LIVING WITH MOSQUITOES

In the Lower Hunter and Mid North Coast Region of NSW

2nd Edition

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All photographs used in this document have been taken by members of staff from the Department of Medical Entomology, University of Sydney and Westmead Hospital, including Dr. Cameron E Webb, Mr. Stephen L Doggett and Prof. Richard C Russell.

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3 BACKGROUND

Mosquitoes are not only nuisance biting pests but also have the potential to spread disease-causing pathogens such as Ross River virus and Barmah Forest virus. However, mosquitoes are also an important component of the wetland ecosystem, providing food for some birds, bats, amphibians, fish and macroinvertebrates. The management and control of mosquitoes is a major concern for local authorities but strategies should be employed that minimise adverse impact on the environment.

The Lower Hunter and Mid-North coast of NSW is predicted to undergo significant population growth over the next 15 years. The rapidly increasing residential population, combined with ever increasing tourism in the region, will raise pressures for expanding urbanisation and is likely to increase the contact between people and mosquitoes. The habitats from which mosquitoes are produced represent local, state, national and internationally important wetland habitats for a range of flora and fauna.

There are many different types of mosquito, each closely associated with particular habitats and representing a range of nuisance and public health risks. Mosquitoes are, however, an integral part of the environment and, regardless of the control strategies implemented, mosquitoes will always be active locally during the warmer months.

In 2002, a mosquito management plan, 'Hunter Estuary Integrated Mosquito Management Plan', was compiled but never officially adopted by local authorities. While that document provided useful information on local mosquito species and mosquito control options, this current management plan supersedes that document and provides the basis for mosquito management in the Lower Hunter and Mid North Coast Region of NSW.

In considering the various organisational policy positions within the consortium, environmental values and a range of statuary provisions relevant to estuarine mosquito habitats, the consortium considers that education, supported by sound information and data, will be the favoured management approach.

In 2005, the first edition of the "Living with Mosquitoes" document was produced and provided a valuable resource for local stakeholders. Following the launch of the document, a mosquito awareness program commenced that involved the production and distribution of educational material throughout the local communities. To address some of the gaps in knowledge of local mosquitoes and mosquito-borne disease activity, additional research and monitoring was undertaken gaining an increased understanding of regionally specific issues. In order to maintain the relevance and completeness of the "Living with Mosquitoes" document, a review was undertaken in 2009 to incorporate the most recent information available on local mosquitoes, mosquito-borne disease, management strategies and personal protection measures for the local region.

4 SCOPE OF MANAGEMENT STRATEGY

Coordinated by the Premier's Department, Hunter, this mosquito management strategy has been developed to assist the local authorities, including Newcastle City Council, Port Stephens Council, Lake Macquarie Council, Great Lakes Council and Maitland Council, as well as local agencies including the Hunter-Central Rivers Catchment Authority, Department of Industry & Investment (previously Department of Primary Industries - Fisheries), Hunter New England Health and Department of Environment, Climate Change and Water, better understand and communicate the issues surrounding mosquitoes and their management to a range of stakeholders, including politicians, the wider community, the media, planners, educators, government authorities and natural resource managers.

The area covered by this management strategy covers over 5,500 sq. km and includes the Great Lakes, Port Stephens, Maitland, Newcastle and Lake Macquarie local government areas (Figure 1). While it is not possible to provide detailed, site specific management strategies for all actual and potential mosquito habitats within the region, this strategy has been designed to provide important and relevant information on the biology, ecology and pest status of mosquitoes known in the region and an overview of the most important issues influencing mosquito management in general.

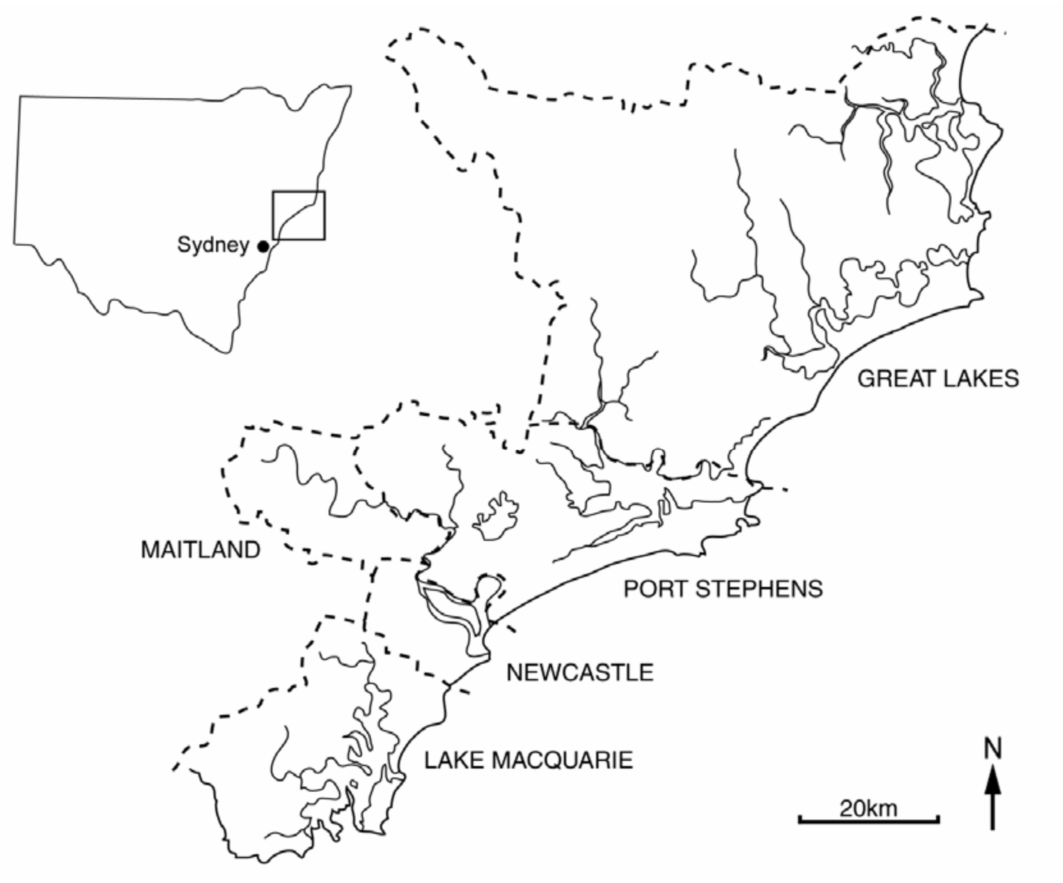


Figure 1. The Lower Hunter and Mid-North Coast region of NSW covered by this document including the Local Government Areas of Lake Macquarie, Newcastle, Maitland, Port Stephens and Great Lakes.

5 MOSQUITO BIOLOGY

Mosquitoes are small blood sucking insects that belong to the family of flies called Culicidae (Order Diptera) and within Australia there are more than 300 different species. Each of these species is closely associated with particular habitats, and the nuisance and public health risks vary markedly between species, but overall they have similar biological requirements.

Mosquitoes have a relatively short but complex life cycle consisting of eggs, four aquatic larval stages (instars), an aquatic pupal stage and a terrestrial adult stage (Figure 2). Mosquitoes are dependent on water, with the immature stages being totally aquatic, and without access to free-standing water of some kind the larvae cannot complete their development to the adult phase. Larvae cannot develop out of water or in damp mud, soil or vegetation. However, adult mosquitoes do take refuge in dense vegetation in bushland or in long grass, and the abundance of mosquitoes encountered in these refuge habitats often leads to the misconception that these dry areas are producing the mosquitoes.

A gravid adult female mosquito will typically lay eggs either on the water surface (usually in the form of a floating raft) or on a frequently inundated substrate (usually singularly or in small groups). These ‘oviposition sites’ may include soil or vegetation at the edge of a wetland, soil or leaf litter where temporary pools form after rainfall, or the inside of water holding containers (eg. tins, tyres etc).

While some mosquito eggs (usually those laid by *Aedes* or *Verrallina* species) can be desiccation resistant, most eggs (particularly those laid by *Culex* and *Anopheles* species) will hatch within 2-3 days. On hatching, the young larvae (commonly called wrigglers) feed continuously on aquatic particulate matter and grow through four different instars or moults. The larvae of some mosquito species have developed specialised mouthparts and are predatory, feeding on other mosquito larvae and aquatic invertebrates. The final larval stage (4th instar) develops into a pupa (commonly called a tumbler) from which the adult mosquito emerges approximately 2 days later. The length of larval development is dependent on water temperature (and thus is usually shorter during the warmer months of the year) and the availability of food, but generally is about one to two weeks from the hatching of eggs to the emergence of adults.

On average, a female mosquito may live approximately 2-3 weeks but the male's lifespan is much shorter. Adult mosquitos are most active from dusk until dawn, seeking refuge during the day in cool and humid habitats such as well-vegetated areas or under houses. Many mosquitoes do not travel far from breeding habitats. However, there are some species that can fly up to and beyond five kilometres, and a few species will disperse up to 50 kilometres downwind from the larval habitats.

Within their lifetime, both adult male and female mosquitoes will feed on nectars and other plant sugars, to provide an energy resource, but it is only the female that will seek a blood meal. The blood meal is required to provide protein for egg development. While many mosquitoes are generalist feeders, some specialise in feeding on humans, mammals, birds or amphibians. The ‘host seeking’ behaviour of female mosquitoes is driven by a combination of different stimuli including carbon dioxide, body odours, and body heat/humidity. Upon locating a suitable host, the female will probe the skin for a blood capillary then inject a small amount of saliva containing chemicals that prevent the blood from clotting. This is often the pathway for potential pathogens such as viruses to enter a host. After engorging on the host's blood the female will find a resting place to digest her meal and develop eggs before flying off to deposit them in a suitable habitat. On average, most mosquitoes will lay up to 3 batches of eggs in their lifetime.

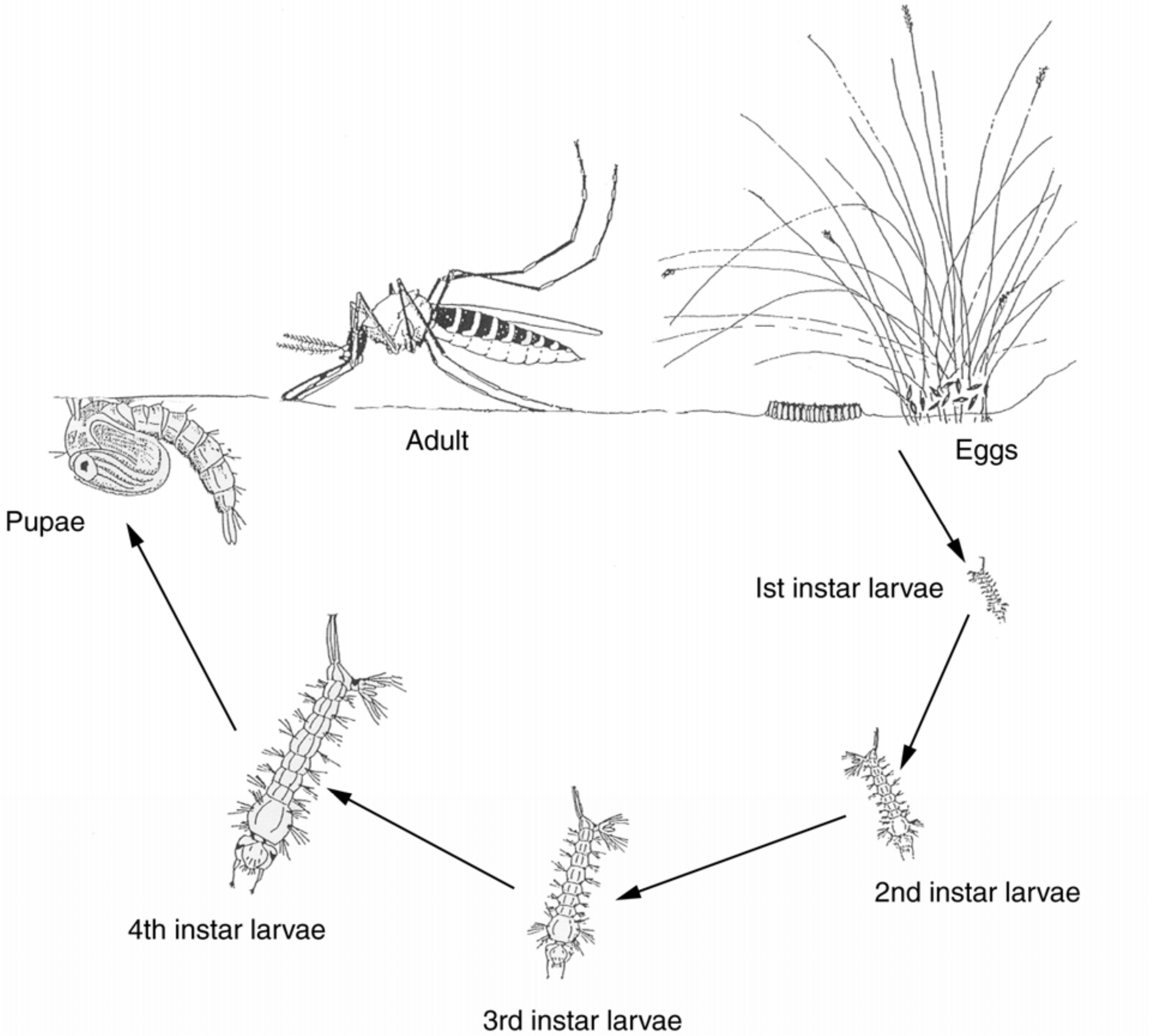


Figure 2. The typical lifecycle of a mosquito including eggs, four larval instars, pupae and adult.

6 MOSQUITO POPULATIONS OF THE LOWER HUNTER & MID-NORTH COAST REGION OF NSW

6.1 Scientific names and common names

There has been some debate over recent taxonomic revisions of mosquito species in the genus *Aedes*. The sub-genus had been elevated to genus status for many species (for example, *Aedes vigilax* is now called *Ochlerotatus vigilax*). For this reason, literature references may refer to either name and care should be taken when reviewing publications.

Following a meeting of the Mosquito Control Association of Australia in 2006, it was decided to retain the scientific names in place prior to taxonomic revisions for use in technical reports, reflecting the editorial policy of the major international scientific journals (e.g. American Journal of Tropical Medicine and Hygiene). As a consequence, for the purpose of this document, the genus name *Aedes* was retained.

