The Society of Wetland Scientists does not endorse the use of any specific management technique identified in this paper. Rather, the intent of the paper is to consider the wide range of options available to wetland scientists in addressing mosquito control.

Current Practices in Wetland Management for Mosquito Control

I. ABSTRACT

Mosquito-transmitted diseases raise public concerns about the relationships between wetlands and mosquitoes. We recommend that anyone working in wetlands gain a basic understanding of mosquito ecology so they can intelligently communicate with others on mosquito issues.

Mosquitoes are a natural part of most types of wetlands, including those that are natural, restored, or degraded. Because wetlands provide many crucial environmental and socio-economic functions, services, and products, wetland protection needs to be at the forefront of strategies for dealing with mosquitoes, and we should continue to support and encourage efforts to restore wetlands.

Changes to wetlands – either degradation or restoration – can change the likelihood that a given species of mosquito will use those wetlands as larval habitat. As a result, restoration may either increase or reduce the mosquito vectors of mosquito-borne diseases. Mosquito population responses to restoration depend upon the wetland processes that were degraded and the characteristics of processes restored.

Where unacceptable mosquito production situations occur, environmentally compatible control methods to reduce mosquito production may be considered and employed, as long as other important wetlands values and functions are not unduly diminished. Control can be effectively practiced in managed wetlands where water is routinely controlled, constructed wetlands for wastewater treatment, or wetlands used for storm water retention. Some control measures may not be applicable or ecologically desirable in natural, unmanaged wetlands. The examples and practices described herein may require permits; the wetland practitioner should identify and comply with all laws applicable to their project area.

Effective mosquito control requires interdisciplinary efforts (e.g., entomologists, wetland ecologists, hydrologists, restorationists) and an integrated pest management approach. No one mosquito-control strategy fits all situations, and mosquito management should be addressed on a case-by-case basis that identifies local and regional differences in mosquito species, geographic setting, and watershed context. The optimal approach requires mixing and matching strategies using the best available science.

II. INTRODUCTION

Wetlands are recognized for providing important ecosystem services such as wildlife habitat, floodwater control, water quality abatement and carbon sequestration. Wetlands are also recognized as natural sources of mosquitoes and are often included in management programs designed to reduce mosquito production from a wide variety of different sources. Wetland scientists are increasingly asked to address mosquito control and disease issues when dealing with wetland permitting, mitigation, and restoration.

There has been substantial research on mosquito ecology, the role of wetlands and other habitats in disease transmission, and mosquito control methods. However, this information is not always readily available to wetland scientists working in the field and is often not directed at the question of how wetland restoration efforts influence mosquito populations and associated risks.

Wetlands managers, regulators, and scientists must recognize and deal openly with the fact that wetlands produce mosquitoes. Willott (2004) gives an overview about wetland-associated mosquito production problems and the need for all involved parties to address them responsibly. In areas with a history of mosquito production problems, organized mosquito control programs have existed for many years at state, county, or municipal levels. These programs can be a source of professional guidance and other assistance to parties who are creating new wetlands, restoring degraded wetlands, or acting as good stewards and managers of natural wetlands. In areas of the U.S. where mosquito control programs do not exist, or are only weakly funded or supported, the mosquito problems associated with wetlands are particularly challenging to manage.

In the United States, responsibility for mosquito control lies within a hierarchy of local, state and federal agencies charged with addressing concerns ranging from threats to human health to pestilence issues that affect tourism, animal husbandry or the general comfort of the local human population. We do not review the scientific evidence for these societal concerns or make judgments about their validity. However, we recognize that wetland management for mosquito control may be at odds with management for other important goals such as maintaining biodiversity.

For society to meet the mandate of ”no net loss” of wetlands through preservation, creation, and restoration, wetland professionals must address the public’s perception of mosquito production and vector-borne disease with an integrated approach that includes providing public education and outreach, soliciting public input from a wide range of stakeholders, and encouraging research on management techniques that achieve mosquito reduction goals while simultaneously maximizing the ecosystem services provided by wetlands.

