Mosquitoes

in Constructed Wetlands

EPA
South Australia

WATER

Mosquitoes in Constructed Wetlands

December 2002

Government
of South Australia

Mosquitoes in Constructed Wetlands

Author: Katherine Sarneckis

Environment Protection Authority
GPO Box 2607
Adelaide SA 5001

Telephone: (08) 8204 2004
Facsimile: (08) 8204 9393
Free call (country): 1800 623 445

ISBN 1 876562 40 4

December 2002

Printed on recycled paper

TABLE OF CONTENTS

List of Figures

List of Tables

SUMMARY

This study assessed the available mosquito habitat in twelve constructed wetlands in the Adelaide metropolitan area. Surveys of the presence and abundance of larval mosquitoes and other aquatic macroinvertebrates (that include predatory waterbugs and beetles), and measurements of various water quality parameters formed the basis of this assessment.

The major aim of this study was to increase the general community's understanding of mosquitoes, particularly in relation to their possible breeding in urban constructed wetland environments.

The results indicate that wetlands with open water bodies, steep edges and little emergent vegetation typically have diverse macroinvertebrate communities and no or very low numbers of larval mosquitoes. Wetlands producing high numbers of mosquitoes consisted of wetlands with shallow water and sheltered, isolated pools that limited predator access, had low macroinvertebrate diversities and poor water quality.

Diversion of stormwater through constructed wetlands is often used to reduce detrimental impacts of stormwater on more natural receiving environments. It is a public perception that constructed wetlands provide breeding grounds for mosquitoes and cause mosquito problems. The results from this study indicate that well-designed wetlands do not promote mosquito growth. The results also highlight the importance of mosquito management to be considered in the planning, design and operational phases and, perhaps most significantly, in the continued maintenance and management of any constructed wetland in an urban setting.

INTRODUCTION

Diversion of stormwater through wetlands can reduce nutrients, organic materials, suspended solids, heavy metals and faecal bacteria levels (Lawrence & Breen 1998; Bastian & Hammer 1993) and consequently reduce detrimental impacts of stormwater on receiving environments. In addition to water quality improvement, wetlands also provide recreational and aesthetic qualities and the provision of habitat for wildlife (Lawrence & Breen 1998).

It is a public perception that wetlands provide breeding grounds for mosquitoes and cause mosquito problems. Whilst virtually any water source is a potential breeding ground for mosquitoes, wetlands can be designed to reduce mosquito habitat (Russell 1999; Lawrence & Breen 1998). Monitoring of mosquito populations in communities before and after wetland construction has shown that well-designed wetlands do not necessarily cause an increase in mosquito numbers (Snell & Kokkinn 2001). Habitats suitable for mosquito breeding within residential areas may lead to an increase in adult mosquito presence possibly causing nuisance levels and/or pose a health threat, as some mosquito species are capable of transmitting disease. It is therefore important that constructed wetlands are designed and monitored to ensure that they do not contribute to the growth of mosquito populations.

This study was carried out to assess the suitability of twelve constructed wetlands as mosquito habitat in the Adelaide metropolitan area. Larval mosquito sampling was carried out at each site, to gain an understanding of the species present in each wetland and to measure their population size. Macroinvertebrate communities and water quality readings were also collected to gain a more detailed understanding of the biology and water chemistry of each site.

Aims

Constructed wetlands or swale areas within the Adelaide metropolitan area that have been designed to receive and treat stormwater were assessed for mosquito habitat and larval mosquito production in autumn–winter 2001. Specific other objectives of this study were to:

- identify mosquito species present in urban stormwater wetlands
- gain an understanding of potential larval population size in each wetland
- identify the composition of the macroinvertebrate community in each wetland
- measure various water quality parameters in each wetland
- assess the suitability of the urban wetlands that were investigated as mosquito habitats.

This work aims to identify the potential for constructed wetlands to support larval mosquitoes, and to discuss ways to minimise or eliminate these nuisance insects from wetlands through better design.

BACKGROUND

Mosquito biology

The life cycle of mosquitoes consists of four distinct stages: eggs, larvae, pupae and adults (Figure 1). Adults lay from fifty to several hundred eggs on or around water bodies, depending on the species, and all require water for their complete development (Le Messurier 1987). *Ochlerotatus* (formerly *Aedes*) lay eggs on moist substrates, *Anopheles* and *Culex* deposit eggs on the water surface and *Mansonia* lay a submerged egg mass attached to aquatic plants.