Common names have been assigned to the more important species of pest or public health concern or of notable appearance. However, the same species may be known by a number of different common names in different places; therefore, to avoid confusion, all mosquito species will be referred to by their scientific names in this document.

6.2 Mosquito species

Mosquito monitoring has been undertaken in the Lower Hunter and Mid North Coast (including traps sites in the Newcastle, Port Stephens, Great Lakes, Lake Macquarie and Maitland local government areas) as part of the NSW Arbovirus Surveillance and Mosquito Monitoring Program (Appendix 1). In addition, The Hunter-Central Rivers Catchment Management Authority has undertaken mosquito monitoring in the wetlands of Kooragang Island, Hexham Swamp and Tomago (Appendix 2). These two monitoring programs have provided extensive information on the diversity of the mosquito fauna and abundance of major pest species.

There are over 55 mosquito species recorded from the greater Lower Hunter and Mid-North Coast region (Table 1) with the most commonly recorded mosquitoes being *Aedes notoscriptus*, *Aedes vigilax*, *Aedes multiplex*, *Aedes procax*, *Aedes notoscriptus*, *Coquillettidia linealis*, *Culex quinquefasciatus* and *Culex annulirostris*. A list of these common species and those that pose significant nuisance biting and/or public health risks, with their seasonal activity and breeding habitat is presented in Table 2.

Generally, the most important species can be grouped into one of four categories based on their preferred larval habitat type. These four habitat based classifications are: Estuarine, Freshwater, Floodwater, and Urban. There are some species that may be found in two or more of these categories but generally there will be one habitat type in which they are most commonly found.

The relative abundance of these four mosquito groups varies across the region (Figure 3). This variation is due to a number of factors, but most important is the availability of larval habitat. In some locations, the estuarine mosquitoes are the most significant pest species, but in areas where freshwater habitats or urban environments become more dominant, the relative importance of each mosquito group will change. This spatial diversity in the mosquito fauna across the region requires a flexible strategy for mosquito management. The major pest species in an area close to estuarine wetlands in Port Stephens may be very different to those in the urban areas of Newcastle.

Table 1. The mosquito species recorded from the Lower Hunter and Mid North Coast as part of the NSW Arbovirus Surveillance and Mosquito Monitoring Program 1989-2009.

Species	**Forster**	**Port Stephens**	**Lake Macquarie**	**Maitland**	**Newcastle**
Aedeomyia venustipes (Skuse)		+			
Aedes alternans (Westwood)	+	+	+	+	+
Aedes aculeatus (Theobald)	+	+			
Aedes alboannulatus (Macquart)	+	+			+
Aedes australis (Erichson)	+	+			
Aedes bancroftianus Edwards		+			
Aedes burpengaryensis (Theobald)	+	+			
Aedes camptorhynchus (Thomson)	+	+			+
Aedes flavifrons (Skuse)	+	+	+	+	+
Aedes gahnicola Marks	+				
Aedes imperfectus Dobrotworsky	+	+			
Aedes kochi (Donitz)	+				
Aedes mallochi Taylor	+	+			
Aedes multiplex (Theobald)	+	+	+		+
Aedes notoscriptus (Skuse)	+	+	+	+	+
Aedes palmarum Edwards					
Aedes perkinsi Marks		+			
Aedes procax (Skuse)	+	+	+	+	+
Aedes quasirubrithorax (Theobaldi)		+			
Aedes rubrithorax Belkin	+	+			
Aedes theobaldi (Taylor)		+			
Aedes vigilax (Skuse)	+	+	+	+	+
Aedes vittiger (Skuse)	+	+			+
Aedes wasselli Marks		+			
Aedes sp. Marks No. 51			+		+
Anopheles annulipes Walker	+	+	+	+	+
Anopheles atratipes Skuse	+	+	+		
Anopheles stigmaticus Skuse	+	+			
Anopheles amictus Edwards		+			
Coquillettidia linealis (Skuse)	+	+	+	+	+
Coquillettidia variegata (Dobrotworsky)	+	+			
Coquillettidia xanthogaster (Edwards)	+	+	+	+	+
Culex annulirostris Skuse	+	+	+	+	+
Culex australicus Dobrotworsky & Drummond	+	+	+	+	+
Culex bitaeniorhychus Giles	+	+	+	+	+
Culex cylindricus Theobald		+			
Culex edwardsi Barraud	+				
Culex halifaxii Theobald		+			+
Culex molestus Forskal	+	+	+	+	+
Culex orbostiensis Dobrotworsky	+	+	+	+	+
Culex postspiraculosus Lee	+	+			
Culex pseudomelanoconia Theobald		+			
Culex quinquefasciatus Say	+	+	+	+	+
Culex sitiens Weidemann	+	+	+		+
Culex squamosus (Taylor)		+			
Culex sp. No.32 of Marks		+	+		+
Culiseta antipodea (Dobrotworsky)		+	+		
Culiseta inconspicua (Lee)	+	+			
Mansonia uniformis (Theobald)	+	+	+	+	+
Mimomyia elegans (Taylor)	+	+			+
Toxorhynchites speciosus (Skuse)	+	+	+	+	+
Tripteroides atripes (Skuse)	+	+			
Uranotaenia pygmaea Theobald	+	+			
Uranotaenia nivipes (Theobald)					
Verrallina funerea (Theobald)	+	+			
Verrallina sp. Marks No. 52'	+	+	+		+
Total number species	**40**	**47**	**22**	**16**	**23**

Table 2. Larval habitat, pest status, distribution and period of peak activity of the most common mosquitoes known to occur in the Lower Hunter and Mid North Coast region of NSW.

Mosquito Species	Larval Habitat	Pest status	Activity
Ae. alternans	Temporary estuarine & brackish	Biting pest close to breeding habitat	Nov - Apr
Ae. multiplex	Temporary brackish & freshwater	Biting pest close to breeding habitat	Nov - Apr
Ae. notoscriptus	Domestic containers	Major biting pest and vector	Sep - May
Ae. procax	Temporary fresh to brackish water	Potential biting pest and vector	Dec - Apr
Ae. vigilax	Temporary estuarine	Major biting pest and vector	Nov - Apr
An. annulipes	Permanent & temporary fresh to brackish water	Rarely a major pest	Nov - Apr
Cq. linealis	Permanent freshwater	Biting pest close to breeding habitat	Nov - Mar
Cx. annulirostris	Permanent & temporary freshwater	Major biting pest and vector	Jan - Mar
Cx. australicus	Permanent & temporary freshwater	Does not bite humans	Sep - Feb
Cx. halifaxii	Permanent & temporary freshwater incl. containers	Not a known pest	Dec - Apr
Cx. molestus	Polluted freshwater	Major biting pest indoors and outdoors	Nov - Apr
Cx. quinquefasciatus	Polluted freshwater	Major biting pest indoors and outdoors	Sep - May
Cx. sitiens	Semi-perm. estuarine	Biting pest close to breeding habitat	Feb - Apr
Ve. funerea	Temporary brackish & freshwater	Major biting pest and vector	Dec - Apr

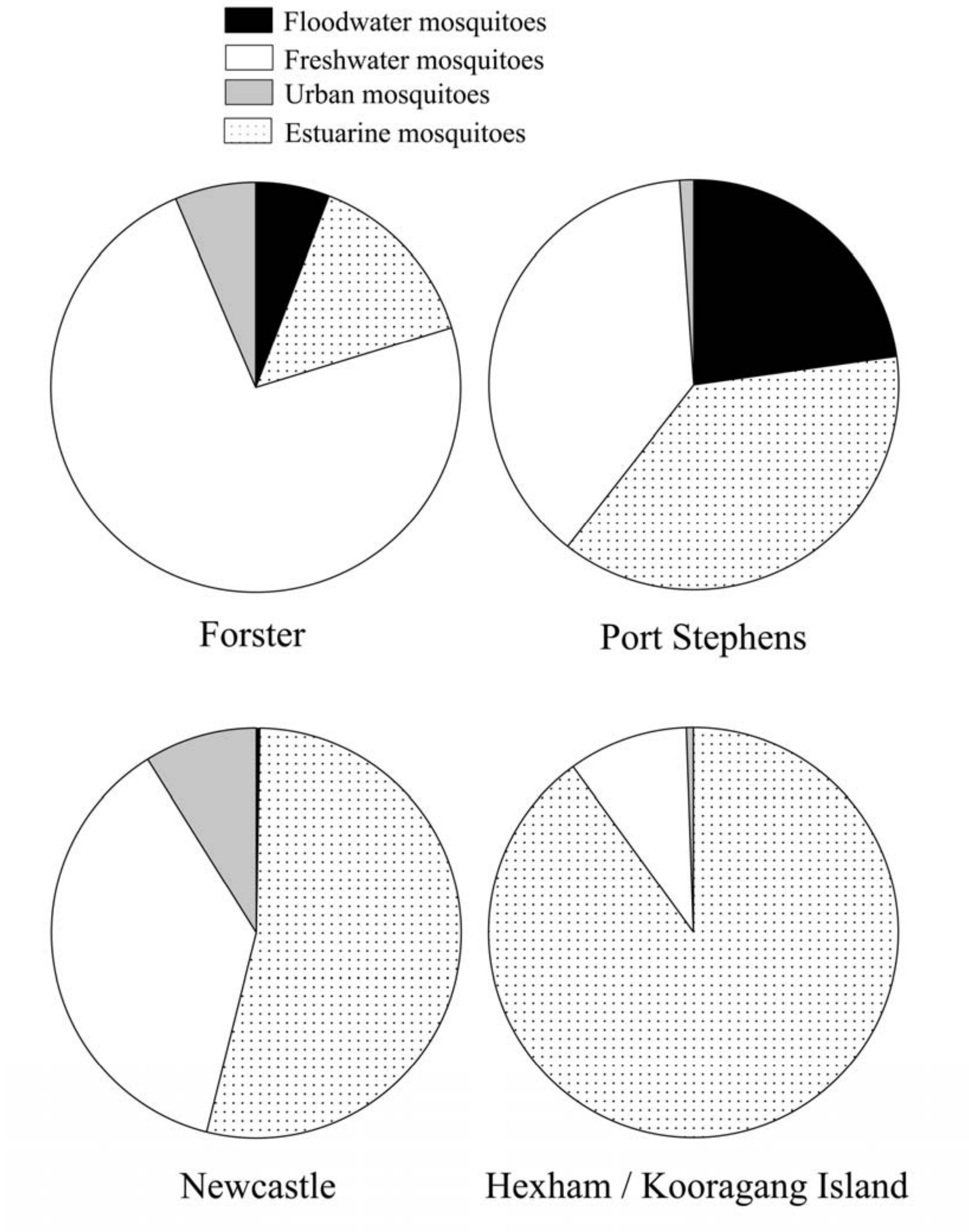


Figure 3. Proportion of four mosquito categories, Floodwater Mosquitoes, Estuarine Mosquitoes, Freshwater Mosquitoes and Urban Mosquitoes, at four locations within the Lower Hunter and Mid-North Coast region of NSW.

6.2.1 Estuarine mosquitoes

The estuarine wetlands provide larval habitats for only a small number of mosquito species. However, amongst these species are significant nuisance biting pests and potential vectors of arboviruses.

- *Aedes vigilax* is a dark, medium sized mosquito with pale bands on the legs (Figure 4). The larvae of this species are usually associated with tidally influenced saltmarsh and mangrove habitats, but can also utilise other saline and brackish water habitats such as flooded sedgelands and forests (eg. *Casuarina* spp. and *Melaleuca* spp.). Eggs are laid at the base of vegetation and/or on damp soil and can tolerate desiccation for many months. Larvae are tolerant of a wide range of salinities and have been collected from highly saline (>40ppk) saltmarsh pools to freshwater flooded grasslands. Population increases of this species are closely linked to the inundation of habitats by the highest tides of each month, and/or major rainfall events, and the adults can disperse great distances (> 10 km) from breeding habitats. The species is a severe nuisance biting pest and major vector of arboviruses.

- *Aedes alternans* is a very large, sandy coloured mosquito commonly known as The Hexham Grey or Scotch Grey (Figure 4). The larvae of this mosquito are predatory on other mosquito larvae and aquatic invertebrates. Although this species causes significant nuisance biting close to breeding habitats, it is not considered an important arbovirus vector. Population increases of this species are linked to the same tidal and rainfall inundations that trigger increases in *Ae. vigilax* populations, consequently, the abundance of *Ae. alternans* is usually overshadowed by *Ae. vigilax* beyond some particular localities.

- *Culex sitiens* is a dark, medium sized mosquito, usually abundant during the late summer and early autumn. The larvae of this species are commonly found, often in large numbers, in permanently inundated saline to brackish habitats, including saltmarsh and mangrove habitats. This species does not disperse far from breeding habitats and is not considered a significant pest or vector, primarily as it is a bird-feeding mosquito. On occasion, exceptionally large populations of immature mosquitoes may be detected in estuarine wetlands during late Summer and early Autumn.

6.2.2 Freshwater Mosquitoes

There are a large number of mosquitoes that are associated with freshwater wetlands in the Lower Hunter and Mid North Coast. However, many of these species are found in low numbers or do not bite humans and are not considered significant pests. In coastal areas of NSW, the importance of freshwater mosquitoes is often overshadowed by the abundance of estuarine mosquitoes. However, within the region, there are mosquitoes associated with freshwater habitats that should be considered to be potentially significant pests.

- *Culex annulirostris* is a medium sized, light to dark coloured mosquito with a banded proboscis (Figure 4). This species is the major nuisance biting and vector species throughout inland areas of NSW, particularly in the major river basins and irrigation areas. Larvae are commonly collected from a range of freshwater habitats from flooded grasslands to permanent, well-vegetated wetlands. While the importance of this species is generally overshadowed by estuarine mosquitoes in coastal areas, this mosquito is becoming of greater concern as constructed freshwater wetlands are increasingly incorporated into urban developments along the NSW coast.