The goal of this SWS White Paper is to provide an overview of the context for present-day mosquito control and review some options available to wetland managers to reduce mosquito production in wetlands. The Society of Wetland Scientists does not endorse the use of any specific management technique identified in this paper. Rather, the intent of the paper is to consider the wide range of options that are currently available to wetland scientists charged with addressing mosquito control concerns. It is the goal of SWS to encourage ongoing research on management techniques and policies that continue to address societal concerns about mosquitoes and maintain robust wetland ecosystem services.

III. MOSQUITO ECOLOGY

Mosquito-transmitted diseases of potential concern to public health officials in North America are West Nile Virus, Eastern Equine Encephalitis, Western Equine Encephalitis, and La Crosse Encephalitis. The biology and ecology of mosquito species is highly relevant to the informed management of wetlands for such mosquito-transmitted diseases. For example, the primary habitat for specific species of *Culex*, the primary vector for West Nile Virus, changes across the United States. Storm water systems may be of concern in urban areas in most cities the US, while over-irrigated agricultural areas are a particular concern in the western US.

The females of different mosquito species can be highly selective of oviposition sites according to environmental factors and hydrologic conditions. However, mosquitoes can be classified into two general groups based on their egg-laying and hatching behavior (Knight et al. 2003), namely the floodwater-ephemeral water habitat mosquitoes or the permanent-semipermanent aquatic habitat mosquitoes. Floodwater mosquito eggs are deposited on moist substrate and do not hatch until subsequently inundated. They include mosquitoes in the genera *Aedes*, *Ochlerotatus*, and *Psorophora* that are primarily daytime or crepuscular feeding mosquitoes. These mosquitoes can be significant vectors for diseases (Monath 1988). Floodwater mosquitoes are prevalent in sites receiving agricultural runoff and along wetland edges. Adults do not overwinter, but eggs laid in soil or in artificial containers do.

Permanent or semipermanent aquatic habitat (includes standing water) mosquitoes lay eggs singly (*Anopheles* spp.) or in large rafts (*Culex* spp.) of 100 eggs or more on the water surface. These eggs hatch within a few days without an external hatching stimulus.

IV. RISK ASSESSMENT

Managers working in wetlands with significant nearby human occupancy may be required to address mosquito production without delay, and often rely on larval and adult mosquito surveillance and control responses provided by mosquito control programs. Risk assessment is the first step in developing a mosquito control strategy. Managers, regulators and the public must recognize that the mere presence of a wetland does not indicate the site is an important source of mosquitoes or mosquito-transmitted disease. Because wetlands are only one facet of mosquito-control, it is important to fully understand the extent to which responses that negatively affect wetland ecosystems will actually contribute to solving a given mosquito problem. People assessing risks should determine the answers to the following questions:

a. How do local and regional wetlands fit into the overall mosquito or mosquito vector problem?
b. When does a mosquito problem become severe enough to warrant interventions that impact wetlands?
c. How will potential control strategies be tailored to address the problem while minimizing wetland impacts?
d. Is there a phased or step-wise approach that can limit response to only that

required to control specific situations?

e. Have alternatives been considered that minimize the loss of valued wetland services or avoid potentially converting wetlands from one type to another?

Mosquito management plans generally include monitoring of mosquito populations and mosquito-transmitted diseases, and they define action levels based on anticipated health threats, nuisance concerns and other societal expectations. Mosquito control programs should follow an established Mosquito Management Plan that incorporates the principles of Integrated Pest Management.

Mosquito monitoring or surveillance results should be used to determine the threat level identified in the mosquito management plan. Mosquito monitoring or surveillance is often carried out by professional mosquito control programs such as mosquito control districts, mosquito abatement districts, vector control districts, or county and state health departments. The objectives of such mosquito monitoring should be to establish both baseline and current data of mosquito species and abundance, map breeding and/or harboring habitats, estimate relative changes in population sizes, assess disease presence and nuisance levels.

Management plans should include threat categories that represent a hierarchical scale of increasing risk to human or wildlife health based on local or regional disease activity, species-specific mosquito-vector population numbers, or simply overall mosquito population numbers. The plan should then include appropriate actions to take for each threat-level category. Perceived threats to human health, wildlife health, economic activity or human comfort vary temporally and spatially, so threats must be determined locally.