There are four larval moults between the egg and the pupa (Le Messurier 1987). Larvae are entirely aquatic, feeding on microscopic organisms, decaying vegetation or bottom detritus. Larvae are commonly found just beneath the water surface film because they breathe air using a siphon attached to the tail end of the body that penetrates the surface. However, larvae of the *Mansonia*/*Coquilletidida* complex breathe oxygen through plant tissues below the surface by attaching themselves with a modified piercing siphon to plant stems. The average larval development time is five to seven days and is dependent on factors such as temperature, food availability, larval crowding, persistence of water and predation by both fish and macroinvertebrates.

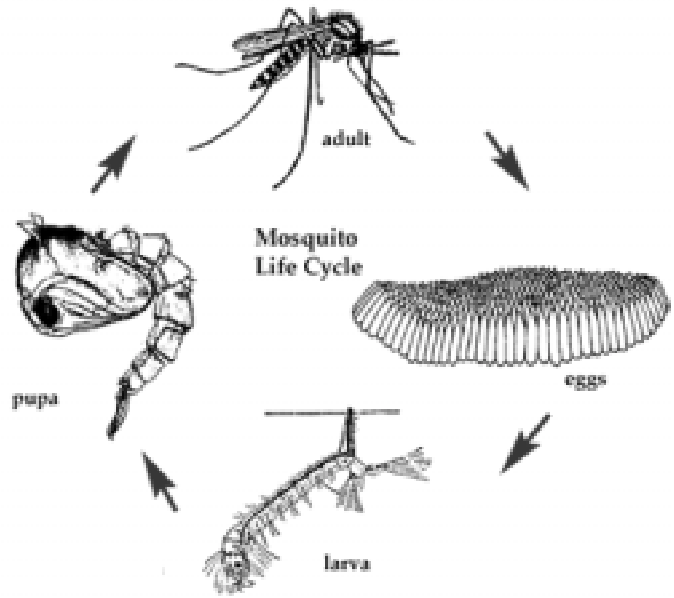

Figure 1 Mosquito life cycle (Source: Lyon *et al.* 2000)

Pupae are also aquatic, but can complete their development on a moist surface if necessary (Anon. 2000). Pupae remain mobile in the water column but do not feed. Inside the body casing of a pupa, larval tissues break down, developing into the adult.

On emerging from the pupal case, adults remain on the water surface until they are strong enough to fly. Both male and female mosquitoes feed on nectar. However, most females also require a blood meal to produce eggs (MacGregor 1927; Gillett 1971). Adults reach sexual maturity in one to two days (Le Messurier 1987). Males develop faster than females (Mattingly 1969; MacGregor 1927) and generally remain near their emergence site to mate. Mating occurs quickly after emergence because mosquitoes have a high mortality rate, with approximately 10%–30% of the population lost every 24 hours (Gillett 1971).

Many mosquitoes have only one generation per year, while others can have two to five or more (Le Messurier 1987). Under favourable conditions, by having a high reproductive potential and a short life cycle, the abundance of mosquitoes can increase (Chester 1990), reaching nuisance levels at particular localities.

Mosquito presence and density

Factors determining mosquito species composition in a water body include the location, permanence, water level fluctuation, size, stillness and organic composition of the water. Mosquitoes can occupy a range of habitats and withstand extreme environmental conditions (Tennessen 1993). Each species of mosquito has preferential breeding habitats and some of the major pest species in South Australia are detailed in Table 1. Therefore, the nature and location of a wetland will influence the species present at a site (Russell 1999).

Larval density in a water body is dependent upon factors such as type of plant cover, water quality, food availability and predator abundance. Habitats such as water bodies which are small (for example, tree holes and containers), shallow, high in nutrients, and with no or very low dissolved oxygen levels and/or high salinity are commonly exploited by mosquitoes. In these types of habitats mosquito predator numbers (for example, fish and aquatic macroinvertebrates) are generally either very low or absent, thereby providing a safe refuge for mosquito larvae to persist and thrive. Consequently, constructed wetlands with standing water that is high in nutrient levels and vegetative cover can provide ideal conditions for mosquito larval growth to cause problems (Tennessen 1993).

Stormwater can contain chemical deposits which can be potentially lethal to both mosquitoes and predator species (Russell 1999). Mosquito larvae are more tolerant of pollutants than many of their potential predators, and are likely to re-establish more rapidly than most other organisms present in a wetland (Russell 1999).