- *Coquillettidia linealis* is a medium sized, dark mosquito with golden scales on the thorax (Figure 4). This species is common along the NSW coast and, while it is generally not a serious pest, there is the potential for this species to be an occasionally significant nuisance biter although little is known of its role in arbovirus transmission. The larval biology of this species differs markedly from most other mosquitoes in the region. The larvae have a modified siphon that, instead of connecting to the water/air interface to breathe, attaches to the roots and/or stems of aquatic vegetation to obtain air. The larval developmental period is temperature dependent and may be as long as many months. In the Hunter region of NSW, it is thought that the species has two major peaks of abundance, one in early spring and another in mid-Summer.

- *Culex australicus* is a medium sized, light to dark coloured mosquito and may be abundant in the Hunter region during spring and autumn. However, while the abundance of this species may occasionally be high, there is no risk of nuisance biting or arbovirus transmission as this mosquito generally does not bite humans and prefers biting birds and smaller mammals. However, as this species is associated with the same types of habitats as *Cx. annulirostris*, the abundance of this species during the Spring and early Summer may assist the identification of potential 'hot spots' for *Cx. annulirostris* production.

6.2.3 Floodwater Mosquitoes

This group of mosquitoes can often be significant pests but population increases are highly dependent on both the quantity and temporal distribution of rainfall. The major habitats for these species are usually ground pools in bushland areas or low-lying woodland or sedgeland habitats.

- *Anopheles annulipes* is a medium sized mosquito with a spindly appearance and speckled grey colouration (Figure 4). The larvae of this species have been collected from a range of habitats including ground pools, freshwater wetlands and some brackish water habitats. This species is only considered a pest risk when populations are high and is not considered an important vector of human disease. Although this species has been shown to be a vector of malaria, there is no concern regarding the transmission of malaria in the Lower hunter and Mid North Coast.

- *Aedes multiplex* is a small dark mosquito with a golden band across the thorax. The larvae of this species are usually associated with ephemeral ground pools, both freshwater and brackish water habitats, particularly in *Casuarina* and *Melaleuca* forests. This species is generally not considered a major pest as it does not disperse far from larval habitats. However, as urban development encroaches on the larval habitats, the relative importance of this species is thought to be increasing. There is little information available on the role this mosquito may play in arbovirus transmission.

- *Aedes procax* is a small to medium sized brownish mosquito with banded legs. The larvae of this species are found in freshwater and (mildly) brackish ground pools in bushland or heath land habitats. Like *Ae. multiplex*, this species is generally not considered a major nuisance biting but in the Hunter region it is occasionally found in high numbers, arboviruses have been isolated from specimens collected in the region and it may be an important pest in areas close to larval habitats. Recent investigations have shown that the role that this species plays in local arbovirus transmission cycles may have been underestimated and further research into this species is considered a priority.

- *Verrallina funerea* is a small to medium sized dark mosquito. The larvae of this species are most commonly collected from freshwater and brackish flooded *Melaleuca* and *Casuarina* woodlands, with its population abundance generally increasing towards northern NSW. Although this mosquito does not travel far from larval habitats, it is considered a relatively important pest and vector species, particularly where urban developments have encroached closer to these habitats.

6.2.4 Urban mosquitoes

Urban mosquitoes have the potential to cause severe nuisance biting and public health impacts due to the proximity of their larval habitats to human habitation. The larval habitats of these species are typically man-made and range from small water holding containers such as pot plant bases, tins, cans and bird baths, to large water and septic tanks, as well as stormwater structures such as gross pollutant traps, drains and sullage pits.

An understanding of these mosquitoes is crucial for the management of nuisance biting impacts as some of these species may be responsible for serious biting within residential areas close to natural or constructed wetlands but will not be directly associated with the wetlands. It is important for the dissemination of information regarding mosquito management that the impacts from urban mosquitoes are disassociated from the mosquito populations produced from wetland areas.

The most important mosquitoes in the Lower Hunter and Mid North Coast region that can be classified as urban mosquitoes include:

- *Aedes notoscriptus* is a small to medium sized mosquito with conspicuous dark with pale banded legs and a silver to golden 'lyre' shaped pattern on the thorax (Figure 4). This mosquito is often a severe nuisance pest, usually biting in the early afternoon and at dusk, and is one of the most common pest species in urban areas. The species has been implicated in the transmission of some arboviruses as well as dog heartworm. The larvae are usually associated with small water holding containers around dwellings such as tins, pots, ornamental ponds, roof guttering and tyres, as well as water holding plants (eg. bromeliads) and tree holes.

- *Culex quinquefasciatus* is a medium sized pale brownish mosquito and another very common pest species in urban areas, usually biting indoors at night, but it is generally not considered to be involved with transmission of pathogens. The larvae of this mosquito are usually associated with, but not limited to, habitats with a high organic content such as drains, sullage pits, septic tanks and other water holding and water storage areas. This mosquito may also be associated with constructed freshwater wetlands, including the water management structures (such as gross pollutant traps and drains) and the wetland itself.

- *Culex molestus* is another medium sized pale mosquito commonly found in polluted habitats within urban areas. The mosquito can be a significant nuisance biting pest indoors at night, and can be active all year round, particularly close to larval habitats such as sullage pits, septic tanks and highly organic ground pools.

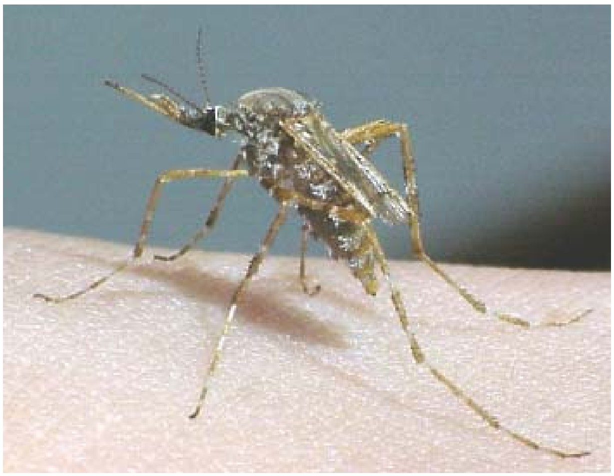
- *Toxorhynchites speciosus* is not a commonly encountered mosquito in urban areas. The adult mosquito is large, has a bent proboscis and does not bite humans, feeding entirely on plant juices. The larvae of this species are predatory, feeding on other common urban species such as *Ae. notoscriptus* and *Cx. quinquefasciatus* in water holding containers (eg, tyres, watering cans, buckets etc).

6.3 Insects commonly confused with mosquitoes

Biting midges (Ceratopogonids) can often cause nuisance-biting impacts in coastal areas and are generally associated with mudflats and sandy shores in estuaries. These biting insects are often mistakenly called sand flies in coastal NSW.

During the summer months there may occasionally be large populations of flying insects in the region that can be commonly mistaken for mosquitoes including other species of Diptera (e.g. Chironomids and Crane Flies). While these insects may cause a mild nuisance when populations are high, there are no serious pest or public health impacts to be expected.

a



b

c

d

e

f

Figure 4. A selection of the most common mosquito species representative of the four main habitat associations, *Aedes vigilax* (a), *Aedes alternans* (b), *Culex annulirostris* (c), *Coquilettia linealis* (d), *Anopheles annulipes* (e) *and Aedes notoscriptus* (f).

6.3.1 Important pest mosquitoes from outside the region

While not known to occur in the region, there are two exotic mosquitoes, *Aedes aegypti* and *Aedes albopictus* that should be made known to local authorities. These mosquitoes are most likely to occur in/or around the shipping port or airport, and surveillance programs by the Australian Quarantine Inspection Service (AQIS) are designed to detect incursions of such exotic mosquitoes. If unusual mosquito larvae are found in water holding containers (in particular tyres) within the local area, particularly close to Newcastle Port, specimens should be sent to AQIS for identification.

- *Aedes aegypti* is a day-biting mosquito and, as well as a nuisance biting pest, is a vector of Dengue viruses in north Queensland. A Dengue Fever Management Plan for North Queensland was developed to manage the public health risks through disease surveillance, mosquito surveillance and control, and community education. Originating from Africa, there are historical records of this species from various parts of Australia (including NSW) but the species is now mostly restricted to Queensland in areas north of Townsville, with occasional interceptions at international ports in various states. The larvae may be found almost exclusively in man-made, water-holding containers such as tins, bottles, tyres, water-barrels, rainwater tanks and wells, and can even be found breeding in smaller containers such as vases inside houses and other buildings.

- *Aedes albopictus*, the Asian Tiger Mosquito, is a significant pest species and a secondary vector of dengue viruses. It has a natural range throughout eastern and southeastern Asia, but over recent decades has become established in the Pacific, North and South America, Africa and parts of Europe. Although originally a forest species, *Ae. albopictus* has become closely associated with human environment and, as well as natural containers such as tree holes, plant axils & bamboo stumps, the species exploits a wide range of water holding containers associated with human habitation. Concern for the introduction of *Ae. albopictus* to mainland Australia has increased following the recent discovery of newly established populations of the species on Torres Strait islands, with the mosquito presumably having been introduced from Papua New Guinea. Computer modelling has predicted that, should this species be introduced to mainland Australia, it may spread substantially further south than the current distribution of *Ae. aegypti*.

These two species, *Ae. aegypti* and *Ae. albopictus*, are not currently known to exist in New South Wales but the importation and establishment of these species is possible, and it is important that the appropriate steps are taken by the authorities to intercept any incursions of these species into the local region.

6.3.1.1 <u>The role of the Australian Quarantine and Inspection Service. (AQIS)</u>

AQIS performs vector monitoring and control within and around international airports and seaports as recommended under World Health Organization's (WHO) International Health Regulations (IHR).

Vector monitoring and control activities are undertaken within a protective zone of at least 400m (this zone surrounding the Port of Newcastle is shown in Appendix 3) around airports or seaports, so that all quarantine risk posed by vessels and aircraft is minimised. AQIS monitors the areas within these zones for target mosquito species using ground surveillance and trapping activities. AQIS also inspect all foreign vessels for presence of exotic mosquitoes and potential breeding sites on arrival at their first port of call in Australia.

Mosquito species targeted by AQIS fall into two categories – import and export species. Import species are those that, if introduced to Australia, could prove damaging as vectors of human disease. These include *Aedes albopictus* and *Ae. aegypti.* Export species are those that, if exported overseas, have the potential to vector diseases not present previously in a particular country. Major export species in the Lower Hunter region are *Aedes vigilax, Anopheles annulipes* and *Culex annulirostris*.

6.3.1.2 The role of the Ports Mosquito Management Group.

This group was formed to assess and implement control strategies in relation to the Quarantine Act 1908 for Proclaimed Port and Airport environments in Newcastle.

The group is working towards a co-ordinated approach to monitoring, reporting, information flow and control strategies in the form of a partnership that clearly demonstrates the agreed roles of each of the partners and other stakeholders, and ensures that all necessary measures and actions are in place to protect the community.

The group consists of representatives from Newcastle Port Corporation, Newcastle City Council, Port Stephens Shire Council, the NSW Premiers Department, Hunter New England Health, Newcastle Airport, RAAF Williamtown, the Regional Land Management Corporation and the Australian Quarantine and Inspection Service.

6.4 Climate change and mosquitoes

Mosquitoes and mosquito-borne disease are often discussed, as a major concern should climate change result in global warming and/or sea level rise. The greatest concern is that, with increased temperatures, the geographic range of pest and vector species will increase and with it the risk of human disease, particularly "tropical" diseases such as Malaria and Dengue (For more information on these two mosquito-borne diseases see Section 8.2). However, there are many factors beside temperature including the availability of suitable habitats, short term changes in rainfall and tidal heights, urbanisation and mosquito control programs that influence the distribution and abundance of mosquitoes as well as the incidence of human disease.

While the risks of 'tropical' diseases are unlikely to rise with predicted climate change, there may be a local increase in the risk of arboviruses, including Ross River virus and Barmah Forest virus. With overall warmer temperatures, there may be a decrease in the incubation period (the time between when a mosquito ingests a virus and when it is capable of transmitting the virus to humans) of the viruses in local vector species. This will mean that a potentially greater proportion of mosquitoes can transmit arboviruses in the local area. In addition, the warmer weather may not increase the magnitude of population increases but it may extend the period of mosquito activity, increasing nuisance-biting and potential public health risks in the spring and late autumn.

It is highly unlikely that any rise in temperature or sea-level will result in a significant change to the mosquito fauna (either the species composition or abundance) of the Lower Hunter and Mid North Coast region. Assessing the impact of climate change is a complex process (with much debate surrounding the potential magnitude of temperature, rainfall and sea level change) but the pest and public health impacts of mosquitoes in the future may be determined as much by urbanisation, wetland management strategies and mosquito control programs as any change to the climate of the region.

There have been a number of publications in recent years discussing the possible impact of predicted climate change on the Australian mosquito fauna and activity of local and exotic mosquito-borne disease. For an informative overview of the issue, see Russell (2009) Mosquito-borne disease and climate change in Australia: time for a reality check in *Australian Journal of Entomology*, 48: 1-7.

7 THE ECOLOGICAL ‘PLACE’ OF MOSQUITOES

7.1 Are mosquitoes just pests?

Mosquitoes are small but incredibly complex organisms that have evolved to exploit even the tiniest of environmental niches. Mosquitoes have adapted their larval and adult morphology, ecology, physiology, and life cycles to suit a diverse range of environments. While some mosquitoes have adapted to the hypersaline conditions of saltmarsh habitats, others exploit small quantities of water inside tree holes or the leaf axils of tropical plants. The larval development of some mosquitoes can be completed in less than a week to take advantage of small ephemeral ground pools, while other species have a prolonged larval development lasting many months in more permanent habitats.

Mosquitoes have developed highly sophisticated sensory organs that can detect subtle differences in the chemical and physical cues of potential hosts, and some prefer blood meals from a single animal group while others mosquitoes are more generalist host seekers.

While mosquitoes are well known as potential biting pests and vectors of disease, only relatively few mosquitoes pose a serious risk to humans. There are many species of mosquito that rarely come in contact with humans, due to their relatively low abundance or limited dispersal from larval habitats. Many mosquitoes do not seek out a blood meal from humans at all, preferring to take blood from other mammals, birds or frogs.