Thresholds for treatment actions may be species specific for larval, pupal, and adult mosquito vectors and reflect the potential significance of a particular species or group of species in a particular health threat. For example, mosquito species known to be important in the transmission cycle of a disease in a particular geographic area, may have a lower action threshold than species with lesser transmission roles. It is also important to distinguish genuine disease-related health threats from public nuisance levels in considering control actions. In some cases, the same mosquito species may be linked to both health and nuisance concerns. In establishing categories, SWS encourages plans that weigh any negative impacts of actions on wetland ecosystems against the negative impacts of mosquitoes on humans and wildlife.

V. MOSQUITO CONTROL STRATEGIES

The control strategies discussed below recognize that some wetlands are more heavily managed than others, either by design or necessity. For the purposes of this paper, *lightly managed* wetlands are those that are intended to be natural or require minimal management. *Heavily managed* wetlands are those that require intensive human management, generally including active water-level manipulation.

Many approaches and techniques are available to lessen mosquito production from wetlands, but the primary environmental, ecological, and regulatory reasons for wetland creation or restoration cannot be ignored when developing mosquito management plans. In some situations, a compromise between achieving all the desired wetland values and functions versus near-total suppression of mosquito production may be necessary (Collins and Resh 1989, Dale and Knight 2008). For constructed or restored wetlands, design features and management practices based on basin configurations, water-level management, mosquito predators, and vegetation management can help reduce mosquito production (Knight et al. 2003, Mayhew et al. 2004). If such steps fail to achieve satisfactory mosquito control, then additional biological or chemical controls might be needed, and may become the responsibility of local mosquito control programs or licensed mosquito control professionals. The extra expense incurred by mosquito control programs for contending with mosquito production from created or restored wetlands can be viewed as another cost of having or creating wetlands, an expense that may need to be planned for as an element of responsible wetland stewardship.

The potential change in mosquito production as a result of restoring wetlands can be minimal, particularly when the proportion of restored wetlands is relatively small relative to the overall wetland resource area. Furthermore, if environmentally compatible mosquito-control, source-reduction measures are incorporated into a restoration project's location, design, construction, management, and maintenance, increases in mosquito production can be minimized. This will be most important where wetland restoration projects involve relatively large acreages in close proximity to human habitations and may help to avoid any increase in mosquito control measures.

A) Techniques Suitable For Natural and Lightly Managed Wetlands

i. Passive approaches

Passive techniques are useful when the wetland manager wishes to avoid ecological impacts to natural or restored wetlands that can result from control techniques. In such cases, managers may warn the public about presence of mosquitoes or restrict public access to the wetland rather than implement mosquito control. Such actions should always be based on surveillance data. In crafting messages to the public, the wetland practitioner must avoid creating a perception that wetlands are inherently mosquito "factories." Rather, it should be stressed that while mosquitoes are produced in wetlands like other aquatic insects, in most cases their numbers do not reach public health concern or even nuisance levels. In some cases, a healthy, balanced ecosystem may retain enough predators of mosquito larvae to regulate mosquito population levels (Brodman et al. 2003). A passive strategy may not be acceptable in cases where there is a public health threat or the wetland produces more mosquitoes than the local human population can tolerate.

ii. Biological control and mosquitocides

If passive approaches are not sufficient and additional control is needed, mosquito control agencies will generally implement an integrated pest management protocol that includes the introduction of mosquito larvae predators and the judicious use of insecticides (i.e. mosquitocides). Biological control is typically focused against the aquatic stages of the mosquito life cycle. At present, small, larvivorous fish are the only biological control agent for larval mosquitoes that is practical and economically viable (Coykendall 1980, Swanson et al. 1996). There is no credible scientific evidence that any avian (Kale 1968) or bat species (Whitaker and Long 1998, Tuttle 2000) can effectively control adult mosquitoes. However, pond-breeding salamanders have been reported to regulate population levels of mosquito larvae and zooplankton (Brodman et al. 2003).