Mosquito-borne disease

Mosquitoes are carriers (or vectors) of many diseases. They are capable of transmitting three types of pathogens: protozoa (malaria), nematodes (filaria) and viruses (arboviruses) (Mattingly 1969). Endemic malaria has been eliminated from Australia. However, there is potential for this disease to occur in Northern Australia by the movement of infected mosquitoes from Asia. The most important and common type of pathogens transmitted by mosquitoes in Australia are the arboviruses. Arboviruses are transmitted from one vertebrate host to another vertebrate via certain species of mosquitoes. Murray Valley Encephalitis (MVE), Kunjin (KUN) and Ross River (RR) virus are arboviruses that occur in Australia. Of the arboviruses, Ross River virus is the most widespread in South Australia. Not all mosquito species transmit disease and Table 1 lists mosquitoes commonly found in South Australia and their vector status. It should be noted that most of these species have been shown in laboratories to be associated with the specified disease, but it is not known if all are responsible for infecting humans.

Table 1 Summary of major breeding site characteristics for the major pest species in South Australia (Source: Russell, 1993)

Species	Habitat characteristics	Distribution	Pest	Possible disease transmission
Ochlerotatus camptorhynchus	Brackish to fresh ground pools	Inland (including the far north), River Murray	✓	RR, MVE; heartworm
Ochlerotatus notoscriptus	Tree holes, rock pools, artificial containers	Suburban, southern, coastal woodlands, River Murray, human habitation as far north as Burra	✓	RR, MVE; heartworm
Ochlerotatus vigilax	Temporary, brackish ground pools associated with marine couch, seablite and samphire.	Coastal (particularly mangrove and samphire swamp), River Murray	✓	RR, MVE, KUN; heartworm
Ochlerotatus vittiger	Temporary ground pools with marginal and emergent vegetation.	Murray Valley	✓	MVE
Anopheles annulipes	Ground and rock pools (generally fresh water but also found in polluted and brackish water).	Murray Valley and South East	✓	RR, heartworm
Culex annulirostris	Shallow freshwater sites (open and sunlit with emergent vegetation), also brackish and polluted waters.	Murray Valley and South East	✓	MVE, KUN, RR; heartworm
Culex australicus	Freshwater swamps, lagoons and grassy pools, occasionally brackish and polluted waters.	Murray Valley and South East	×	MVE, KUN
Culex molestus	Sewage ponds, septic tanks, polluted ground or container water, drainage pits.	Suburban, human habitation as far north as Burra	✓	MVE
Culex quinquefasciatus	Many types of artificial environments near human habitation, containers and ground pools.	Murray Valley and South East	✓	MVE, KUN, RR; heartworm

Arboviruses: Kunjin (KUN); Murray Valley encephalitis (MVE); Ross River (RR)

Mosquito control

Mosquito management in constructed wetlands needs to be site specific and generally relies on the design of the wetland to minimise nuisance insect numbers. Manipulation of physical components, such as water levels and vegetation cover, in combination with chemical and biological control agents, can be used to maintain mosquito populations at low numbers.

Physical

Routine maintenance is essential to ensure that minimal mosquito breeding grounds are present (Russell 1999). Ideally, wetlands should be situated in open areas, so that wind action causes surface waves. These can disrupt larval respiration and inhibit algae and floating plant growth. Water level fluctuations can be detrimental to mosquitoes, by either drowning or stranding their larvae. Maintaining water movement through the wetland can help also decrease mosquito populations. Because of the climate, this is often impractical for South Australian waterways, which cease to flow during summer.

To prevent emergent vegetation, wetland shape should be simple, with a low edge-to-area ratio (Russell 1999), steep edges and deep water. Wetlands that do not support vegetation generally do not support high numbers of mosquitoes. Heavily vegetated areas provide shelter from the wind and predators such as fish, and may cause water to pool and provide localised conditions for mosquitoes to exploit. Periodic harvesting of dense stands of emergent vegetation and sediment build-up will help reduce the production of mosquitoes.

Biological

Biological control of mosquito populations is generally achieved to some degree through predation by other organisms. Natural predators of mosquitoes include fish, predacious mosquito larvae, other insects, crustaceans, spiders, fungal diseases, nematodes, protozoans, aquatic birds, frogs and some reptiles. Macroinvertebrates, such as waterbugs (*Hemiptera*), dytiscidae beetle larvae (*Coleoptera*), dragonflies (*Anisoptera*) and damselflies (*Zygoptera*) are generally more successful predators of mosquito larvae than fish in heavily vegetated areas (Chester 1990). When a system is not heavily vegetated, fish and some larvicides derived from bacteria are generally the most effective means of controlling mosquito numbers.

Chemical

Most mosquito control programs rely on chemical control using insecticides such as organophosphates, carbamates, pyrethrins or insect growth regulators. Chemical control should not be viewed as a long-term solution, because prolonged use of chemicals can lead to insect resistance (Russell 1999; Le Messurier 1987) and off-target impacts on other insect larvae.