7.2 Mosquitoes and aquatic ecosystems

There is very little published information available on the role of mosquitoes in freshwater and estuarine wetland ecosystems. However, like many other aquatic invertebrates, mosquito larvae provide food for predators while assisting nutrient recycling. Mosquito larvae feed on detritus and other organic material in the water and are a food source for aquatic organisms including fish and some macroinvertebrates. It is unlikely that any vertebrate or invertebrate predator relies solely on mosquito larvae but, particularly when larvae are present in large numbers, they can represent a commonly consumed prey item. The larvae of some mosquito species (e.g. *Ae. alternans* and *Cx. halifaxii*) have specialised mouth parts and are predatory on other mosquito larvae and various aquatic macroinvertebrates.

As well as providing prey for aquatic predators, mosquito larvae may be an important source of food for wading birds. Many species of wading bird have been observed undertaking feeding behaviour within known mosquito habitats and, although there are often alternative prey available (e.g. bottom dwelling chironomid or chaoborid larvae) and there is no evidence to suggest that these birds selectively feed on mosquito larvae alone as a primary food source, it is likely mosquitoes are commonly consumed.

7.3 Mosquitoes and terrestrial ecosystems

Adult mosquitoes provide food for a range of terrestrial invertebrates, birds, mammals, amphibians and reptiles as well as playing a role in the pollination of some plants (particularly the male mosquitoes that feed exclusively on plant juices). Quantifying the role of mosquitoes in food chains is difficult but given that they have a short life span and dramatic fluctuations in abundance, they may simply represent ‘snack food’ for many animals rather than a regular food source. However, while there is no evidence that any animal specifically relies on mosquitoes alone, the large abundance of mosquitoes on occasion may provide important nutritional boosts to juveniles or migratory birds prior to departure from wetland habitats at the end of summer.

There is a paucity of published scientific studies identifying or dismissing mosquitoes as an important food source for Australian wildlife. There are studies that have identified aquatic insects (e.g. chironomids) that share similar habitats to mosquitoes as key food sources, particularly for waterbirds but the relative importance of mosquitoes (and other invertebrates) is likely to vary greatly between waterbird species and within particular waterbirds across the course of the year. Further study is required to determine the spatial and temporal relative importance of adult and immature mosquitoes as a food source for waterbirds.

Studies in the Lower Hunter and Mid North Coast region have shown that a number of bat species exhibit foraging behaviour above saltmarsh habitats and, given the local abundance of mosquitoes, it is likely that they form a major component of the bat's diet during these periods. It is difficult, however, to determine the relative importance of mosquitoes to each animal group and the preferences these insectivorous predators have for mosquitoes or other insects. Current research in coastal NSW is attempting to quantify the importance of mosquitoes, compared to other flying insects, to the diet of bats.

Studies with frogs and spiders have indicated that for these groups, larger animals tend to favour the consumption of smaller quantities of larger prey (e.g. moths) rather than large quantities of small prey (e.g. mosquitoes), but further studies are required to identify and quantify these and other relationships.

8 NUISANCE BITING AND PUBLIC HEALTH RISKS OF MOSQUITOES

Notwithstanding the severe nuisance biting impacts of mosquitoes, there are several important human diseases transmitted throughout Australia by mosquitoes, including Dengue fever, Murray Valley encephalitis, Ross River virus disease and Barmah Forest virus disease. Malaria is a serious health concern in many parts of the world, but in Australia in recent decades it has been rarely transmitted and only in the far north of Queensland. These nuisance and public health risks can have wide ranging impacts on the community, and vary with location as the mix of mosquito species and presence of mosquito borne pathogens varies. An understanding of the vectors and arboviruses in the local area is crucial for an assessment of these risks and the selection of appropriate management strategies.

8.1 Nuisance biting

There are strong indicators that nuisance biting alone can have negative impacts on the standard of living in the community as well as having economic impacts on residential, recreational and tourist developments. It is extremely difficult to quantify the impact of nuisance biting as the tolerance level of individuals varies substantially and is often dependent on the extant mosquito populations and previous experiences.

The greatest difficulties lie in determining what constitutes a nuisance biting problem. While a small population of domestic species such as *Ae. notoscriptus* may cause substantial problems in some areas, the impact of these populations would be significantly overshadowed by large *Ae. vigilax* populations in areas close to estuarine wetlands.

There are many mosquito species known to bite humans in the Lower Hunter and Mid North Coast but the most significant pest is *Ae. vigilax,* with *Cq. linealis, Cx. annulirostris, Ae. alternans, Ae. multiplex and Ve. funerea* all likely to cause moderate impacts on occasion or in specific areas close to larval habitats.

The nuisance impacts of *Ae. vigilax* are considered significant as this species is a day and night biting mosquito and capable of substantial increases in population size. The adults can disperse great distances from larval habitats and, although the relative abundance of this mosquito will decrease with distance, some pest impacts can be experienced over at least 5kms from estuarine wetlands.

The most effective measure of potential nuisance biting impacts is routine adult mosquito sampling that enables a comparative measure of mosquito abundance during and between mosquito ‘seasons’.

8.2 Public health risks

Nuisance biting impacts from mosquitoes can have serious impacts on the community. However, a more serious risk is that to personal and public health through the transmission of disease-causing pathogens by mosquitoes.

The mechanisms involved in the transmission of vector-borne disease can be complex and vary with both the mosquito species and pathogen. When a mosquito bites a bird or mammal infected with an arbovirus it takes in a small amount of blood, which may contain virus. If the mosquito species is susceptible to infection with the virus, the virus will move through the body of the mosquito from the gut wall to the salivary glands. If the salivary glands become infected, the mosquito can pass on the virus when it injects saliva during blood feeding. This process of virus infection is called the incubation period and can take between 3 and 12 days to complete, depending on virus type, mosquito species and temperature. The mosquito will not be able to transmit the virus until the salivary glands are infected. The biological processes involved in producing an infective mosquito are very specific and that is why only arboviruses are transmitted by mosquitoes and not other viruses such as influenza, measles, hepatitis and HIV that are degraded by the digestive process of the mosquito.

The NSW Arbovirus Surveillance and Mosquito Monitoring Program has isolated arboviruses such as Ross River virus and Barmah Forest virus from mosquitoes collected in the Lower Hunter and Mid North Coast Region (Table 3).

8.2.1 Ross River virus and Barmah Forest virus

Ross River virus (RRV) and Barmah Forest virus (BFV) are the most common disease-causing pathogens spread by mosquitoes in Australia. There are, on average, approximately 5,000 and 600 human cases of RRV and BFV, respectively, per year across Australia.

While the symptoms can vary greatly between individuals and include fever and rash, infection with either of these viruses may result in a condition known as polyarthritis with arthritic pain in the ankles, fingers, knees and wrists. Generally, the rash tends to be more florid with BFV infection but the arthritic pain is greater with RRV infection. The presence of specific antibodies showing infection with RRV and BFV can be determined with a blood test, with samples being taken during the acute and convalescent phases of the illness, and a fourfold rise in antibody levels will confirm the clinical diagnosis. Under the NSW Public Health Act 1991, both viruses are classified as a notifiable infectious disease.

The numbers of human notifications from the region have fluctuated over the last nine years with a combined (RRV + BFV) average of 75.5 notifications per year (Table 3) with the number of notifications greatest in May and June. The notification rates of these two arboviruses are generally lower in more urbanised areas of NSW, as habitats capable of producing substantially large mosquito populations are low, as is the abundance of suitable animal hosts.

The transmission cycles for RRV and BFV generally require the presence of suitable reservoir hosts. Mosquitoes take a bloodmeal from a host carrying the virus and the virus disseminates throughout the mosquito's body until the salivary glands are infected. The mosquito is then capable of infecting a person when saliva is injected while blood feeding. As it takes between 5-10 days for a mosquito to become infective, adult mosquitos must live long enough following initial infection to pose a health risk. Serological studies and laboratory investigations have indicated that native mammals (in particular native macropods such as kangaroos and wallabies) are natural hosts for RRV, but little is known about the hosts of BFV and they may include birds as well as mammals. However, RRV transmission from human to mosquito to human (thus occurring without the involvement of an animal) appears to occur in some circumstances, particularly during periods of intense virus activity. Some cases of 'urban transmission' have been reported in Brisbane and Perth when virus has been introduced with humans returning from rural areas to urban areas that have had high mosquito populations.

RRV and BFV have been isolated from thirteen mosquito species in NSW from 1989/90 until 2004/2005, with the majority of isolates coming from *Cx. annulirostris* in the inland and *Ae. vigilax* on the coast (Table 4). In total, these two mosquitoes accounted for 77.92% of all arbovirus isolations in NSW. RRV was the most commonly isolated arbovirus from mosquitoes collected in the Central Coast/Lower Hunter/Mid-North Coast region (Table 5). The majority of isolates came from *Ae. vigilax*, *Ae. procax* and *Cq. linealis* with monitoring sites in Port Stephens, particularly Heatherbrae, Karuah and Salt Ash, frequently providing evidence of virus activity.

Table 3. The annual (July-June) number of human notifications of Ross River virus and Barmah Forest virus disease in the Hunter and Mid North Coast Area Health Services.

Year	Hunter		Mid North Coast	
	Ross River	Barmah Forest	Ross River	Barmah Forest
1996-1997	288[1]		172	
1997-1998	55		69	
1998-1999	149		145	
1999-2000	117		194	
2000-2001	140	14	92	179
2001-2002	19	89	42	155
2002-2003	29	32	94	153
2003-2004	69	23	116	163
2004-2005	61	52	142	196
2005-2006	172	163	157	166
2006-2007	160	128	117	101
2007-2008	240	114	110	111
2008-2009	249	102	135	91

[1] Prior to 2000, the notifiable disease database does not differentiate between RRV and BFV infection.

Table 4. Total number of virus isolates from each mosquito species collected at coastal sites in NSW Arbovirus Surveillance and Mosquito Monitoring Program, 1989/90 through until 2008/09.

MOSQUITO	RR	BF	SIN	GG	TRU	EH	KOK	KUN	STR	Virus?	TOTAL
Ae. aculeatus	0	0	0	0	0	0	0	0	1	1	2
Ae. alternans	1	0	0	0	0	1	0	0	0	0	2
Ae. camptorhyncu	2	1	0	0	0	0	0	0	0	0	3
Ae. eidsvoldensis	2	0	1	0	0	0	0	0	0	1	4
Ae. flavifrons	1	0	0	0	0	0	0	0	0	0	1
Ae. multiplex	2	0	0	0	0	1	0	0	0	1	4
Ae. nr. *normanen*	0	0	0	0	0	0	0	0	0	1	1
Ae. notoscriptus	5	1	0	0	0	2	0	0	6	1	15
Ae. procax	8	14	0	0	0	2	0	0	8	2	34
Ae. theobaldi	1	0	0	0	0	0	0	0	0	0	1
Ae. vigilax	64	133	0	2	0	30	0	0	22	13	264
An. amictus	0	0	0	0	0	0	0	0	0	5	5
An. annulipes	9	0	4	0	3	0	0	0	1	57	74
Cq. linealis	6	1	1	0	0	0	0	0	0	2	10
Cq. xanthogaster	0	0	0	0	0	0	0	0	0	1	1
Cq. variegata	1	0	0	0	0	0	0	0	0	0	1
Cx. annulirostris	77	3	201	1	0	6	7	11	0	127	433
Cx. australicus	0	0	0	0	0	0	0	0	0	10	10
Cx. molestus	1	0	0	0	0	0	0	0	0	1	2
Cx. orbostiensis	0	0	0	0	0	0	0	0	0	2	2
Cx. quinquefascia	0	0	0	0	0	0	0	0	0	3	3
Cx. sitiens	1	0	2	0	0	0	0	0	0	7	10
Mansonia	0	0	0	0	0	1	0	0	0	0	1
Ve. funerea	3	0	0	0	0	0	0	0	0	2	5
Mixed pools	4	0	3	1	0	0	0	0	0	10	18
TOTAL	188	153	212	4	3	43	7	11	38	247	906

RR=Ross River virus, BF=Barmah Forest virus, SIN=Sinbis virus, GG=Gan Gan virus, TRU=Trubanaman virus, KOK=Kokobera virus, EH=Edge Hill virus, KUN=Kunjin virus, STR=Stratford virus, , Virus?= Virus was present in the sample of mosquitoes but was not identified as one of the major Alphaviruses or Flaviviruses

Table 5. Ross River and Barmah Forest virus isolates from mosquitoes collected in the Lower Hunter and Mid North Coast in the NSW Arbovirus Surveillance and Mosquito Monitoring Program, 1989-2005.

Season	Location	Arbovirus isolated	Mosquito species	Number
2008-2009	Port Stephens	Ross River virus	*Ae. flavifrons*	1
2008-2009	Port Stephens	Ross River virus	*Ae. multiplex*	1
2008-2009	Port Stephens	Ross River virus	*Ae. vigilax*	4
2007-2008	Port Stephens	Barmah Forest	*Ae. procax*	5
2007-2008	Port Stephens	Barmah Forest	*Ae. vigilax*	1
2007-2008	Port Stephens	Ross River virus	*Ae. vigilax*	1
2006-2007	Port Stephens	Ross River virus	*Ae. flavifrons*	1
2006-2007	Port Stephens	Ross River virus	*Cx.*	1
2006-2007	Port Stephens	Ross River virus	*Ae. procax*	1
2006-2007	Port Stephens	Ross River virus	*Ae. vigilax*	2
2006-2007	Lake Macquarie	Barmah Forest	*Ae. procax*	1
2005-2006	Lake Macquarie	Barmah Forest	*Ae. procax*	1
2005-2006	Lake Macquarie	Barmah Forest	*Ae. procax*	1
2005-2006	Lake Macquarie	Barmah Forest	*Ae. vigilax*	10
2005-2006	Lake Macquarie	Ross River virus	*Ae. vigilax*	1
2005-2006	Port Stephens	Barmah Forest	*Cx. sitiens*	1
2005-2006	Port Stephens	Ross River virus	*Ae. procax*	1
2005-2006	Port Stephens	Barmah Forest	*Ae. procax*	4
2005-2006	Port Stephens	Barmah Forest	*Ae. vigilax*	11
2005-2006	Port Stephens	Ross River virus	*Ae. vigilax*	11
2004-2005	Port Stephens	Ross River virus	*Ae. procax*	3
2004-2005	Port Stephens	Ross River virus	*Cx. molestus*	1
2004-2005	Port Stephens	Ross River virus	*Ae. multiplex*	1
2004-2005	Port Stephens Salt Ash	Ross River virus	*Ae. vigilax*	6
1998-1999	Forster	Ross River virus	*Cq. linealis*	1
1998-1999	Port Stephens	Ross River virus	*Cq. linealis*	1
1998-1999	Port Stephens	Ross River virus	*Cx. annulirostri*	1
1998-1999	Port Stephens	Ross River virus	*Ae. vigilax*	2
1996-1997	Port Stephens	Ross River virus	*Ae. procax*	1
1995-1996	Port Stephens	Ross River virus	*Ae. vigilax*	1
1994-1995	Forster	Barmah Forest	*Cq. linealis*	1
1993-1994	Port Stephens: Salt Ash	Ross River virus	*Ae. vigilax*	2
1991-1992	Port Stephens	Ross River virus	*Ae. vigilax*	3
1991-1992	Port Stephens	Ross River virus	*Cq. linealis*	1
1989-1990	Port Stephens	Ross River virus	*Cq. linealis*	1
1988-1989	Port Stephens	Ross River virus	Pooled sample[2]	1

[1]Virus was present in the sample of mosquitoes but was not identified as one of the major Alphaviruses or Flaviviruses
[2]Pooled sample containing *Ae. procax*, *Ae.vigilax*, *Cx. australicus*, *Cx. annulirostris &*, *Ve. funerea*.