The primary predator species used for biological control has been the mosquitofish (*Gambusia* spp., family Poeciliidae); however, the efficacy of alternative species continues to be evaluated (Cech and Moyle 1983, Bay 1985, Offill and Walton 1999, Walton 2007). Some of the controversies regarding the efficacy of *Gambusia* outside its native range are examined in Rupp (1996), Gratz et al. (1996) and Pyke (2008). One important issue is the risks to native ecosystems of introducing a non-native species. Questions that remain to be addressed include: (i) under what environmental conditions are the fish effective as biological control agents?, (ii) do the reductions in mosquito populations significantly reduce disease transmission to humans?, and (iii) do mosquitoes show compensatory responses to the reduced effects of larval stage density dependence?

Although there are drawbacks to using non-native larvivorous fishes, there are settings where this approach can be ecologically-sound, practical and cost-effective, while avoiding or reducing the need for insecticide treatments (Sakolsky-Hoopes and Doane 1998, Kent and Sakolsky-Hoopes 1999). The creation or restoration of aquatic habitat for native larvivorous fishes such as killfish in salt marshes, or certain species of minnows in freshwater wetlands, can substantially assist with mosquito control (Harrington and Harrington 1961, Nelson and Keenan 1992, Kent and Sakolsky-Hoopes 1999, Van Dam and Walton, 2007, Meredith and Lesser 2007).

When passive and biological control methods are insufficient, current mosquito control programs prefer to use larvicides because control efforts are focused on the source of the problem and the area treated with larvicides is typically much smaller than with adulticides that are applied after adult mosquitoes have emerged and dispersed widely. The most commonly used larvicides are:

(1) Monomolecular films (MMF) to treat container-type habitats or other relatively small wetland areas MMFs spread across the water surface and suffocate immature mosquitoes. MMFs usually persist for a short period (~1-2 days), and some formulations are approved for use on potable water supplies.,

(2) Bacteria that produce mosquito toxins must be ingested by the larvae to be effective. Two types that are toxic to mosquitoes are naturally occurring bacilli -- *Bacillus thuringiensis* var. *israelensis* (Bti) (de Barjac) and *B. sphaericus* (Neide) -- and present minimal risks to humans and other non-target organisms at current application rates and by common modes of contact. They also degrade rapidly in the environment.

(3) Insect growth regulators such as methoprene mimic insect hormones involved in molting. Immature mosquitoes exposed to sufficient dosages of methoprene do not molt

into adults. Methoprene also has very little (if any) effect on non-target wetland organisms when used in mosquito control formulations (Schmude et al. 1998, Balcer et al. 1999).

(4) The organophosphate temephos is a chemical insecticide that for some mosquito control programs provides the only affordable, practical, and effective larvicide for treating large geographic areas. It can also be an alternative control product for mosquito species or in habitats where Bti or methoprene do not give efficacious control.

If larvicides cannot be used or prove ineffective, it might be necessary to resort to the use of adulticide. This method usually involves more widespread applications of the insecticides, often directly over or within where people live, work, or recreate. The most commonly used adulticides include organophosphates (e.g., malathion, naled) and synthetic pyrethroids (e.g., permethrin, resmethrin, sumithrin).

The U.S. Environmental Protection Agency registers mosquitocides (for larvae or adults) that it determines do not pose unreasonable risks to human health, wildlife, or the environment. Information about how the EPA registers and authorizes the use of mosquitocides, and the agency's perspectives about the risks of mosquitocide use to humans, wildlife, or the environment, are contained in the "Mosquito Control Fact Sheets" available at http://www.epa.gov/pesticides/factsheets/health_fs.htm.

The choice of the mosquitocide to use is a complex decision involving many variables, including types of mosquito species to be controlled, life stages involved, types and extents of habitats to be treated, the presence of non-target species of special concern, and other environmental impacts.

iii. Water-level management

The flow of water through a wetland and its related volumetric turnover rate influence mosquito production, but flow rates detrimental to immature mosquito survival are too high to be practical for effective mosquito control in most types of wetlands. Managing wetlands for adequate water turnover rates enhances mosquito control by helping to eliminate the accumulation of stagnant, organically-rich waters that attract certain standing-water mosquitoes such as *Culex* spp. Flowing water also maintains high oxygen levels, which contributes to reducing toxic metabolites. These factors enhance the survival of the aquatic predators of mosquito-larvae. In many Midwestern wetlands, such as fens, sedge meadows, dolomite prairies, etc., groundwater contributions from seeps, springs, and upwellings can provide this slow flushing, as well as maintain colder water temperatures not suitable for many mosquito species. Water levels management is also used as an indirect means to manipulate the presence and biomass of vegetation (see B-iii below).