Monitoring program

Monitoring and maintenance of constructed wetlands is a necessary component to evaluate the performance of each wetland and identify potential problems from nuisance insects, such as mosquitoes. Information, such as the identification of species present, breeding sites, seasonal fluctuations and flight movements and range, can be collected through a number of surveys. A mosquito monitoring program should ideally be established at least one year before commencement of any ground-disturbing activities and for at least three years after wetland construction (WA EPA 2000). Monitoring of mosquito species, size of adult population, seasonal distribution of potential mosquito breeding sites, larval abundance, impact of control measures and incidence of mosquito-borne diseases is important to gain a comprehensive understanding of any mosquito populations associated with constructed wetlands. If a control program is implemented, follow-up evaluation is also essential to assess the effectiveness of the program (WA EPA 2000) and to assist in future maintenance planning and funding.

Sampling of mosquito larvae is commonly used to identify potential mosquito outbreaks from wetlands. Ideally, larval monitoring should be carried out on a weekly basis (mosquito activity tends to be less during winter and weekly sampling may not be necessary during this period) at a number of pre-selected sites around and within wetland areas (Russell 1999). Presence of larvae may not necessarily translate into an adult 'problem'; however, densities as low as 0.5 *Culex* larvae per dip sample have been proposed as an indicator of a potential population explosion (Russell 1999). This can provide an early warning of a potential problem in an area and assist in determining if further action may be necessary to intervene and actively reduce mosquito numbers.

METHODS

Site selection

Sites sampled for mosquito presence were located in the Adelaide, Onkaparinga, Port Adelaide Enfield and Salisbury council areas (Table 2). Criteria to select sites were that they were either constructed wetlands or swale areas receiving stormwater and that they were likely to contain water at the time of sampling in autumn–winter 2001. After consultation with each council area, fifteen possible sites were visited for an initial survey that was carried out from 17–20 April 2001 to determine whether the site would be suitable for the larger mosquito sampling program. A total of twelve sites were selected for sampling (Table 2); only Site 02 and Site 10 were swale habitats.

Table 2 Location of sites for mosquito survey*

Site No.	Site name	Street location	Suburb	UBD 2000
01	Burbridge Road	Burbridge Rd, Catholic Cemetery Rd	Adelaide	3 D12, E11
02	Oakdale Road	Oakdale Rd & Blacks Rd	Gilles Plains	95 K11
03	Regency Reserve Wetlands	Sir Ross Smith Bvd & Regent Ct	Oakden	95 H11
06	Folland Ave	Folland Ave & Dumfries Ave	Northfield	95 A12
08	Dyson Road	Commercial Rd, opposite Marlborough St	Port Norlunga South	195 J4
09	Effluent Pond	River Rd	Norlunga Downs	195 P2
10	New Road	New Rd & Old Honey Pot Rd	Norlunga Downs	185 M16
11	McLaren Flats Wetlands	Blewitt Springs Rd & Main Rd	McLaren Flat	208 C7
12	Montague Farm Wetlands	Warrendi (Mawson Lakes Blvd) Rd	Mawson Lakes	82 L9, M9, L11, N10
13	Greenfield Wetlands	Salisbury Highway & Port Wakefield Road	Greenfields	82 E6 & E7
14	Walpole Wetlands	Walpole Rd & Kings Road	Paralowie	70 F5
15	Burton Wetlands	Waterloo Corner Rd & Helps Rd	Burton	60 F8

*Note: sites 04, 05 and 07 were unsuitable for sampling

Sampling

Sampling was carried out 9–11 May 2001. At each site, a datasheet was completed (Appendix 1), mosquito larvae and macroinvertebrates were sampled, water quality was measured and photographs were taken. Site characteristics and the extent of likely mosquito habitat (size of wetland, complexity) determined the extent of sampling at each wetland and drain environment.

Wetlands

Five-metre sweeps of stillwater edge habitat, both with and without emergent vegetation, were completed at each site using a dip net. In the absence of one of the two types of edges, five-metre sweeps were taken of the edge type present at the site. Contents of the dip net were then placed into a white sorting tray and mosquito larvae or pupae were collected and placed in labelled vials. A total of 15 minutes sorting was completed for each sample. Macroinvertebrates were identified in the field from the sorting tray and recorded on the assessment sheet to provide an indication of the complexity of the aquatic community, including the presence of invertebrate predators at each site (Appendix 1). Mosquito samples were preserved in 70% methylated spirits, and identified using a dissecting microscope and the keys from Russell (1993).

