Occurrence and relative abundance of mosquitoes in stormwater retention facilities in North Carolina, USA


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Abstract Throughout the 2004 mosquito season, 52 stormwater retention facilities were sampled to characterize the seasonal occurrence and relative abundance of mosquito species in relation to the structural complexity and biological diversity of the facilities. The three different types of facilities included standard wet ponds (n = 20), innovative ponds (n = 14), and wetland ponds (n = 18). All retention structures were sampled at the beginning, middle and end of the mosquito season so that seasonal changes in mosquito production could be characterized. Overall samplings, mosquitoes were collected from 34% of the retention structures. Fourteen species representing 7 genera were collected, but only 5 species (Culex erraticus, Cx. territans, Anopheles quadrimaculatus, An. punctipennis and Uranotaenia sapphirina) were commonly collected in all three types of stormwater management facilities. In general, the seasonal prevalence and relative abundance of mosquito species did not vary among three types of retention structures. A significant association (P < 0.01) between the presence of mosquito larvae or pupae and the absence of mosquitofish was found for innovative and wetland stormwater retention facilities but not for standard retention facilities (P > 0.05).

Keywords Gambusia; mosquitoes; North Carolina; stormwater; wetlands; wet ponds

Introduction
Suburban population growth leads to increasing concentrations of people in smaller and smaller geographic areas. With escalating population growth, communities are confronted with meeting increased demands for services that involve water disposal as well as water supply. Development of management plans to handle run-off from pavement is a critical environmental issue. Parking lots, roads and other impervious surfaces increase substantially the amount of runoff delivered as non-point discharge into receiving waters in the surrounding landscape. To mitigate the potential environmental impacts of surface runoff and to meet Federal and State water quality regulations that restrict discharges from non-point sources to surface water, communities have developed stormwater management programs around Best Management Practices (BMPs) (Maršálek and Sztruhár, 1994). These systems may involve typical curb and gutter, separately sewered catchment systems and various forms of infiltration or retention structures for stormwater.

Stormwater retention facilities, including innovative ponds and wetland ponds, constructed today are structurally and biologically complex relative to wet ponds that have been used traditionally for retaining runoff. Modern facilities are usually planted with a variety of species of macrophytes that are efficient at removing nutrients and, these structures may have forebay areas for trapping suspended sediments in runoff. Usually these structures are placed in the landscape in close proximity to human habitations.
Stormwater management facilities have been reported to produce nuisance and vector species of mosquitoes (Smith and Shisler, 1981; Santana et al., 1994; Russell, 1999). Public concern over mosquito-transmitted disease agents, principally West Nile virus, prompted us to survey stormwater management facilities in North Carolina for mosquitoes. Throughout the 2004 mosquito season, we sampled stormwater retention facilities for mosquitoes. The premise of our survey was that as the structural and biological complexity of retention facilities increased, the diversity and relative abundance of mosquito populations would correspondingly decrease. In this report, we present results of the survey and we provide recommendations on how stormwater retention facilities should be constructed to reduce mosquito production.

Materials and methods

Study sites

Stormwater facilities were selected for sampling in consultation with local water resources personnel. All of the 52 facilities that we sampled were designed to be stormwater retention structures. The facilities were located in suburban landscapes of 12 counties in the coastal plain and piedmont regions of NC. The facilities ranged in size from approximately 0.25 to 2 ha in surface area and, consisted of constructed wetlands (18/52), wet ponds (20/52), and innovative ponds (14/52).