8.2.2 Murray Valley encephalitis and Kunjin virus

The term 'Australian Encephalitis' has been used to describe human illness caused by infection by Murray Valley encephalitis virus (MVEV) or Kunjin virus (KUNV), but the term is now considered inappropriate because the seriousness of symptoms following infection by each virus is quite different and the infections are now considered as separate entities. It has recently been acknowledged that Kunjin virus is a subspecies of West Nile virus (WNV). However, KUNV is considered a far less significant public health threat in Australia than those subspecies known to cause occasional encephalitic disease in North America, the Middle East, Europe and Africa.

Cases of MVEV infection vary from mild to severe to fatal, with symptoms almost invariably including a sudden onset of fever, anorexia and headache, while vomiting, nausea, diarrhoea and dizziness may also be experienced along with lethargy and irritability. Drowsiness, confusion, convulsions and neck stiffness can be experienced a few days after the onset of initial symptoms. The disease can be fatal and many who survive the encephalitic syndrome have some residual mental or functional disability. For KUNV, there are fewer human cases reported, the disease is milder and there are no known fatalities resulting from the infection.

Both MVEV and KUNV viruses have a natural endemic cycle in northern Australia, which involves water birds as the vertebrate host and the freshwater mosquito *Culex annulirostris* as the major vector. Epidemic activity of the viruses in the southeast of Australia is rare and has been associated with excessive rainfall and flooding, which increases bird and mosquito populations, but it is still uncertain whether the viruses are introduced occasionally to the southeast from the north or whether either or both are endemic in inland areas at undetectable levels and only become evident with periods of intense bird and mosquito breeding.

With respect to the local region, no activity of MVEV or KUNV has been recorded east of the Great Dividing Range in NSW and thus the risks from these viruses are considered to be relatively low.

8.2.3 Dengue

Dengue is currently considered one of the most important viral diseases transmitted by mosquitoes to humans in a world context. In Australia, most locally acquired cases of dengue occur in North Queensland, particularly around Townsville and Cairns, where the vector mosquito, *Aedes aegypti* is abundant in the urban environments.

In Australia, epidemics of dengue occurred in the late 19th century and early 20th century. Australia was considered to be free of local dengue following 1955 (when there had been a large outbreak in Townsville), but in 1981 a major outbreak with an estimated 3,000 infections occurred in northern Queensland, presumably initiated by an infected traveller. During the recent 2008-2009 outbreak, 1,000 confirmed cases, including one fatality, were reported.

The normal cycle of dengue infection is considered to be a mosquito feeding on an infected and viraemic human and then, after an incubation period of 8-10 days, the mosquito remains infective for life and can infect other humans each time it feeds. The clinical symptoms range from mild fever to a severe and potentially life threatening haemorrhagic disease. The so-called 'classical' Dengue Fever form usually affects older children and adults with fever, violent headache, and severe pains in the muscles and joints following an incubation period of 5-8 days, and lasts about 4-7 days; recovery is generally complete although convalescence may be long.

The only known vector of dengue to occur in Australia, *Ae. aegypti*, does not occur currently in NSW and thus there is no risk of dengue transmission in the Lower Hunter and Mid-North Coast region.

8.2.4 Other local arboviruses

There are other arboviruses present in the Lower Hunter and Mid North Coast that may pose minor health risks on occasion.

Sindbis virus (SINV) is an Alphavirus that occurs in all mainland states of Australia. However, disease from Sindbis is virtually unknown in Australia. Birds are considered the main host and the virus has been isolated from many mosquito species.

Edge Hill virus (EHV), Kokobera virus (KOKV) and Stratford virus (STRV) are all Flaviruses that may cause symptoms including myalgia, arthralgia and muscle fatigue, although there have been few documented symptomatic patients. These viruses have been isolated from a number of mosquito species, and EHV and STRV have been isolated from *Ae. vigilax* collected in the Port Stephens area .

Gan Gan virus (GGV) and Trubanaman virus (TRUV) are both Bunyaviruses that can cause a mild illness with symptoms of fever, malaise, myalgia, polyarthralgia/polyarthritis and rash. The viruses have been found in a number of mosquito species but documented human disease is rare. As the name suggests, GGV was first identified (1970) from the Lower Hunter region, and two isolates of GGV were made from *Ae. vigilax* in the Port Stephens area during the 1991-1992 monitoring season but for the past decade the testing procedure has not allowed for the detection of bunyaviruses.

8.2.5 Malaria

This disease in humans results from infection with a protozoan blood parasite (one of four species of the genus *Plasmodium*: *Plasmodium falciparum*, *P. vivax*, *P. malariae*, and *P. ovale*) transmitted by a species of the mosquito genus *Anopheles*. The clinical symptoms of malaria include periodic fever, varying degrees of anaemia and splenic enlargement, and a range of syndromes resulting from the physiological and pathological involvement of certain organs including the brain, liver and the kidneys. Infection with *P. falciparum* and *P. vivax* is the most common, and *P. falciparum* infection can be fatal in the absence of treatment.

In Australia, malaria was endemic historically, but local activity had been eliminated by the mid-1960s and malaria was declared eradicated from the country in 1981. Cases that are reported now in Australia typically are acquired overseas (and called ‘imported’ cases) or rarely by local transmission from imported cases (and called ‘introduced’ cases). Little is known of local vectors because few outbreaks were studied, but laboratory investigations have revealed that a number of local *Anopheles* species are susceptible to infection and can play a role in transmission. *Anopheles farauti* is a major vector of malaria in Papua New Guinea and it is presumed to be the species of greatest concern in the north of Australia, but this mosquito does not occur in NSW. In southern Australia, *An. annulipes,* a species common in the Lower Hunter and Mid North Coast, has apparently been the vector where occasional cases of malaria have been contracted. However, there should be no concern that malaria currently poses a health risk in NSW.

9 MOSQUITO HABITATS

9.1 Estuarine wetlands

The estuarine wetlands can be divided into two main categories; the mangrove forests and saltmarsh. The term "saltmarsh" may be used to describe a number of different vegetation communities, with over 200 flowering plants known to occur in NSW saltmarshes. However, while mosquitoes may use saline and brackish water pools amongst any type of vegetation, the most important larval habitats are those primarily vegetated with *Sarcocornia quinqueflora*, *Sporobolus virginicus* and *Triglochin striatum* (Figure 5).

The most productive habitats for *Ae. vigilax* are vegetated pools and depressions inundated by the highest tides (Spring tides) of the month. Habitats at higher elevation only inundated by the highest of Spring tides, or rainfall, can also represent productive habitats on occasion. Saltmarsh mosquitoes can tolerate a wide range of salinity, including hyper saline conditions (>40ppK).

Pools and depressions need to stay inundated for 7-10 days to allow larvae to complete their development, but then dry completely to expose the preferred oviposition sites at the base of vegetation. If habitats remain inundated, *Ae. vigilax* mosquitoes cannot access these oviposition sites and predator populations are more likely to become established, reducing the suitability of the site for mosquito production; however, in the absence of sufficient predators, *Cx. sitiens* can exploit persistently inundated sites.

Mangrove habitats, generally, do not represent important mosquito habitats. Typically existing in the intertidal zone, these habitats are frequently flushed by tides and are usually characterised by abundant fish populations. However, in situations where tidal flows to mangrove areas are restricted, or mangroves have colonised channels or pools within saltmarsh areas, mosquito production can be high.

Large estuarine lakes and lagoons are generally not significant mosquito habitats due to their depth and abundance of predatory fish. The most likely mosquito habitats associated with these water bodies are along the lake or lagoon margin, particularly low lying areas that may be prone to inundation following rainfall.

9.2 Brackish water habitats

Coastal sedgeland communities including *Juncus*, *Eleocharis* and *Baumea* species can provide important mosquito habitat with productivity dependent on inundation and the abundance of pools and depressions. The mosquito species that use these habitats will be dependent on the influence of salinity. Saltmarsh mosquitoes including *Ae. vigilax* and *Ae. alternans* may be more dominant if salinity is relatively high, but habitats with greater influence from rainfall will provide habitat for less saline tolerant species including *Ve. funerea*.

Coastal floodplain forests represent potentially important mosquito habitats. *Melaleuca* and *Casuarina* forests, where there is an abundance of ephemeral pools persisting after rainfall, provide suitable conditions for a range of pest mosquitoes including *Ve. funerea*, *Ae. multiplex, Ae. procax* and, on occasion, *Ae. vigilax* (Figure 5). These habitats appear to be of increasing importance in the local area as urban developments are undertaken in close proximity and within these environments. These habitats are often extensive and difficult to survey and, as a result, little is known of the specific habitat characteristics that may predispose some areas to being productive mosquito habitats.

Heavily vegetated dune swamps and small lagoons can also provide locally significant mosquito habitats. These areas are more typically influenced by rainfall and tend to be less brackish than sedgelands or floodplain forests and, as a result, provide larval habitats for a range of different mosquitoes, most importantly, *Cq. linealis*.

9.3 Freshwater habitats

There is a wide range of mosquito habitats that fall into this category including permanent freshwater wetlands (Figure 5), flooded pastureland, ephemeral bushland pools, creeks, dams and constructed wetlands (Figure 5). The diversity of mosquitoes present and productivity of individual sites is predominantly dependent on characteristics including water depth, water quality, vegetation composition, vegetation density and predator (fish and macroinvertebrate) populations. The most important pest mosquitoes associated with freshwater habitats are *Cq. linealis*, *Cx. annulirostris* and *Cx. quinquefasciatus*.

For permanently inundated wetlands, the macrophyte zone is more likely to support mosquito larvae when the vegetation density is high and/or there is an accumulation of debris or filamentous algae that restricts water movement and provides refuge from predators and wind/wave disturbance.

There is limited information available on the associations between specific vegetation types and mosquito productivity. The species of greatest concern are *Typha* spp. and *Phragmites* spp. that are prone to wetland invasion and dense growth. These species may "clog" wetland systems, creating refuge for mosquito larvae and restricting access of predators. Also, dead plant material increases the organic content of the water, increasing the suitability of the habitat for mosquito species such as *Cx. annulirostris* and *Cx. quinquefasciatus*.

9.4 Urban environments

There is a range of different habitats within urban environments that may support the production of mosquitoes. Generally, these habitats are divided into those usually high in organic content, associated with stormwater and waste-water structures, such as drains, detention basins, Gross Pollutant Traps (GPT) (Figure 5), and small water holding containers found around residential and/or industrial areas.

The larvae of *Ae. notoscriptus* are usually associated with small water holding containers around dwellings such as tins, pots, ornamental ponds, roof guttering, water tanks and discarded tyres, as well as water holding plants (eg. bromeliads) and tree holes. Essentially, any small to medium sized water holding container can be used by this species.

The larvae of *Cx. quinquefasciatus* and *Cx. molestus* are usually associated with habitats with a high organic content such as drains, sullage pits, septic tanks and other water holding and water storage areas. Any structure constructed as part of the stormwater or waste-water system that retains water and is accessible by mosquitoes can provide habitat for these species.

Figure 5. Some examples of suitable mosquito habitats in estuarine (a), brackish-water (b), freshwater (c & d) and urban (e & f) environments.

10 ENVIRONMENTALLY SUSTAINABLE MOSQUITO MANAGEMENT

It would not be possible, or desirable, with methods currently available to eradicate mosquitoes entirely from the Lower Hunter and Mid North Coast region. Not withstanding an acknowledgement that mosquitoes make a valuable contribution to the overall wetland ecosystem and complete eradication would be counter productive to current wetland conservation, no control strategy is 100% effective and it would be impossible to identify and remove and/or undertake source reduction in all mosquito habitats.

Environmentally sustainable mosquito management should follow the principles of Integrated Pest Management. The basis for any integrated pest management program is a multidisciplinary strategy built on an appropriate mosquito-monitoring program. Without a monitoring program it is impossible to determine critical treatment thresholds, assess effectiveness of control strategies or provide quantitative measures of spatial and temporal nuisance biting and/or public health risks.

The mosquito management strategy should consider site-specific characteristics, including the extant mosquito fauna, major nuisance biting and vector mosquitoes, size and distribution of larval habitats relative to current and future residential and recreational areas, environment triggers of mosquito population increase, and previous arbovirus activity.

In situations where routine control agent application may not be practicable or desirable, it is important to consider the mosquito control options available in the case of unusually large mosquito populations occurring and/or when population control is required during disease outbreaks. There is a range of products and product formulations that have been effectively used in many freshwater and estuarine systems in Australia without adversely impacting the non-target flora or fauna. These should be determined by each local government prior to outbreak events occurring so that there is no delay in implementing control measures.

The Mosquito Management Code of Practice for Queensland produced by the Local Government Association of Queensland in 2002 outlines an overall process in the development of a mosquito management strategy. This proposed that if preliminary assessments of actual and/or potential mosquito problems within a Local Government Area found that mosquito control was required (as identified by risk assessments and population surveillance) a mosquito management program should be developed for the area. The program must incorporate an integrated mosquito management approach that includes, at least, consideration of site-specific source reduction, habitat modification, biological control, insecticide usage and public education strategies. Most importantly, the mosquito management program should determine the impact management strategies would have on the environment.