Drains

Drains were sampled by scooping the water with a soup ladle (Service 1993). The number of soup dips varied per site and was dependent on the size of the drain, water level and quantity. Contents of the soup ladles were poured into a white sorting tray, mosquitoes were collected and macroinvertebrate families were identified and recorded on the assessment sheet (Appendix 1). The samples were preserved and specimens identified as described above.

Water quality

Water quality was measured at each site using a Hanna pH meter, YSI 55 DO meter and an ICI conductivity meter.

RESULTS

Mosquito numbers and species

Nine of the twelve sites sampled contained mosquitoes (Table 3). Sites 02 and 09 had numerous mosquito larvae, while the other sites had low numbers or none present at the time of sampling.

Table 3 Numbers and species of mosquitoes found

Site	Drain	Edge and vegetation sweep	Edge	Species identified
01	1	1	0	*Culex australicus*
02	58	NA*	NA*	*Ochlerotatus flavirons*
				Culex quinquefasciatus
				Culex australicus
03	1	0	0	Unidentified
06	NA*	NA#	0	None present
08	NA+	7	6	Unidentified
09	NA+	137	NA^	*Culex australicus*
10	6	2	NA^	*Culex molestus/quinquefasciatus*
11	1	NA#	1	*Ochlerotatus alboannulatus*
12	0	NA#	1	Unidentified
13	NA+	0	0	None present
14	NA*	7	NA^	Unidentifed
15	NA+	NA#	0	None present

* Inadequate amount of water for sampling, + Drain location not found,
# No emergent vegetation, ^ No edges free of vegetation

Five species of mosquito were identified from the wetlands sampled (Table 3). Of these, *Culex australicus*, *Culex molestus* and *Culex quinquefasciatus* are known pest species. Due to lack of distinguishing features of some immature larvae and the loss of characteristic features during preservation, identification was not always possible to species level. Identification of mosquitoes from the pupal life stage was very difficult, resulting in unidentified species from sites 03, 08, 12 and 14. The *Culex molestus and Culex quinquefasciatus* species in particular are difficult to separate at the larval stage due to a lack of defining characteristics.

Mosquito habitat

Wetlands

Table 4 summarises the general characteristics and mosquito habitats for each of the wetlands (not drains) sampled and further site descriptions are given in Appendix 3. The presence of litter, emergent and floating vegetation, algae and pollutant traps increase the potential breeding habitats for mosquitoes in urban wetlands. However, other factors such as water permanence, flow, and depth of the wetland also influence the suitability of a site for mosquito breeding. With the exception of site 09, all wetlands had very low numbers of mosquito larvae, suggesting that the control by natural predators and good wetland design were assisting in keeping mosquito breeding in urban wetlands under control.

Table 4 Mosquito habitat in wetland at time of sampling

Site no	Potential mosquito habitat and contributing features	Status	Water movement	Max depth of wetland	Mosquitoes detected
01	Litter, emergent vegetation, algae	Permanent	Slow flow	> 1m	Yes
03	Emergent vegetation	Permanent	Subject to wind	> 1m	No
06	None	Permanent	Subject to wind	> 1m	No
08	Emergent vegetation, algae	Permanent	Subject to wind	> 1m	Yes
09	Emergent and floating vegetation	Temporary	Still standing	< 0.5m	Yes
10	Emergent vegetation, litter, algae	Temporary	Slow flow	< 0.5m	Yes
11	Algae	Permanent	Subject to wind	> 1m	Yes
12	Emergent vegetation, litter, algae	Temporary	Slow flow	> 1m	Yes
13	Emergent vegetation, algae	Permanent	Slow flow	> 1m	No
14	Emergent vegetation, litter, pollutant traps	Temporary	Subject to wind	> 1m	Yes
15	Emergent vegetation, litter, algae	Temporary	Still standing	> 1m	No

Temporary wetlands at sites 10 and 14 were subject to rapid water volume changes between the initial survey and the sampling period. On initial site inspection in April, the wetland at site 10 contained water (Figure 2) and numerous mosquito larvae were observed. Less than a month later the wetland was completely dry (Figure 2). It is not known how quickly the site dried out and whether there was sufficient time for larvae to pupate and emerge as adults. There is no data to confirm if this site successfully produced any adult mosquitoes.

Site 14 was dry on the first visit (Figure 3), but was filled with water in the next month (Figure 3). Mosquito larvae were abundant and were likely to increase over the following weeks, as more adults used the wetland as a breeding ground.