Wet ponds were defined to be traditional retention basins that maintained a constant pool of water. The ponds were relatively deep throughout, typically 2 m or greater. Standard wet ponds were designed so that there was little, if any, vegetation growth along the fringe of the water body. This did not preclude the growth of more aggressive species like cattail (Typha spp.) or black willow (Salix nigra). In contrast, stormwater wetlands represent the opposite extreme in retaining facilities as they are designed so that vegetation grows across the water surface of the facility. Any impoundment with at least 60% plant coverage was designated as a stormwater wetland in our study. Stormwater wetland design guidance in North Carolina (Hunt and Doll, 2000) recommends that portions of stormwater wetlands be kept as open water areas so that there are portions of the wetland that will not go dry in times of drought. These deep pool areas continuously support small fish. Other than deep pools, the average depth in a stormwater wetland ranges from 10 to 20 mm. Innovative wet ponds are a combination of a standard wet pond and a stormwater wetland. Aquatic vegetation fringes are specifically designed into the wet pond. These fringes, also called littoral shelves, are wetland features inside ponds that typically comprise about 20–30% of the pond’s surface area. In our study, an impoundment was considered an innovative wet pond if the vegetative coverage (by design) of the surface area ranged between 5% and 60%. Like stormwater wetlands, the average water depth over littoral shelves is shallow, and the shelves include zones that range from being nearly always wet to those areas that are dry except during and in the immediate aftermath of a moderately sized rain event (ca. 25 mm). Well designed wetlands and wet ponds (Hunt and Doll, 2000) force a variety of plants to grow by incorporating undulating topography and planting a diversity of species. Some of the most popular stormwater wetland and innovative wet pond herbaceous species are pickerelweed (Pontedaria cordata), arrowhead (Sagittaria spp.), softstem bulrush (Scirpus validus), and several species of Juncus. Certain species, such as cattail (Typha spp.), are never intentionally planted due to their aggressive nature and proclivity toward becoming a dominant monoculture. Another feature usually associated with stormwater wetlands and innovative wet ponds is the forebay inlet area for trapping sediment. Some standard wet ponds also include forebays, particularly newer facilities. Generally, wetland stormwater management structures were located in wooded landscapes in residential areas or in...
institutional settings such as school campuses. Wet ponds were generally associated with commercial businesses; consequently, these stormwater facilities were located in open areas with little bank side vegetation that would shade the pond edge. These ponds often contained trash and other floatage as the facilities were designed to catch and retain runoff from parking lots. Innovative pond facilities tended to be located in suburban residential areas or in lower density commercial applications. From all facilities, stormwater exited through a series of outlets, including risers and weirs.

**Study design**

All 52 stormwater facilities were sampled from mid May to mid October 2004 on three occasions that corresponded to the beginning, middle and end of the mosquito season so that seasonal changes in occurrence and relative abundance of mosquito species could be characterized in each facility. From facilities that were approximately 0.25 ha in size, a sample was taken near the inlet or from the forebay area, along the shoreline from the middle area of the main water body, and near the outlet or from the area that was opposite the inlet. For facilities that were > 0.25 ha but less than 1 ha in size, an additional two samples were taken from the shoreline of the main body of the facility. An additional 1–2 samples were collected from facilities that exceeded 1 ha in size. Thus, a minimum of 3 samples and a maximum of 7 samples were collected from the stormwater management facilities in our study. When a retention structure was sampled, conditions that would have likely promoted the production and survival of mosquitoes were noted. Such conditions included a lack of mosquitofish (*Gambusia affinis*), debris and other floatage, and willow trees (*Salix* spp.) or cattail (*Typha* spp.) along the shoreline or in the structure that shaded the surface of the water and provided harborage for mosquitoes from predators.

**Collecting and processing mosquitoes**

Mosquito larvae and pupae were sampled along the shoreline with a standard “pint” dipper. Samples were collected by the same person throughout the survey. Each sample consisted of 10 dip collections that were pooled and placed in a labeled Whirlpak bag (Fisher Scientific, Pittsburgh, PA). Within each facility, samples were collected from areas that would likely have harbored mosquitoes. Areas sampled included floating debris, algal mats and, around emergent herbaceous plants (e.g. cattail) and woody vegetation (e.g. willow trees). After collection, samples were transported to laboratory facilities where mosquitoes were killed in hot water and transferred to labeled vials containing ethanol (80%). Some pupae were allowed to emerge and the adults were pinned and labeled with collection information. Larvae and adults reared from pupae collected in the retention ponds were identified using characters described in Slaff and Apperson (1989) and Darsie (2002), enumerated, and the mosquito counts entered into a database. Reinert et al. (1997) determined that the species previously called *An. quadrimaculatus* Say, is a complex of 5 species. Because of poor quality of specimens and many early instars we identified them as *An. quadrimaculatus sensu lato*. *Anopheles quadrimaculatus sensu stricto*, is a common member of this complex in North Carolina (Levine et al., 2004).