There is no legislation in place that makes it mandatory for local governments to control mosquito populations in NSW. NSW Health does not have a specific policy on mosquito control. However, the NSW Arbovirus Disease Control Strategy Green Paper (1998) states that mosquito management should be directed towards reducing the risks of disease transmission through the reduction of mosquito populations as opposed to their complete elimination. While NSW Health funds the NSW Arbovirus Surveillance and Mosquito Monitoring Program, funding only covers mosquito population surveillance and not mosquito management, and there is no earmarked funding available to undertake mosquito control activities.

In NSW, the emphasis is placed on local councils to deliver mosquito management, and the NSW Arbovirus Disease Control Strategy Green Paper proposed that statutory or regulatory amendments of *NSW Public Health Act 1991* or the *NSW Local Government Act 1993* might be required to ensure councils undertake mosquito management. There is an acknowledgement, however, that there may be considerable ongoing financial outlays for local councils undertaking mosquito control. In NSW, Tweed, Griffith, Newcastle and Port Stephens Councils have undertaken active mosquito control with *ad hoc* control of localised mosquito habitats also undertaken by Parramatta Council and Ryde Council.

The most significant mosquito management program in NSW is currently undertaken in the estuarine wetlands within Sydney Olympic Park. The program of mosquito monitoring and treatment of wetlands is funded and coordinated by the Sydney Olympic Park Authority (SOPA). Following inundation of wetlands by tides and/or rainfall, larval population monitoring is undertaken and if a pre-determined critical larval density threshold of *Ae. vigilax* is exceeded, aerial (and occasionally ground) based applications of an environmentally sensitive control agent are employed. The treatment program has been in place since 1998, with mosquito population monitoring having been undertaken since 1993. As well as providing an assessment of the treatment program, the mosquito monitoring enables the dissemination of information on mosquito activity to the local community, and helps educate residents and visitors on wider wetland management issues.

One strategy to improve the efficiency and funding base for mosquito management is for neighbouring councils to co-operate and work together. In 1978, local authorities in south-east Queensland, came together to form a Contiguous Local Authority Group (CLAG) to promote a regional approach to mosquito management. Two more regional groups have subsequently been formed: the North East Moreton Mosquito Organisation (NEMMO) and the Sunshine Coast Mosquito and Midge Committee (SCMM). These groups work with the Mosquito and Arbovirus Research Committee (MARC) Inc in Queensland to achieve and maintain high standards of mosquito management.

In NSW, there are no regional consortiums of councils currently undertaking mosquito control. However, the recently formed North Coast Mosquito Focus Group (NCMFG), coordinated by the Northern Rivers Public Health Unit and including representatives of Ballina, Tweed, Byron, Pristine Waters, Maclean and Lismore Councils, as well as wetland ecologists and entomologists, regularly meet to discuss issues surrounding mosquitoes and arboviruses in far north coastal NSW.

The councils surrounding Sydney Olympic Park, including Strathfield, Parramatta, Ryde and Canada Bay Councils undertake mosquito monitoring during each season with the mosquitoes being processed in the NSW Arbovirus Surveillance and Mosquito Monitoring Program. There is no formal organisation of these local authorities but SOPA coordinates annual meetings to discuss the results of the mosquito monitoring and treatment programs.

In NSW, there is legislation in place that will influence mosquito management strategies. A recent paper by Webb, Prichard, Plumb and Russell (2009) titled "How does legislation influence mosquito-borne disease management in New South Wales? Appeared in Arbovirus Research in Australia, 10: 176-182.

Some examples of legislation that may influence mosquito management strategies include:

- *State Environmental Planning Policy No 14—Coastal Wetlands*. The aim of this policy is to ensure that the coastal wetlands are preserved and protected against clearing, draining, filling or any other form of habitat modification except with appropriate consent. Permits will be required to undertaken mosquito source reduction in estuarine wetlands.

- *Fisheries Management Act 1994.* The Act aims to conserve NSW fishery resources by protecting habitats, conserving threatened species, populations and communities and encouraging ecologically sustainable development. Approval must be sought for mosquito management strategies that may impact on fisheries including the construction of runnels, removal of mangroves or other aquatic vegetation, regulation of natural tidal flows and introduction of fish.

- *Threatened Species Conservation Act 1995*. Coastal saltmarsh was recently listed as an Endangered Ecological Community. The Act is designed to conserve biological diversity and promote ecologically sustainable development by protecting the threatened ecological communities, and eliminate or manage certain processes that threaten the species, populations and communities. Any mosquito control activities in saltmarsh areas carried out in accordance with a property management plan (so approved by the

Director-General) does not require a licence. However, in wetland areas where property management plans do not exist, licences will be required.

- *Environmental Planning and Assessment Act 1979.* This Act aims to provide protection of the environment, including the conservation of native animals and plants, including threatened species, populations and ecological communities, and their habitats by encouraging ecologically sustainable development. Mosquito management activities on NPWS property will be required to be assessed under Part 5 of this Act (Environmental Assessment) to determine if there is likely to be a significant impact on ecological communities and their habitats.

- *Pesticides Act 1999*. Under this Act it is illegal to use a pesticide in NSW unless it is registered by the National Registration Authority for agricultural and veterinary chemicals, or covered by permit issued under the *Commonwealth Agricultural and Veterinary Chemical Code Act 1994*. There are a number of rules under this Act that relate to the training and record keeping associated with commercial pesticide use, including individuals employed by local council, government agency or statutory authorities. Pest management technicians must have a Certificate of Competency issued by Workcover NSW who administers safety laws to ensure that their staff and the people who use their services are not adversely affected by pesticides under the *Occupational Health & Safety Regulation 2001* and the *Occupational Health & Safety Act 2000. Pesticides Regulation 1995* requires public authorities, such as local councils and government agencies, to notify the community when they use pesticides in public places (e.g. recreational parks, sporting fields, national parks, State forests, Crown land or any public land owned or controlled by a public authority such as road verges). Notification will be via a pesticide use notification plan that lists the name of the pesticide, location where it will be used, dates when it will be used, the purpose of the pesticide's use and any relevant warnings on the label.

- *Native Vegetation Conservation Act 1997.* This Act provides for the conservation and management of native vegetation on a regional basis and encourages the rehabilitation and revegetation of land with appropriate native vegetation. Consideration should be given to this Act when considering mosquito source reduction in coastal floodwater swamps and other non-saltmarsh habitats.

11 MOSQUITO CONTROL STRATEGIES

11.1 Controlling larval populations

The most effective strategy to control adult mosquito populations, and minimise nuisance and public health risks, is to target larval populations and their habitats. The most appropriate strategy to reduce larval populations of a specific mosquito will be dependent on the habitat identified as the productive source of mosquitoes. A summary of options available for controlling larval populations in natural habitats and urban environments is provided in Table 6.

11.1.1 Environmental Management

With an increasing desire to move away from chemical pesticides, mosquito control authorities have looked to introduce strategies that remove, reduce, or modify mosquito habitats that can be integrated with the overall environmental management of wetlands. Advances in habitat modification techniques have shown that the suppression of mosquito populations is possible without reliance on chemical control or jeopardising the flora, fauna or ecological function of the wetland itself.

Strategies to remove (or modify) mosquito breeding sites, without the use of control agents to reduce or eliminate the production of mosquitoes are known as environmental management. In natural environments, source reduction is generally directed towards the modification of habitats to manipulate water flows and/or vegetation to reduce the suitability of the habitat for mosquito production. In urban environments, source reduction is generally directed towards habitats such as sullage pits, drains, guttering, backyard containers and other areas where water is retained for long periods of time.

11.1.1.1<u>Estuarine wetlands</u>

The primary objectives of habitat modification in estuarine wetlands is to increase the frequency of tidal flushing, improve the drainage of water and maximise access of fish to mosquito habitats to minimise production of *Ae. vigilax*. The most common form of habitat modification currently practiced in saltmarsh habitats for mosquito control is ‘runnelling’, the construction of shallow, spoon-shaped channels (generally less than 300mm deep) that connect pools and depressions on the saltmarsh and allow improved exchange of tidal water over the marsh.

Studies in Australia have shown that the construction of runnels has significantly reduced mosquito breeding when compared to pre-runnelling sampling and non-runnelled habitats, and there have been very few adverse impacts on the estuarine wetland reported. However, due to changes in the soil moisture of the runnelled area, a reduction in the suitability of the habitat immediately surrounding the runnel for the grapsid crab, *Helograpsus haswelliannus*, has been identified in southeast Queensland saltmarshes. It is also important to note that, as runnels promote increased tidal inundation of the saltmarsh, there is the potential for increased mangrove propagule dispersal and, consequently, mangrove colonisation at higher elevations on the marsh – potentially threatening the overall area of saltmarsh.

When tidal exchange within estuarine wetlands is restricted through human interference or natural sedimentation processes, the wetlands may become degraded and often unusually large mosquito populations are a symptom of such degradation. Restricted tidal flows may contribute to increased mortality of vegetation (e.g. mangroves), increased sedimentation and blocked drainage channels. Lack of drainage from these habitats following substantial tidal and/or rainfall inundation often results in extensive inundation of habitats and facilitates the production of mosquitoes.

In habitats with restricted drainage, the construction of channels through degraded mangrove habitats has been shown to increase the frequency of tidal inundation and increase the volume of water flushing the habitats, resulting in a substantial reduction in mosquito populations.

In wetland areas where tidal inundation can be regulated (e.g. via floodgates or weirs), the production of pest mosquitoes is dependent on the frequency of inundation and the length of time that water remains on the wetland. The population increases of *Ae. vigilax* may be reduced if the wetlands remain dry (typically not an option) or if relatively consistent water levels are maintained on the wetland (this strategy may be preferred to achieve wetland management objectives designed to provide wader bird habitat and/or manage acid sulfate soils). With the latter, although inundation of the wetlands by tides and rainfall typically results in population increases of pest mosquitoes, when water remains impounded on the saltmarsh for extended periods (e.g. longer than 4 weeks) the productivity of the wetland can be much reduced. This is because the initial generation of mosquitoes produced by the inundation is unable to lay eggs at their preferred sites and any introduced predator populations are able to persist.

While the concept of maintaining 'higher' water levels to preclude activity of *Ae. vigilax* may be sustainable for a short time, maintaining the water levels over an extended period may be difficult because of evaporation. There is also the consideration that long-term inundation would enhance the production of secondary mosquito pest species, such as *Cx. sitiens*.

11.1.1.2 Freshwater Wetlands

Mosquito production from natural and constructed freshwater wetlands is dependent on a combination of physical and vegetative characteristics.

Aquatic vegetation management is the most useful strategy for mosquito management in these habitats. When wetlands contain large areas of open water and vegetation at the margin is sparse, wind/wave action is relatively high and predatory fish have unobstructed access to larvae – all these contribute to a reduction in larval populations but may not completely eliminate mosquito production.

11.1.1.3 Urban environments

Structures associated with stormwater retention (e.g. inlet pits, sullage pits or gross pollutant traps) or drains may contain free-standing water that persists and provides suitable habitats for some mosquitoes. The production of mosquitoes (particularly *Cx. quinquefasciatus*) from these areas can be avoided by ensuring that the structures are self draining, have the siltation depth shallow enough to encourage evaporative drying, and that the accumulation of organic material is maintained at low levels. Also, smaller structures as part of domestic drainage (eg. courtyards, pool areas, driveways, car parks etc) should have the same principals of design. In addition to the design of these drainage structures, a routine maintenance program is essential to remove the inevitable buildup of organic material (leaves and other plant material, sediment and general rubbish) that can create blockages and, subsequently, opportunities for mosquito breeding.

Mosquito breeding in septic tanks, usually by *Cx. quinquefasciatus*, can be problematic and occurs when mosquitoes can access the interior of the tank through a damaged or open top, or unscreened vents. While modern fibreglass tanks are less likely to pose a significant mosquito risk, the older style concrete tanks are much more likely to allow access by mosquitoes, particularly if allowed to fall into a state of disrepair. Larvicides are not an appropriate solution (the high organic content render the chemicals ineffective) and sealing the tank to exclude mosquitoes is the primary course of action.

For container breeding mosquitoes such as *Ae. notoscriptus*, the maintenance of a property free of as many water holding containers as possible will reduce available habitat. Many of the potential habitats could be classed as rubbish and are best disposed of appropriately. However, while other items in the property may need to be stored and/or covered so that they are not filled following rainfall events, it is important that these coverings themselves do not allow pooling of rainfall and subsequent mosquito breeding. These mosquitoes only require small volumes of water and the least likely objects can be productive habitats, such as garden ornaments, open fence posts and children's toys. Any object that can hold standing water for more than five days should be considered a potential larval site.

One of the most common larval sites for domestic mosquitoes is associated with garden plant pots and saucers. The saucers, whether pottery or plastic, can provide substantial opportunities as they readily hold water after rainfall or 'watering' of the plants. Ideally, saucers should be emptied of water but in some situations that is often impractical. Avoiding the use of saucers is advisable or, alternatively, saucers may be filled with fine sand that will retain the moisture while not allowing free water that can be used by mosquitoes.

NSW State Environmental Planning Policy No. 4 states that rainwater tanks must be maintained at all times so as not to cause a nuisance with respect to mosquito breeding but there are no specific standards relating to mesh size on inlets that prohibit mosquito entry. Similarly, NSW Health recommends all entry points to the water tank be sealed or screened to prevent mosquito breeding.

In Queensland, rainwater tanks are required to be fitted with mosquito proof screens (constructed of brass, aluminium or stainless steel) of no more than 1mm gauge to prevent mosquitoes entering the tank under the Queensland Development Code.

11.1.2 Larval control agents

In many cases, the most effective way to manage mosquito populations is to specifically target the immature stages. This can be achieved through the application of agents that are toxic to larvae, prevent larvae developing to adults, or are efficient predators of larvae.

Under the *Pesticides Act 1999*, it is illegal to use a pesticide in NSW unless it is registered by the National Registration Authority for agricultural and veterinary chemicals, or covered by permit issued under the *Commonwealth Agricultural and Veterinary Chemical Code Act 1994*.

Formulations of Temephos, *Bacillus thuringiensis israelensis* and methoprene are registered for use as mosquito control agents in NSW.