Temporary wetlands provide mosquitoes with a degree of protection from predators. These wetlands are not permanent water bodies, nor are they connected to other permanent water bodies, therefore, a diverse ecosystem containing other macroinvertebrates and fish is not expected, because only early colonising species are able to utilise such habitats. Unlike the dramatic changes in water level observed in the temporary wetlands, the permanent wetlands showed little variance in their water level between the initial site investigation and sampling period.

Figure 2 Water level changes at Site 10, New Road, within 23 days

Figure 3 Water level changes at Site 14, Walpole Wetlands, within 21 days

Drains

Drains were sampled at eight of the twelve sites and are briefly described in Table 5. Sites 08, 09, 13 and 15 did not have drains that were readily identified, mainly due to the presence of dense vegetation.

With the exception of site 02, drains had low numbers of mosquito larvae at the time of sampling. However, the design of some drains, in allowing standing pockets of water to form, has the potential to provide mosquitoes with suitable breeding grounds. This highlights the need for appropriate design of drains as well as wetlands to minimise nuisance insects.

Drains sampled were generally one of two designs—either rock pools (Figures 4 & 5) or flat concrete strips (Figures 6–9). Some drains were fenced by structures which allowed for silt, rubbish and plant material to build up, preventing water from draining out when water levels dropped (Figures 7 & 8). This prevents predators from the wetland accessing the drain and may allow mosquito larvae to exploit these habitats in relatively predator-free environments.

Table 5 Drain description and mosquito presence in drains

Site no.	Drain description	Flowing	Description of water in drain	Mosquitoes present
01	Flat concrete	Yes	Oily, bubbles	Yes
02	Dense rock pool	No	Clear	Yes
03	Dirt and rock pool	Yes	Clear	Yes
06	Dirt and rock pool	No	No water	No
08	NA	NA	NA	NA
09	NA	NA	NA	NA
10	Flat concrete	No	Clear	Yes
11	Flat concrete	No	Clear	Yes
12	Flat concrete	Yes	Clear	No
13	NA	NA	NA	NA
14	Flat concrete	No	No water	No
15	NA	NA	NA	NA

The dense rock pool drain catchment of site 02 (Figure 4) created mosquito habitat in the form of numerous small, still standing pockets of water. By way of comparison, the more open rock pool structure of site 03 (Figure 5) allowed predators to access the water and mosquito larval numbers were consequently very low.

Figure 4 Site 02 dense rock pool

Figure 5 Site 03 open rock pool

Figure 6 Site 01 flat cement drain

Figure 7 Site 10 cement drain with barrier and rubbish build up

Figure 8 Site 11 cement drain, showing build up of silt/dirt

Figure 9 Site 14 cement drain with gross pollutant trap

A gross pollutant trap was present at site 14 (Figure 9). At the time of sampling, the trap did not create any mosquito breeding habitat because there was no build-up of rubbish in the trap and all drain water had either discharged into the receiving wetland or had evaporated. Gross pollutant traps, nevertheless, have the potential to create water pools if they are not regularly cleaned out.

Macroinvertebrate and predator presence

All macroinvertebrate groups collected with each sample were identified to varying taxonomic levels to give an understanding of each site's diversity and to highlight the predatory component of the aquatic fauna (Figure 10). Sensitive predatory invertebrate groups, such as dragonflies (*Anisoptera*) and damselflies (*Zygoptera*), were present at five of the sites. Tolerant predators, such as back swimmers (*Notonectidae*), were present at nine of the sites. Fish, most likely mosquito fish (*Gambusia*), an introduced pest species, were seen at sites 03, 09, 12, 13 and 15 and were likely to be present at all other sites except for 02 and 14. Sites 02 and 14 were temporary waterbodies and separated from any permanent water source, which would make fish presence unlikely. Frogs were heard or seen at sites 01, 10, 12, 13, 14 and 15. Sites 02 and 09, which had the largest number of mosquito larvae, were characterised by few types of macroinvertebrates and the absence of predatory species.