**Data analysis**

Univariate descriptive statistics were calculated for each sampling period and over all sampling periods for the relative abundance of each mosquito species and the prevalence of mosquito-positive retention facilities. Contingency tables were constructed using presence-absence data. The statistical significance of differences in observed frequencies of occurrence of mosquitoes for the three types of facilities were tested by chi-square analysis (PROC FREQ, SAS Institute, 1999). The hypotheses that the presence of
mosquitoes in retention facilities was associated with the absence of fish or, presence of cattail or willow was tested using a chi-square test (PROC FREQ, SAS Institute, 1999). In these analyses, the number of each type of facility or total number of each type of facility sampled over the entire mosquito season that contained mosquitoes were dependent variables, and the number of facilities that lacked fish or contained stands of cattail and/or willow were independent variables. Frequency distributions for the numbers of species collected in each type of retention facility were constructed using presence-absence data. We used Cochran’s Q test (PROC FREQ, SAS Institute, 1999) to evaluate the supposition that species richness for all three types of retention facility was not equivalent. The Q statistic, which is an approximate chi-square statistic, has been used for testing the homogeneity of species-by-samples data (McCullough, 1985). The intensity of mosquito production was evaluated by comparing the average number of mosquitoes collected per sample in the three types of retention facilities using a nonparametric Kruskal-Wallis test (PROC NPAR1WAY, SAS Institute, 1999). Only the 5 most common mosquito species were included in this analysis; i.e., Culex erraticus (Dyar & Knab), Cx. territans Walker, Anopheles quadrimaculatus sensu lato, An. punctipennis (Say), and Uranotaenia sapphirina (Osten Sacken).

Results

Occurrence and relative abundance of mosquitoes

A total of 14 mosquito species representing 7 genera were collected from the stormwater retention facilities sampled (Table 1). Mosquitoes were collected most frequently during the second sampling period in summer when the prevalence rate for mosquito-positive retention facilities was 38.5%. Over the three sampling periods, larvae or pupae of at least one mosquito species were collected in 34% of the retention facilities sampled. Mosquitoes were less prevalent in the fall sampling period, but collections yielded higher dip counts on average for most species (Table 1). Culex erraticus, Cx. territans, Anopheles quadrimaculatus, sensu lato, An. punctipennis and Uranotaenia sapphirina were, in general, the most commonly collected mosquito species. Floodwater mosquitoes, Aedes vexans (Meigen) and Psorophora columbiae (Dyar & Knab), were collected in a

<table>
<thead>
<tr>
<th>Species</th>
<th>Average number per sample† (% occurrence)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spring (n = 52)§</td>
</tr>
<tr>
<td>Aedes vexans</td>
<td>3.7 (7.7)</td>
</tr>
<tr>
<td>Anopheles crucians</td>
<td>0.3 (1.9)</td>
</tr>
<tr>
<td>Anopheles punctipennis</td>
<td>0.5 (7.7)</td>
</tr>
<tr>
<td>Anopheles quadrimaculatus</td>
<td>0.3 (11.5)</td>
</tr>
<tr>
<td>Culex erraticus</td>
<td>1.0 (7.7)</td>
</tr>
<tr>
<td>Culex nigripalpus</td>
<td>0.0 (0.0)</td>
</tr>
<tr>
<td>Culex pipiens</td>
<td>0.3 (1.9)</td>
</tr>
<tr>
<td>Culex restuans</td>
<td>0.0 (0.0)</td>
</tr>
<tr>
<td>Culex saltinarius</td>
<td>1.0 (1.9)</td>
</tr>
<tr>
<td>Culex territans</td>
<td>2.0 (13.5)</td>
</tr>
<tr>
<td>Culiseta melanura</td>
<td>0.0 (0.0)</td>
</tr>
<tr>
<td>Ochlerotatus japonicus</td>
<td>0.0 (0.0)</td>
</tr>
<tr>
<td>Psorophora columbiae</td>
<td>1.0 (1.9)</td>
</tr>
<tr>
<td>Uranotaenia sapphirina</td>
<td>0.3 (7.7)</td>
</tr>
<tr>
<td>Overall species</td>
<td>0.7 (30.8)</td>
</tr>
</tbody>
</table>