B) Techniques Suitable for Heavily Managed Wetlands

Mosquito control techniques are applied somewhat differently than described above in wetlands that are intended to be heavily managed. The discussion below assumes that mosquito control, as opposed to maintaining of enhancing other wetland functions and services, is the primary goal of wetland management in such cases.

i. Basin Design And Topographic Configurations

Natural and lightly managed wetlands should generally not be subjected to changes in topography for the sole purpose of mosquito control, with the possible exception of restoring predator balance in a degraded wetland. However, in heavily managed wetland systems where mosquito reduction is the primary goal, there are topographic design considerations that may be applied to minimize mosquito production and the need to apply pesticides.

Wetlands that lack deep water zones (water depth > 1.5 m) and vigorous populations of mosquito predators are more prone to mosquito production problems than those that contain permanent deep water zones. Although having deep water zones will not always prevent high levels of mosquito production from occurring, deep water areas provide habitat for important predators of mosquitoes such as larvivorous fishes, predaceous aquatic insects, and salamander larvae.

Wetlands that have gently sloping margins or edges (e.g., a vertical:horizontal slope of <1:10) tend to develop dense emergent vegetation in shallow areas. The physical structure of emergent vegetation provides several important wetland functions (Mitsch and Gosselink 2000, Kadlec and Wallace 2009) and is frequently a goal in wetland mitigation or restoration. However, dense vegetation can also create refugia where mosquito larvae hatch and survive to emergence as adults. In less disturbed systems, this increase in mosquito production may be offset with predation; however, more disturbed wetlands may not provide for this control. Steeper side slopes (e.g., >1:4) are less prone to develop dense vegetative cover across extensive areas of a wetland. Unfortunately, such slopes may be more susceptible to soil erosion. Regardless of the slope angle, if the intent of the slope angle is primarily to control mosquito production, the sides should uniformly and continuously taper downward from shallow edges towards a deeper central water body to prevent isolated pockets of standing water along a wetland's margins during drawdown or droughts, as well as after rainfall events that do not completely fill the wetland basin (Mulhern 1980, Knight et al. 2003).

ii. Water-Level Management

Design features and operations that move water through wetlands are critical to managing mosquitoes; however, prior to selecting this management technique, a wetland scientist must examine the type and functions of the wetland in question. Numerous wetland types are not suitable candidates for significant water-level management.

In addition to the goal maintaining a permanent pool of water (see B-iii below), the margins of wetlands should not undergo extensive wet-dry-wet cycles that can lead to production of floodwater mosquitoes from peripheral micro-habitats that lack mosquito predators. When a wetland dries out (e.g., as in seasonal wetlands or vernal pools), many aquatic predators of mosquito larvae perish, while floodwater mosquitoes can survive as eggs that remain viable in moist mud or desiccated bottoms and then hatch soon after water is again present. The floodwater mosquitoes (*Aedes*, *Ochlerotatus*, and *Psorophora* spp.) produced from such temporary waters can transmit the causative agents of serious diseases and are capable of long-distance flights. When a wetland has permanent water cover, along with open channels or paths through thick vegetation for aquatic predators of mosquito-larvae to move around, the production of standing-water mosquitoes (e.g., *Culex* spp.) is lessened. Deeper water also reduces production of mosquito larvae that attach to the roots of emergent plants (e.g. *Coquilletidia perturbans*).

iii. Vegetation Management

Dense emergent or floating vegetation cover creates refugia for mosquitoes from their predators. The primary goal of vegetation management is to create open water areas that present unfavorable conditions for immature mosquito development and for adult mosquito resting. Open water areas enhance the negative effects of wind on mosquito activity, deter oviposition, reduce immature mosquito survival by increasing predation and drowning by waves, and lower the accumulation of organic debris in a wetland system.