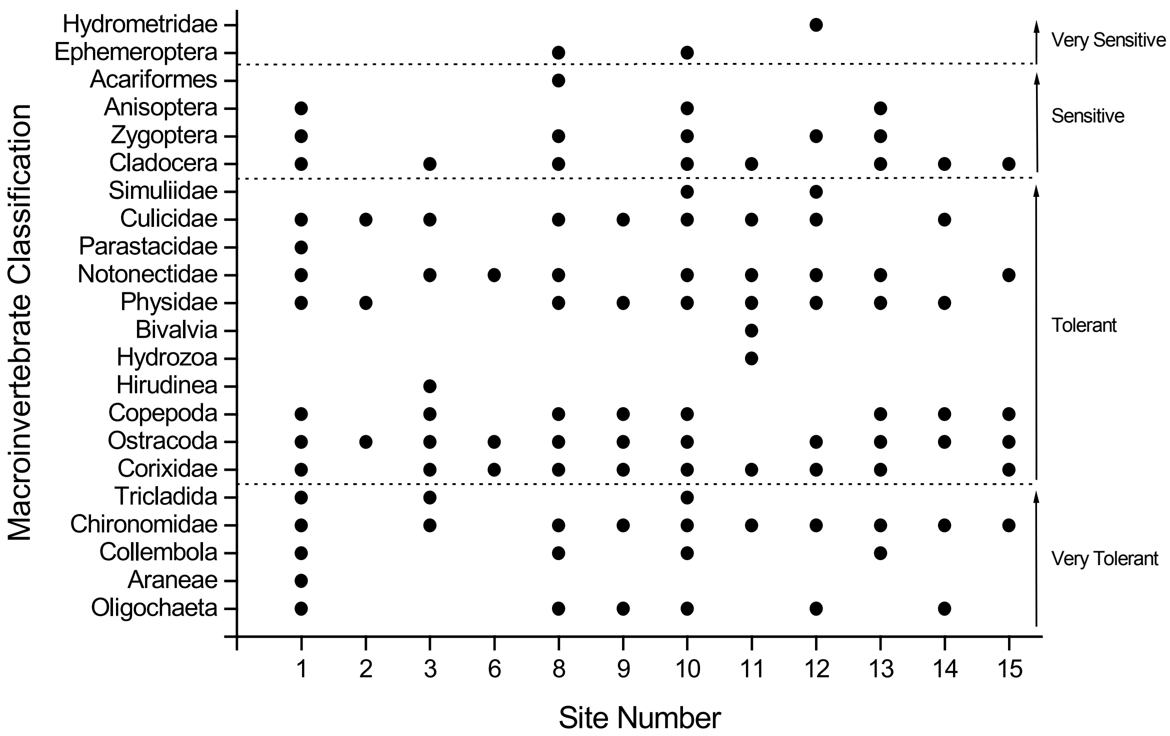

Figure 10 Macroinvertebrate groups present at each site

Water quality

Water quality results are shown in Appendix 2. Sites 02, 09, 10 and 14 had the lowest dissolved oxygen readings. Mosquitoes are quite tolerant of low oxygen levels, whereas some of their predators are not. Water was clear in appearance at most sites; however, the water in the wetland at site 06 had a very muddy appearance that was likely to be due to it being a newly constructed site with the presence of muddy banks and edge habitats.

CONCLUSIONS

The results from this work highlight the physical differences between each wetland and the factors that contribute to the development of potential mosquito habitats in urban wetlands. Wetlands with open waterbodies, steep edges and little emergent vegetation had no or very low numbers of mosquitoes.

Wetlands and drains producing high numbers of mosquitoes were shallow, protected waterbodies, with isolated pools of water that limited predator access and contributed to poor water quality. They are a source of some nuisance species of mosquitoes known to be potential carriers of some debilitating diseases to humans and pet dogs.

It is important that mosquito management is included in the planning, design, operation and maintenance phases of constructed wetlands and associated drains in residential areas, to ensure that mosquito habitats are kept to a minimum (Russell 1999; Lawrence & Breen 1998). Mosquito monitoring programs are also important, as they help identify species composition and provide an indication of the magnitude of any problem that may be arising (Snell & Kokkinn 2001). Such programs may also highlight the production of nuisance species from containers and roofs in surrounding residential houses, and may lead to greater community awareness and action to minimise such habitats on private property.

REFERENCES

Anonymous, 2000. *Mosquito Control in Maryland*, Maryland Department of Agriculture, *http://www.mda.state.md.us/mosquito/progdesc.html*

Bastian, R. K. & Hammer, D. A. 1993. 'The Use of Constructed Wetlands for Wastewater Treatment and Recycling' Part 1 No. 5 in *Constructed Wetlands for Water Quality Improvement*, Ed G. A. Moshiri, Lewis Publishers, London.

Chester, E. T. 1990. *A Review of Mosquito Control Strategies and their Potential for the Control of Saltmarsh Mosquitoes in the South-West of Western Australia,* Waterways Commission.

Gillett, J. D. 1971. *Mosquitoes*, Weidenfeld & Nicolson, London

Lawrence, I. & Breen, P. 1998. *Design Guidelines: Stormwater Pollution Control Ponds and Wetlands*, Ed. A Milligan, Cooperative Research Centre for Freshwater Ecology, Canberra.

Le Messurier, J. 1987. 'Mosquitoes and their Control' *Shire and Municipal Record* 80(5): 207-210.