11.1.2.1 Temephos

Temephos (trade name ABATE) is an organophosphate compound that has been used in mosquito control since the early 1950's but although it is highly effective it is not totally selective for mosquitoes and may have toxic effects on non-target organisms such as birds, fish and some invertebrates - particularly in estuarine habitats. Additionally, there have been concerns regarding the development of resistance in target species and, combined with the potential for non-target and environmental impacts, local mosquito control authorities have reduced the use of temephos in favour of alternative control agents. However, for the treatment of water holding containers where contact with non-target organisms is minimal, such as tyre piles, this product may be appropriate and is available in liquid or granular formulations.

11.1.2.2 Bacillus thuringiensis israelensis

The bacterium *Bacillus thuringiensis israelensis* (*B.t.i*) produces a protein crystal which contains a number of microscopic pro-toxins that when ingested are capable of destroying the gut wall and killing mosquito larvae within 12 hours of ingestion. Commercial formulations of the bacterial culture product (various trade names e.g. TEKNAR, CYBATE, AQUABAC, VECTOBAC) and available and liquid *B.t.i.* formulations are most often used, undiluted or diluted in water, and the recommended application rates vary from 600ml – 1.2L/ha depending on habitat.

The greatest benefit of *B.t.i.* is that it is highly specific to mosquito larvae and very few non-target effects have been recorded when the product is applied at recommended rates. In Australia, it has been used successfully to reduce *Ae. vigilax* populations in both saline and freshwater habitats. The product does, however, have some disadvantages in that the efficacy is reduced in habitats with a high organic content (so it is less likely to be effective in some wetlands, stormwater systems and waste-water structures), and when applied when larval populations are young (i.e. 1st instar) or nearing pupation (i.e. late 4th instar larvae that have stopped feeding and will not ingest the *B.t.i*).

As the product has no residual activity, there can be only a very small window of opportunity for effective treatment of larval populations. It must be applied after larval populations have hatched, and during hot summer months there may be only a 3 day period when applications can be effective in some habitats (e.g. saltmarsh pools). Treatments will also be required following each new inundation event (eg. tide or rainfall) due to the absence of residual activity.

When aerial applications are undertaken by experienced pilots with aircraft fitted with GPS equipment, effective control of mosquito populations can be achieved while minimising over-application and controlling spray drift.

11.1.2.3 Methoprene

The insect growth regulator, *s*-methoprene (trade name ALTOSID) is a synthetic mimic of the juvenile hormone produced by insect endocrine systems and, in Australian urban environments, it has been shown to be an effective control agent of pest mosquitoes without adversely affecting non-target organisms. When absorbed by the larvae, development is interrupted and larvae fail to successfully develop to adults, usually dying in the pupal stage. A side benefit of *s*-methoprene is that it retains mosquito larvae and pupae in the aquatic ecosystem long enough to provide food for predators.

The product is available in three formulations, a liquid, and slow-release solid pellets and briquets. The application rate for the liquid formulation is 220ml/ha for shallow water, low density mosquito habitats and 290-360ml/ha for organic rich, high density mosquito habitats. The advantage of the pellet and briquet formulations is that they offer extended periods of control, reducing the need to treat wetlands or stormwater structures on numerous occasions during the ‘mosquito season’. The recommended application rate of the pellets is 3kg/ha with an increased rate required in habitats with a high organic content. At the recommended application rate, one briquet can effectively treat an area of $20m^2$ if pools are less than 30cm deep or an area of $10m^2$ if pools are greater than 30cm.

11.1.2.4 Biological control

A number of organisms have been investigated to determine their suitability as effective predators of mosquito larvae. These include invertebrate (e.g. Diptera and Coleopteran larvae, Crustaceans, Notonectids, Odonates) and vertebrate (fish) predators. In urban environments, fish are often used to control mosquito production in ornamental ponds and constructed wetlands, while Odonates and Copepod crustaceans have been used to control container-breeding mosquitoes.

The ‘mosquitofish’ *Gambusia holbrooki* was introduced to Australia from North America at the beginning of the 1900s and has since spread to most of the waterways in Australia. There is some debate as to the effectiveness of *G. holbrooki* as a mosquito control agent, but where they are less effective it is often because of obstructive vegetation and in such circumstances alternative species are similarly ineffective. The ‘mosquitofish’ has been implicated in significant adverse impacts on aquatic native fauna, particularly other fish and amphibians, and under no circumstances should *G. holbrooki*, or other exotic fish or non-endemic native fish, be released into aquatic habitats for mosquito control.

A number of native fish has been identified that may be appropriate for mosquito control in Australia. The most likely candidates for introduction in the Lower Hunter and Mid North Coast region are *Pseudomugil signifer* (Pacific Blue-eye), *Hypseleotris compressa* (Empire Gudgeon) and *Hypseleotris galii* (Firetail Gudgeon). These species are all endemic to the region and known to consume mosquito larvae. While native fish introductions alone will not significantly reduce mosquito populations, they do provide an important component of integrated pest management and have been shown to provide a valuable link to the wider community promoting environmentally sensitive mosquito management. However, the frequently polluted water of urban wetlands, the 'obstructiveness' of heavy vegetation, and the widespread distribution and local proliferation of *G. holbrooki* all serve to limit the likely success of native fish for mosquito control.

Copepods are small crustaceans that naturally occur in many types of environments and some species will prey on young mosquito larvae. Most commonly, *Mesocyclops* species have been used to control breeding by *Ae. aegypti* in large water holding containers and wells and could be applied, if required, to the control of *Ae. notoscriptus*.

Tadpoles are often mistakenly promoted as effective predators of mosquito larvae, but most are general herbivores and suspension feeders and there is little evidence that effective control of mosquito larvae can be achieved through the use of tadpoles alone. Recent studies have shown that, although tadpoles of *Limnodynastes peronii*, *Limnodynastes tasmaniensis*, *Litoria aurea* and *Litoria peronii* consume mosquito larvae in small containers, there is no evidence that they are actively preying on larvae.

11.2 Controlling adult mosquitoes

11.2.1 Adulticides

There are a number of products (pyrethrins, pyrethroids and organophosphates) registered for use as adult mosquito control agents in NSW. Although these insecticides (e.g. Maldison, Chlorpyrifos and Permethrin) are available and may be useful against adult mosquitoes during times of exceptionally large populations, or epidemic virus activity, these products are not appropriate for the long-term management of mosquitoes across a large area.

Adulticides are typically applied via a vehicle mounted machine (fogger) that delivers the product in a fog of very small droplet sizes (usually less than 20 microns in diameter). The application should be selectively timed, ideally for when the target mosquitoes are most active (generally at dusk and dawn), for when there is a light breeze blowing to help with the dispersal of the product, and for when there is a temperature inversion to maintain the fog a low level. Adulticides can be expensive, their effectiveness is dependent on favourable weather, multiple treatments are often required and potential non-targets are a concern, so the use of adulticides is not common in Australia but may have application in an early Public Health response to an outbreak of vector-borne disease.

11.2.2 Barrier treatments

A relatively new strategy for protection against adult mosquito populations is through the treatment of mosquito harbourage sites with a residual insecticide. These treated areas then create a "barrier" between residential and/or recreational areas and mosquito habitats.

The product most commonly used for this purpose is the synthetic pyrethroid bifenthrin (trade name BISTAR). The product provides a residual layer of pesticide that kills landing and/or resting mosquitoes and is currently registered for treating mosquito resting places (internal & external areas of domestic, commercial, public and industrial buildings). However, there are some environmental concerns surrounding the widespread use of this product, in particular for non-target insects and aquatic organisms. There are warnings on the label that the product is toxic to bees, fish and aquatic organisms and that mud, sand, mangroves and other aquatic habitats should not be directly treated or exposed to spray drift.

As with all adulticides, targeting adult populations rather than larval (immature) populations will be less effective, particularly for pest mosquitoes such as the saltmarsh mosquito that can disperse widely from breeding habitats. While barrier treatments may provide protection in the immediate surrounds of a treated dwelling, they will not reduce mosquito impacts beyond the treated area.

11.2.3 Commercial mosquito traps

A number of commercial trapping units are available that utilise attractants (e.g. light, heat, carbon dioxide, odour, etc.) to catch and/or kill adult mosquitoes. There are many different types of units available and, while many will collect mosquitoes, there is no quantitative evidence that they can reduce nuisance biting impacts or public health risks in areas close to productive mosquito habitats. Units that use light alone to attract mosquitoes (e.g. blue light electrocutors) have been shown to have little impact on nuisance biting rates and often kill many more harmless insects (e.g. moths) than mosquitoes.

The traps with the greatest potential are those that use carbon dioxide as the main attractant, have a relatively high release rate of the gas and incorporate a suction fan to collect mosquitoes. The mode of carbon dioxide generation can vary from the inclusion of dry ice and the conversion of propane, to the fermentation of yeast, and each will differ in the volume of gas released and the relative attractiveness of the trap to mosquitoes. The larger units that convert propane to carbon dioxide are most effective, collecting greater numbers of mosquitoes than units that have a low release rate of carbon dioxide, use light as the main attractant or rely on sticky paper to collect the mosquitoes.

While these units may offer some limited protection for individual homeowners, a network of multiple traps would need to be employed to completely protect a large area from exposure to mosquitoes and there is no information available in Australia regarding the design of effective trapping networks to achieve such an objective.

These products usually fail to offer complete protection because they do not compete adequately with the stimuli of a living, breathing human. While some of the components of overall human attractiveness can be broken down and replicated, and used in such devices, these individual components will rarely be as attractive as the whole package (i.e. a human) itself.

11.2.4 Biological control

Given the trend towards more ‘environmentally sensitive’ control strategies, the ‘use’ of predators such as dragonfly adults, frogs and spiders against mosquitoes is often raised, but there is no evidence they can have any significant impact on pest mosquito populations. In particular, the installation of ‘bat houses’ to maintain local populations of insectivorous bats has become a popular proposal for biological control of adult mosquitoes. There is evidence that 10 insectivorous bat species are active in the lower Hunter estuary and exhibit feeding behaviours over the saltmarsh habitats, but there is no indication that mosquitoes are a preferred food source or that the bats can significantly reduce the mosquito populations. While providing increased refuges and habitat for bats may be advantageous for bat conservation, it would be unwise to link bat conservation to mosquito control as the sole objective of this strategy, and there is no scientific evidence from anywhere in the world that insectivorous bats or birds have any significant impact on adult mosquito populations.

Table 6. Common mosquito habitat sites, the pest species associated with them and control strategy options available in the local region

Habitat	Major pest species	Control strategy options
Saltmarsh (dominated by *S. quinqueflora*)	*Ae. vigilax* *Ae. alternans*	Runnelling; *B.t.i.*; Methoprene
Mangroves (typically degraded)	*Ae. vigilax* *Ae. alternans*	Increase tidal flow (channel construction); *B.t.i.*; Methoprene
Brackish water *Casuarina* and/or *Melaleuca* forests	*Ae. vigilax* *Ae. alternans* *Ae. multiplex* *Ve. funerea*	Filling pools and depressions; *B.t.i.*; Methoprene
Freshwater wetlands	*Cx. annulirostris* *Cq. linealis*	Reduce aquatic vegetation; Introduce native fish; *B.t.i.*; Methoprene
Constructed wetlands	*Cx. annulirostris* *Cx. quinquefasciatus* *Cq. linealis*	Ensure wetland is initially designed to minimise mosquito production; Reduce aquatic vegetation; Manage water levels; Introduce native fish; *B.t.i.*; Methoprene
Farm dams, ponds	*Cx. annulirostris* *Cx. quinquefasciatus* *Cq. linealis*	Introduce native fish; Reduce aquatic vegetation; Methoprene
Backyard fish, frog or ornamental pond	*Cx. annulirostris* *Cx. quinquefasciatus* Also occasionally *Ae. notoscriptus*	Introduce native fish; Methoprene; *B.t.i.*; regularly remove dead or decaying plant material; install water movement devices (eg. fountains or recirculation pumps).
Water tanks	*Ae. notoscriptus*	Install mesh screening to exclude mosquitoes; copepods
Septic tanks	*Cx. quinquefasciatus* *Cx. molestus*	Install mesh screening to exclude mosquitoes; repair damaged structures; Methoprene
Drainage structures	*Cx. annulirostris* *Cx. quinquefasciatus* Also occasionally *Ae. notoscriptus*	Ensure correctly designed & install to prohibit pooling water; regularly remove debris to stop blockages and/or pooling; remove plants or excessive algal growth; Methoprene

Table 7. Advantage and disadvantages of *Ae. vigilax* control options available for the Lower Hunter and Mid North Coast region.

Control option	Advantages	Disadvantages
Environmental modifcation	▪ Potential long term solution without reliance on routine application of control agents ▪ May assist the rehabilitation of degraded wetlands (e.g. restore tidal flushing) ▪ Cost effective in long term compared to control agent applications	▪ May not significantly reduce mosquito populations over large saltmarsh areas ▪ May impact some elements of wetland ecosystem (e.g. increased soil moisture, reduced crab populations) ▪ May assist the encroachment of mangrove seeds/seedlings into saltmarsh habitats ▪ May require regular maintenance to maintain effectiveness ▪ Potential exposure of acid sulfate soils
B.t.i.	▪ Proven effective control agent of *Ae. vigilax* larvae ▪ Minimal non-target impacts ▪ In small areas can be applied with inexpensive equipment ▪ Aerial applications can cover extensive wetland areas effectively ▪ Easy to assess treatment success and reapplication possible if treatment fails	▪ Reapplication required following each wetland inundation ▪ Small window for effective treatment ▪ Larvae quickly removed from ecosystem ▪ No residual control
Methoprene	▪ Proven effective control agent of *Ae. vigilax* larvae ▪ Minimal non-target impacts ▪ Sustained release formulations provide residual efficacy (i.e. reapplication frequency reduced) ▪ Larvae are retained in ecosystem for longer periods to provide food for birds, fish and macroinvertebrates	▪ Potentially expensive ▪ Time consuming to apply sustained release formulations (i.e. briquettes must be tethered to stakes to prevent 'encapsulation' by sediments) ▪ Treatment assessment cannot be carried out until larvae pupate, no opportunity for reapplication if treatment fails
Biological control	▪ Potentially effective ▪ Potential long term solution without reliance on routine application of control agents ▪ Introduction of native fish complementary to other wetlands management objectives ▪ Very acceptable to community	▪ Very few proven successful introductions to control *Ae. vigilax* populations ▪ Not appropriate for ephemeral and/or highly polluted habitats ▪ Only fish species endemic to the local area can be released ▪ Permanent water bodies potentially recolonised by *G. holbrooki* ▪ Community may feel mislead if introductions do not reduce mosquito impacts
Adulticides	▪ Ground based applications may be effective in small areas, particularly mosquito harbourage sites ▪ Aerial applications can cover extensive areas ▪ Useful strategy in emergence response to disease epidemics as provides fast knockdown of mosquitoes	▪ Difficult to achieve effective long term control ▪ Treatments may need to be repeated at daily intervals ▪ Potentially significant non-target impacts ▪ Expensive ▪ May not be acceptable to community
Barrier treatments	▪ Potentially significant control in some circumstances	▪ Potentially significant non-target impacts ▪ Is not appropriate close to nature reserves ▪ Is not appropriate close to aquatic ecosystems

11.3 Ecological effects of mosquito control programs

Although broadscale mosquito control is not currently being considered for the estuarine wetlands in the Hunter region, it is important that possible direct and indirect impacts of any future programs be considered. One region of coastal NSW that recently considered adopting a broad scale mosquito control program is the Central Coast. The following section is an updated discussion of the issues that was included in the document "Living with Mosquitoes on the Central Coast of NSW".

