity may be more of a factor than dissolved oxygen for fish survival. This would indicate that fish may not be the best control choice at industrial sites or in waters known to be highly acidic. The natural ranges of these fish should be noted: guppies are non-native; pupfish are native to desert springs and streams of the western US; species of *Gambusia* have a wide range in the US. Native minnows and killifish have done a good job in keeping down mosquitos in Maryland and Delaware and overwinter successfully if ponds are deep enough (at least three feet) (Wolfe, Lesser, personal communication). State DNR personnel should be contacted before any fish are introduced into wetlands.

Copepods

Copepods, tiny swimming crustaceans, feed on mosquito larvae and show some promise. Mosquito larvae consumption by a copepod was compared along with the performance of pupfish and guppies (Mian, 1986). The copepod was not adversely affected by effluent in the water and consumed between 50 and 90% of the mosquito larvae in a 24 to 72 hour period, whether there was other suitable food or not.

Other Animals

Putting up nest boxes to make the site more attractive to martins, swallows, etc., wouldn't hurt in reducing number of adult mosquitos. Tadpoles can be introduced into ponds to increase the frog population but it is unlikely that they are as effective as some of the larvae-eating fish.

Ecological Impacts of Control

Mosquito control techniques other than actual draining or flooding of marshes are fairly recent. The research has focussed on the efficacy of the new techniques and little is known about the ecological side effects. *Bacillus* larvicides supposedly act only on flies and mosquitos. Larvicides tend to be tested in the lab or in the field for target species only (mosquitos). Aside from cursory observation of aquatic invertebrate abundance, no one seems to know what the effects on the whole invertebrate community are. As for the impounding of tidal marshes to control temporary pool species, there are conflicting observations on the impacts to fish diversity and plant productivity depending on the location and native species.

Conclusion

It would seem then, from both an ecological and management standpoint, that designing a wetland that optimizes surface area and plant growth without excessive mosquito production is a more efficient approach than costly manipulations after the fact. It would also seem that, where necessary, biological rather than chemical control of mosquitos is preferred, since the biological controls specifically target mosquito larvae and are harmless to humans, unlike many chemicals even at standard doses. As more comparisons are made between stormwater and wastewater wetlands and also reference natural wetlands, it could well be discovered that mosquito control in stormwater wetlands is rarely warranted. ***—JMC***

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