Management involving selective plant removal, limited controlled burning, or minimal applications of herbicide may be necessary when water depth manipulation cannot adequately prevent the excessive growth of emergent plants. Limited mowing, disking, and grazing are also used to alter plant species composition and abundance in order to enhance use by certain species of wildlife (Payne 1992, Kwasny et al. 2004).

In most instances, routine vegetation management can significantly reduce mosquito production, but if done incorrectly, it can greatly enhance mosquito production. For example, razing macrophytes or inundating dried plant biomass for vegetation control purposes may significantly increase mosquito production. Incorporating design features such as raised planting beds and deep water zones that limit the proliferation of emergent macrophytes (Thullen et al. 2002) provide more effective mosquito control than does repeated vegetation removal.

Although vegetation suppression is effective for mosquito control, it is generally not favorable for important wetland functions and services such as wildlife habitat or water quality improvement. Many wetland functions emerge directly from the diversity and primary productivity of the plant community. In addition, disturbances such as mowing, disking and grazing may introduce opportunities for invasive species. Some level of compromise in vegetation cover management may be required, depending on the balance between the desires for maintaining wetland functions and avoiding increased mosquito production.

iv. Source Reduction

Source reduction refers to techniques that are generally, but not always, non-chemical and designed to limit mosquito production at oviposition sites or larval-rearing sites. Because source reduction typically involves habitat modification, the strategy is generally used as a final recourse to reduce mosquito production or as an alternative to reduce insecticide use. The range of effects that source reduction approaches have on wetland functions has not been fully assessed, but individual techniques present problems in a variety of situations. The use of source reduction techniques in natural wetlands requires careful consideration by stakeholders because of the inevitable tradeoffs between the benefits for mosquito control and reduced pesticide use, and the adverse effects of habitat alteration on wetland ecosystem function. For this reason, we consider source reduction appropriate primarily for wetland ecosystems that are heavily managed.

Source reduction approaches in mosquito-control integrated pest management programs are usually preferable to the use of insecticides, provided that the source reduction can be practicably and effectively applied and it does not cause unintended or unacceptable environmental impacts. The type and extent of source reduction that is possible in a given wetland depends upon how much water-management capability exists for managing water flows or wetland water levels. More sophisticated source reduction can be achieved in a coastal impoundment with an automated vertical lift than one with a simple riser-board structure. The automated vertical lift allows fine-tuned dynamic management of tidal exchanges and marsh water levels. Similarly, more can be achieved in a stormwater retention pond with an adjustable riser-board outlet versus a fixed-crest weir outlet. For many natural wetlands, especially groundwater-fed wetlands with saturated soils for a significant portion of the growing season, this technique is not appropriate or even possible without destroying the wetland or converting it to a completely different wetland type.

Source reduction in wetlands customarily encompasses three broad categories of control measures: (1) basin/topography design configurations, (2) water-level management, and (3) vegetation management. These measures are most applicable wetlands that were constructed or developed for specific purposes, often focusing on a single wetland function, while often providing other wetland functions. Managed wetlands include wildlife refuges in which water control is routinely practiced, wetlands constructed for wastewater treatment, and wetlands constructed for or used as stormwater retention facilities, although there are many other wetland types that may fall under this category (e.g., wetlands created on golf courses). The source reduction measures specified may or may not be applicable to natural or less managed wetlands.

There is a large literature on best management practices (BMPs) for achieving source reduction in wetlands, only a few of which we cite here. While the reports are often written for a particular geographic region, similar approaches are applicable across regions. Besides offering prescriptions for applying source reduction techniques to control mosquito production in wetlands, some of the works cited below also contain citations of studies and surveys that have documented the types and extent of mosquito production found in natural wetlands, stormwater management basins, wetlands mitigation projects, waterfowl impoundments, and other kinds of wetlands.

Analyses, recommendations or BMPs that address mosquito production in wetlands have been published for New Jersey (Shisler and Charette 1986, NJDEP 2004), Maryland (Dorothy and Staker 1990, Bradley and Kutz 2005), Florida (O'Meara 1997, University of Florida 1998), California (Metzger 2004, Walton 2003), and coastal wetlands (Brockmeyer *et al.* 1997). California published a set of BMPs for mosquito control in seasonal, semipermanent, and permanent wetlands managed for waterfowl and other birds (Kwasny et al. 2004). Finally, the EPA recently released a new nationwide set of BMPs for stormwater retention ponds and their associated wetlands (see the agency's *Stormwater Wet Pond and Wetland Management Guidebook*). EPA has incorporated these mosquito control measures in the siting, design, construction and management of such facilities (EPA, 2009).