Lyon, W. F., Berry, R. L. & Collart, M. F. 2001. *Mosquitoes*, HYG-2058-98, Ohio State University Extension Fact Sheet, *http://ohioline.osu.edu/hyg-fact/2000/2058.html*

MacGregor, M. E. 1927. *Mosquito Surveys: A Handbook for Anti-Malarial and Anti-Mosquito Field Workers,* Bailliere, Tindall & Cox, London.

Mattingly, P. F. 1969. *The Biology of Mosquito-Borne Disease*, Ed Carthy, J. D. & Sutcliffe, J. F., London.

Russell, R. 1993. *Mosquitoes and Mosquito-Borne Disease in Southeastern Australia: A Guide to the Biology, Relation to Disease, Surveillance, Control and the Identification of Mosquitoes in Southeastern Australia.* Westmead, Department of Medical Entomology.

Russell, R. 1999. 'Constructed Wetlands and Mosquitoes: Health Hazards and Management Options – an Australian Perspective' *Ecological Engineering* 12: 107-124.

Service, M. W. 1993. *Mosquito Ecology Field Sampling Methods*, 2nd Edition, Elsevier Applied Science, London.

Snell, A. E. & Kokkinn, M. J. 2001. 'Pre- and Post Establishment Mosquito Studies of the Warriparinga Constructed Urban Wetland in Adelaide, South Australia', *Arbovirus Research in Australia*, 8: 362-365

Tennessen, K. 1993. 'Production and Suppression of Mosquitoes in Constructed Wetlands', Ed. G. Moshiri, *Constructed Wetlands for Water Quality Improvement*, Lewis Publishers, London.

Western Australia Environmental Protection Authority 2000. 'Guidance for the Assessment of Environmental Factors (in accordance with the Environment Protection Act 1986) *Guidance Statement for Management of Mosquitoes by Land Developers* No. 40, Western Australia.

APPENDIX 1 –DATASHEET

Physical, Chemical and Biological Record Sheet

Site Name:	**Site Code:**
Site Location:	
Person(s) Conducting the Monitoring:	

Date of Monitoring:	**Time of Monitoring:**	**UBD 2000** Map

	% saturation	mg/L		°C		µs/cm or ms/cm
D.O			Temperature		Conductivity	

Pipe Diameter ___________cm ☐ Drain flow ☐ Drain not flowing

Description of drain water Colour Odour

Weather conditions at the time of sampling:

☐ sunny ☐ cloudy ☐ overcast ☐ raining ☐ windy

Rainfall: Amount of Rain:

Last rainfall ☐ > week ago ☐ During last week ☐ During last 24 hrs ☐ Raining now

Water conditions:

Water flow

☐ Not flowing ☐ Slow

☐ Fast ☐ Rapid

☐ Temporary ☐ permanent

Water appearance:

☐ Clear ☐ Milky ☐ Foamy /frothy

☐ Muddy ☐ Smelly ☐ Stained green

☐ Scummy ☐ Oily ☐ Stained brown

☐ Other (description)

Mosquito Habitat:

☐ Litter ☐ Floating Plants ☐ Algae ☐ Vegetation ☐ Pollutant Traps

Deepest part of wetland: (estimate only) ☐ Up to 10 cm ☐ Up to 50cm ☐ Up to 1 metre

☐ Up to 2 metres ☐ Over 2 metres ☐ unknown Average dimensions:

Mosquito Larvae (collected):

☐ none ☐ < 10 ☐ >10 ☐ >50 ☐ > 100

Aquatic Life (describe community)									
Fish:									
Frogs:									
Macroinvertebrates:		☐	Turbellaria	☐	Nematoda	☐	Oligochaeta	☐	Physa
☐	Araneae	☐	Cladocera	☐	Ostracoda	☐	Copepoda	☐	Amphiphoda
☐	Parastacide	☐	Collembola	☐	Zygoptera	☐	Anisoptera	☐	Notonectidae
☐	Corixidae	☐	Chironomidae	☐	Other				
Plants:									
Comments:									

APPENDIX 2 –WATER QUALITY DATA

Site No.	Dissolved oxygen (mg/L)	Conductivity (µs/cm)	Temperature (°C)
01	5.28	925	12.9
02	1.38	558	16.8
03	6.10	648	15.9
06	7.23	2300	16.3
08	5.87	393	11.9
09	3.02	3570	12.5
10	2.46	466	11.6
11	5.98	360	17
12	11.14	905	14.4
13	4.44	2660	15.8
14	0.99	133	15.1
15	NA	420	NA