†Each sample consisted of 10 dip collections
§n = the number of stormwater retention facilities sampled
small number of facilities. *Culiseta melanura* (Coquillett) and *Ochletotatus j. japonicus* (Theobald) were collected in only one wetland and one innovative retention facility, respectively. Over the mosquito season, a total of 6, 7 and 11 mosquito species were collected in innovative, standard and wetland retention facilities, respectively. The average number of species collected from mosquito-positive facilities was 1.8, 2.7 and 2.7 species for standard, innovative and wetland pond retention facilities, respectively. There was no difference in the richness of mosquito species collected in the three types of stormwater retention structures (\(P > 0.05\); df = 10; \(Q = 10.4\); by Cochran’s \(Q\) test). Overall mean numbers for the 5 most common mosquito species were 1.9, 1.9 and 2.1 specimens per 10-dip sample for standard, innovative and wetland ponds, respectively. The intensity of mosquito production did not vary significantly between the types of retention facilities (\(P = 0.63\); chi-square = 0.91; df = 2; by Krushal-Wallis test).

Observed numbers of retention facilities that produced mosquitoes were not significantly different (\(P > 0.5\); df = 2; chi-square < 1.0; by chi-square test) between the types of retention facilities that were sampled. Likewise there were no apparent differences in the seasonal production of mosquitoes in the three types of retention facilities sampled.

**Environmental determinants of mosquito production**

A significant association (\(P < 0.01\); df = 1; chi-square = 10.0; by chi-square test) between the absence of mosquitofish based on visual detection and the collection of mosquitoes was found for innovative and wetland stormwater retention facilities, but not for standard wet ponds (\(P = 0.056\); df = 1; chi-square = 3.6; by chi-square test) (Table 2). The presence of mosquitoes was not significantly associated (\(P > 0.05\); df = 1; chi-square = 3.0; by chi-square test) with the presence or absence of cattails or willows in innovative and wetland stormwater retention impoundments (Table 3). In contrast in standard wet ponds, when mosquitoes were not collected, it was more likely that cattail or willow would be absent than present (\(P < 0.01\); df = 1; chi-square = 10.2; by chi-square test).

**Discussion**

The premise of our survey that mosquito species diversity and abundance would decrease as biological diversity and structural complexity of retention facilities increased appears to be incorrect. There was no apparent difference in the richness of mosquito species or the intensity of production in innovative or wetland ponds relative to standard wet ponds. Only 34% of the retention structures that we sampled contained mosquitoes. This finding is in contrast to results of a survey completed by Santana and coworkers (1994) in southwest Florida and by Smith and Shisler (1981) in New Jersey. Mosquitoes were collected from 89% of permanently flooded stormwater management systems in Florida and 81% of the retention structures sampled in New Jersey. The intensity of mosquito production

**Table 2** Occurrence of mosquitoes in relation to the presence or absence of fish in some North Carolina stormwater retention facilities that were sampled three times during the 2004 mosquito season

<table>
<thead>
<tr>
<th>Retention facility</th>
<th>Mosquitoes collected</th>
<th>Mosquitoes not collected</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fish seen</td>
<td>Fish not seen</td>
</tr>
<tr>
<td>Innovative(^5)</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>Standard(^6)</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>Wetland(^6)</td>
<td>2</td>
<td>17</td>
</tr>
</tbody>
</table>

\(^5\)Observed association between the number of innovative or wetland retention facilities producing or not producing mosquitoes and the sighting of fish is significant (\(P < 0.01\); df = 1; chi-square = 10.0)

\(^6\)Observed association between the number of standard retention facilities producing or not producing mosquitoes and the sighting of fish is not significant (\(P > 0.05\); df = 1; chi-square = 3.6)
in the retention structures that we surveyed appeared to be much less than reported previously. In general, dip collections for North Carolina stormwater retention facilities approximated 0.1 specimens per dip whereas in Florida and New Jersey retention structures, dip collections generally exceeded 1 larva per dip.