The source-reduction technique known as "open marsh water management" (OMWM) is a selective ponding-and-ditching technique designed to encourage predation of mosquito – larvae by native fishes in tidal wetlands. The technique is described by Meredith et al. (1985) for Delaware, with other states such as Massachusetts, New Jersey, Maryland, and Florida having their own OMWM guidelines. OMWM alters the wetland topography and hydrology to achieve mosquito reduction. Although the goal is to minimize changes in wetland structure and function, OMWM can effectively alter the functional type of a wetland. For this reason and others, this is not a technique applicable to all locations or one that would be accepted in all locales. "Runnelling" is a modification of OMWM (Hulsman et al. 1989) that may be used in tidal marshes with acid sulphate soils. Runnelling involves the selective excavation of shallow channels that provide tidal circulation and larvivorous fish access to mosquito-breeding depressions. OMWM and its impacts are reviewed by Wolfe (1996) and the long-term impacts of runnelling are described by Dale (2005).

It should be noted that the old parallel-grid-ditching method of source reduction for salt marsh mosquito control, which involved non-selective excavation of open tidal ditches geometrically placed over vast acreages, was generally ineffective in controlling mosquitoes, had significant negative impacts on coastal marshes, including substrate disturbances that led to the introduction of invasive species (e.g., Phragmites), drying of marsh surfaces that led to increased oxidation and loss of marsh substrate, and changes in plant communities (e.g. establishment of shrubs) and wildlife habitat values The technique of OMWM, when properly employed, avoids almost all of these past adverse impacts. In fact, in previously parallel-grid-ditched marshes, the installation of OMWM systems is often viewed as a habitat-restoration technique by restoring standing water to marsh surfaces that have been dewatered by the parallel-grid-ditches (Meredith et al 1985).

VI. SUMMARY

Wetlands are fragile systems that nevertheless provide many crucial environmental and socio-economic functions, services, and products As society is confronted with new and emerging mosquito-borne diseases, the need to simultaneously protect human health and wetland functions will only increase. If society wishes to sustain the mandate of "no net loss" of wetlands through preservation, creation, or restoration of these valuable ecosystems, then wetland professionals must address the public perception of mosquito production and vector-borne disease with an integrated approach that includes providing public education and outreach while soliciting public input. Additionally, society must confront development that significantly degrades wetlands, juxtaposing humans with unstable biological systems.

Wetland professionals, regulatory agencies, public health organizations, and mosquito control agencies should consult with one another and the public during the planning, design, implementation, management and maintenance phases of wetland creation, restoration or enhancement projects. One price of creating and restoring wetlands may be the need to monitor for mosquito production. Criteria for the long-term success of wetland creation or restoration projects must include the minimization of mosquito production to the extent practicable, done in an environmentally-compatible manner consistent with the achievement of other objectives specified for a particular project (Willott 2004).

Mosquito species have evolved to exploit a wide variety of habitats. Because mosquitoes are a natural part of wetland ecosystems, permanent and total elimination of mosquitoes from wetlands is not a realistic or achievable goal. However, current scientific understanding supports the position that we can take environmentally-compatible measures to help minimize mosquito production from natural, created, or restored wetlands, and especially from many types of degraded wetlands. The SWS advocates science-based use of system design concepts that encourage ecological diversity and natural mosquito predators in all wetland types, minimizing to the extent practicable the creation or perpetuation of site features that promote mosquito production in the first place.

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ABBREVIATIONS

Bti	Bacillus thuringiensis var. israelensis
BMPs	best management practices
EPA	U.S. Environmental Protection Agency
MMF	monomolecular films
NJDEP	New Jersey Department of Environmental Protection
OMWM	open marsh water management
SWS	Society of Wetland Scientists
WNV	West Nile virus

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