All of the mosquito species collected during our investigation have been previously reported to occur in stormwater management facilities (Smith and Shisler, 1981; Santana et al., 1994) with the exception of *Ochlerotatus japonicus*. This species inhabits natural and artificial containers (Tanaka et al., 1979), not ground water habitats like stormwater retention facilities. It is likely that the single larvae that we collected washed into the retention facility in a discarded container. Stormwater retention facilities are designed to remain permanently flooded, and the occurrence of floodwater species, *Ae. vexans* and *Ps. columbiae*, indicates that some facilities that we sampled were not operating properly.

In our investigations, the occurrence of mosquitoes was not independent of the presence of mosquitofish, indicating that, in general, predators are a limiting factor for mosquitoes in the retention facilities that we sampled. Our observations suggested that retention structures containing cattail and/or willow tree were associated with mosquito production. Floatage accumulated around the based of these plants, providing refugia for mosquitoes to escape predation by fish. Also, plant stems and tree branches trailing into the water would provide shade so that water temperature would likely remain within tolerable ranges for mosquitoes. Santana et al. (1994) concluded that retention structures in southwest Florida that were productive for mosquitoes contained a mixture of plant species, including woody vegetation and cattail.

We conclude that the probability of mosquito production in stormwater retention facilities in North Carolina is moderate and that the type of stormwater management facility does not affect the likelihood of mosquito production. Because our survey was conducted over only one mosquito season, it is not possible for us to make definitive statements about the significance of the mosquitoes that originate from stormwater retention facilities in the context of local nuisance or vector problems. However, field-collected specimens of all of the mosquito species collected in our survey have been reported to be infected with West Nile virus (CDC 2004). Also, the floodwater mosquitoes *Ae. vexans* and *Ps. columbiae* are major nuisance pests in North Carolina and elsewhere. Because of the proximity of stormwater management facilities to communities, mosquito production in these structures should be monitored routinely and appropriate management efforts taken when needed.

Stormwater managers responsible for the maintenance of BMPs should consider employing a new management technique. Because observations from this study, though

<table>
<thead>
<tr>
<th>Retention facility</th>
<th>Mosquitoes collected</th>
<th>Mosquitoes not collected</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cattail or willow present</td>
<td>Cattail or willow not present</td>
</tr>
<tr>
<td>Innovative*</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>Standard*</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>Wetland*</td>
<td>19</td>
<td>0</td>
</tr>
</tbody>
</table>

*Observed association between the number of innovative or wetland retention facilities producing or not producing mosquitoes and presence of cattails is not significant (*P* > 0.05; df = 1; chi-square < 3.5)
*Observed association between the number of standard retention facilities producing or not producing mosquitoes and the presence of cattails is significant (*P* < 0.01; df = 1; chi-square = 10.2)
not statistically significant, showed that mosquitoes were often collected from woody fringe areas of stormwater wetlands and innovative ponds, stormwater managers may want to adopt a maintenance plan that removes woody vegetation from wetlands on an annual or bi-annual basis. Stormwater BMP designers should consider planting herbaceous vegetation solely and not specifying the use of woody plants. Byplanting a large variety of herbaceous species, but specifically excluding cattail (*Typha* spp.), during the wetland’s construction, a diverse wetland habitat can more easily be maintained. The practice of incorporating deep pools in stormwater wetlands should be continued since these pools provide a continuous refuge for *Gambusia affinis*, and the presence of this fish was a significant sign of limited or non-existent mosquito populations. Including these pools toward the rear of stormwater wetland facilities is important, if the forebay pool is prone to fill with sediment.

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**References**