There is considerable debate surrounding mosquito control in NSW, particularly since the major nuisance-biting pest and arbovirus vector is associated with coastal saltmarsh, itself an endangered ecological community protected by legislation. There is strong evidence (from both laboratory and field testing) indicating that the currently used mosquito control agents in Australia (Bti and methoprene) have little impact on water quality and very few non-target impacts when used at recommended application rates. Studies have found that these control agents had no significant impact on shrimp (*Leander tenuicornis*) or fish (*Melanotaenia duboulayi, Pseudomugil signifer*) that are commonly found in the same habitats as *Ae. vigilax*.

When direct non-target impacts have been recorded, it is generally only when the control agents are applied at substantially higher rates than recommended. It is important to note that some scientific publications may report direct non-target impacts of these larvicides against some organisms, but the simulated 'application rates' in laboratory trials substantially exceed the levels approved by the APVMA for field use (e.g. thousands of times the recommended quantity of larvicides would need to be applied to cause direct non-target impacts).

Following a thorough review of literature, the New Zealand government considered the environmental risk of Bti and methoprene use in their estuarine wetlands to be minimal and both products have been used extensively in an attempt to eradicate the introduced (from Australia) southern saltmarsh mosquito *Aedes camptorhynchus*. Considering previously published studies, the assessment of minimal environmental impact of control agents and that any non-target impacts are expected to be temporary, large scale non-target impact studies were considered unnecessary. To date, both Bti and methoprene have been used extensively to eradicate *Ae. camptorhynchus* and there are no published reports of non-target impacts.

Recent laboratory studies in Australia have suggested an estuarine species of chironomid, *Kiefferulus longilobus*, may be susceptible to Bti when applied at the highest recommended field rate. However, previous studies have identified the limitations in extrapolating laboratory based studies to field scenarios due to interactions between the organisms, including chironomids, tested, larvicide efficacy and environmental conditions. Further research is required to refine current mosquito control program design if susceptible species of non-target organisms are identified in estuarine wetlands.

There are considerable gaps in our knowledge of estuarine wetland ecosystems and the design of mosquito control programs will greatly benefit from an increased understanding of invertebrate fauna, their biology, ecology and spatial and temporal distribution. Of particular concern is the identification of factors contributing to high population fluctuation in invertebrate populations (including mosquitoes) that result from natural temporal changes to environmental conditions (e.g. drought, flood, sea-level rise).

There are few published studies that have investigated the indirect impact to the wider environment of an ongoing significant reduction in adult mosquito populations resulting from a broad scale mosquito control program. Without local long-term studies, or quantitative studies identifying the relative importance of mosquitoes as specific components of the ecosystem (e.g. as a food source, pollinator or nutrient recycler), it is difficult to accurately assess the indirect environmental impacts of mosquito control programs. With year to year fluctuations across a range of environmental variables, natural changes in the abundance, diversity and behaviour of local wildlife will further complicate these assessments.

There has been extensive use of mosquito control agents in estuarine and freshwater wetlands in North America and potential non-target impacts have been studied within a number of mosquito control districts. No detectable impact on amphipods or flying insects were recorded in a study associated with Bti and methoprene use on estuarine wetlands in Florida A three year study in the freshwater wetlands of Wisconsin using a larvicide similar to Bti, *Bacillus sphaericus* (Trade name Vectolex®), found no detrimental effects to non-target organisms were recorded.

One of the most extensively studied wetland areas where mosquito control activities have been undertaken are the freshwater wetlands in Minnesota, USA. In response to concerns regarding direct and indirect non-target impacts of mosquito control activities, the Metropolitan Mosquito Control District established a scientific peer review panel to develop a research program to investigate the ecological consequences of mosquito control targeting larval populations using *Bti* and methoprene.

The results highlight the complexity in assessing the potential long-term impacts of mosquito control. Sampling populations of a range of wetland organisms (including zooplankton, invertebrates, frogs and birds) over an eight year period, researchers found that there was no permanent impact on the wetland ecosystem. Interestingly, during two of the five years in which sampling was undertaken, reduced numbers of some chironomid species (a key food source for waterbirds) was observed. The change in abundance was attributed to natural environmental fluctuations and an over application of control agents during those seasons and, with the introduction of modern application equipment in subsequent seasons, there was no significant difference in chironomid numbers or overall insect biomass between treated and untreated wetlands.

A six year study of chironomid populations associated with a floodwater habitat in Sweden concluded that the Bti-based mosquito control program had no major impact on chironomid populations.

It is difficult to draw direct comparisons between the North American and Swedish studies and potential ecological impacts of mosquito control in Australia, due to substantial differences in the wetlands and target pests. Whereas in Minnesota mosquito control activities were undertaken in freshwater wetlands, mosquito control in NSW will be primarily focused on ephemeral habitats in estuarine wetlands that support substantially fewer non-target organisms. Further investigation is required to determine the vulnerability of locally important non-target organisms and an assessment of impacts caused by substantial reductions in mosquito populations on animals that may consume mosquitoes.

There is a paucity of published scientific evidence regarding the ecological importance of mosquitoes. In estuarine wetlands, adult mosquitoes are consumed by birds and microbats but there is little evidence that any species within those two groups rely specifically on mosquitoes. Both birds and bats have been observed in feeding or foraging behaviour within saltmarsh habitats but there are no quantitative published studies indicating any preference for mosquitoes and, in most cases, chironomids are often listed as a primary food source for waterbirds.

The most productive mosquito habitats within the saltmarsh are generally the shallow, highly ephemeral pools in the upper marsh that often have hyper saline conditions making them unsuitable for most vertebrate and invertebrate organisms. Under such circumstances, it is unlikely that substantial resident populations of fish or macroinvertebrates will be present and rely on immature mosquito populations.

12 MOSQUITO SURVEILLANCE STRATEGIES

Detailed information on a range of mosquito surveillance techniques including sampling techniques for larval, pupal and adult populations is included in the Australian Mosquito Control Manual (Mosquito Control Association of Australian 2009), `Mosquitoes and Mosquito-Borne Disease in South-eastern Australia (Russell 1993) and Mosquito Ecology Field Sampling Methods 3rd Edition (Silver 2008).

Mosquito sampling should be undertaken between the months of November and April. Outside this period, mosquito populations can be unpredictable and the results of larval and/or adult populations may provide misleading information on the relative abundance, likely pest impacts or habitat productivity.

Regardless of the surveillance strategy undertaken, it is important that a qualified entomologist, preferably one with experience in mosquito ecology and taxonomy, undertake identification of specimens.

12.1 Larval populations

Remote Sensing and Geographic Information Systems technology is becoming increasingly applied for mosquito habitat and larval population surveillance, but these technologies are expensive and require experience with various software applications. Aerial photography and topographic maps can provide a cost effective alternative to identify potential larval habitats.

The collection and correct identification of larval samples is the only method available to confirm actual larval habitats. Regardless of habitat characteristics and/or the abundance of adult mosquitoes in nearby areas, larval surveys must be undertaken at appropriate times to confirm the presence of mosquitoes and the productivity of the habitat.

Larval are most commonly sampled using a metal or plastic ‘dipper’ with an approximate diameter of 100m and volume of 300ml. In shallow habitats, random samples are taken from the margin of ponds or flooded depression, usually amongst vegetation where larvae may be taking refuge. Individual larvae are removed from the dipper and returned to the laboratory for instar and species identification. In deeper habitats, nets may be used but there is a greater likelihood that collected specimens may be damaged, making identification difficult.

Surveillance strategies for larval populations will vary between habitats. In saline wetlands, surveys are designed to detect hatching of larvae following wetland inundation and provide a quantitative measure of abundance that can be compared between habitats and inundation events. Therefore, sampling *Ae. vigilax* in estuarine wetlands should be carried out within five days following tidal and/or rainfall inundation, before larvae have completed their development and emerged as adults.

In freshwater habitats, it is more difficult to accurately measure larval abundance as the spatial distribution of larvae, due to vegetation density, and ecological requirements of larvae vary over time and between species. In areas of thick emergent vegetation, particularly when vegetation has been flattened or contains large amounts of dead plant material, it is difficult to penetrate the vegetation to sample and the physical disturbance resulting from simply accessing these areas is likely to cause mosquito larvae to disperse, increasing the difficulty in accurately sampling larval populations.

A well-designed larval surveillance program will assist the determination of larval threshold levels for treatment, indicate correct timing for applications (noting the restricted window of opportunity for maximum impact by the control agents on the larval populations) and assess the effectiveness of the treatment.

12.2 Adult populations

To monitor the activity of pest mosquitoes and assess the impact of control strategies, adult mosquito populations should be sampled on a weekly basis between December and March. Adult populations should be sampled using dry-ice baited Encephalitis Vector Surveillance (EVS) traps operated at fixed sites. These traps use carbon dioxide (supplied as either block or pellet dry ice or via gas cylinder) to attract host seeking mosquitoes. Female mosquitoes are attracted to the carbon dioxide, thinking the trap may actually be an animal, a small light serves as a focus and a battery operated fans blows the incoming mosquitoes into a catch bag. Traps are usually set in the late afternoon and collected the following morning. Collections may be influenced by wind and rain but, if appropriate adult trap site are selected, the influence of these factors can be minimised while optimising mosquito collections.

With accurate identification critical, adult mosquito surveillance provides important information on the activity of pest species and, in conjunction with larval surveillance, provides an assessment of the success of a treatment program. Importantly, adult surveillance can identify species creating a pest nuisance in the community that are <u>not</u> being produced from particular sites and this provides for optimal strategic approaches to mosquito management.

12.3 Arboviruses

The NSW Arbovirus Surveillance and Mosquito Monitoring Program commenced in the summer of 1984/85 with the program designed to cover the period of seasonal increase and decrease in the populations of the major arbovirus vectors, from mid-spring to mid-autumn, and also to cover the period for natural activity and transmission of arboviruses (especially the alphaviruses and the flaviviruses). The program provides a laboratory resource to enhance data collected from local mosquito surveillance programs

The processing of mosquito collections for virus infection can greatly assists mosquito management by identifying locally significant viruses and vector species that can inform mosquito management policy decisions, and the surveillance of mosquito and arbovirus activity can provide an early warning of arbovirus activity and an increased risk of human disease, allowing local authorities the option of undertaking mosquito control activities and issuing public health warnings.

12.4 Climatic conditions

To better understand the factors contributing to the suitability of habitats for mosquito production and population increases of pest mosquitoes, it is important that data on climatic/environment variables such as temperature, rainfall and tides is collected.

Predicted daily tidal heights are available and can be useful guides for identifying periods of increased mosquito abundance. However, actual tidal heights can often vary markedly above or below the predicted values and this variation makes accurate predictions of mosquito population increases difficult. Research has shown that for *Ae. vigilax*, predicted tidal heights are a good indicator of the timing of population increases, but not the magnitude of increases as there are often complex interactions between a number of factors including the frequency and duration of wetland inundation as well as extant mosquito and predator populations.

Access to accurate rainfall and tidal data will greatly assist the assessment of potential pest mosquito population increases. Daily rainfall, wind and temperature are recorded by the Bureau of Meteorology at 47 meteorological stations throughout the Lower Hunter and Mid North Coast regions. Rainfall and tidal information is available and can be readily accessed by local authorities via phone, fax or internet.

13 MOSQUITOES AND URBAN DESIGN

13.1 Mosquito Risk Assessments

Mosquito Risk Assessments (MRA) can provide valuable information to local authorities on actual and potential mosquito impacts resulting from proposed urban developments and constructed wetlands. These assessments usually entail an evaluation of the extant mosquito habitats and populations within the vicinity of the site, the collection and identification of the species involved, a detailing the risk each species poses with respect to pest nuisance or disease risk, an expert consideration of the proposed development with respect to its potential for producing mosquitoes or adding to any local mosquito populations and their associated problems or concerns, and the provision of expert opinion on these risks with recommendations for their minimisation.

This process requires larval and adult mosquito surveillance for a proper evaluation of the pre- versus the likely post-development situation. Risk assessments can be undertaken without such faunal investigation but the resulting report will be necessarily deficient in not providing baseline data for later comparison.

13.2 Urban development approvals

The NSW coast has experienced rapid population growth in recent years with increasing demand for new residential developments. Conservative estimates predict that the residential population in the Hunter region will exceed 500,000 by 2020 with most being concentrated along the coast in the local government areas of Great Lakes, Port Stephens, Newcastle, Lake Macquarie and Maitland.

An increasing concern in coastal NSW is the proximity of new residential and recreational developments to estuarine and brackish water wetlands. Notwithstanding the environmental impacts of adjacent urbanisation on wetlands, as humans are brought closer to mosquito habitats there is a greater likelihood of nuisance biting occurring and health risks increasing. This problem has been demonstrated on the far north coast of NSW where the rapidly expanding residential areas are encroaching on brackish sedgelands and *Melaleuca* swamps. The major pest mosquitoes produced from these habitats, including *Ae. multiplex*, *Ae. procax* and *Ve. funerea*, do not travel far from larval habitats but as people are brought closer to these areas the pest and potential health risks increase.

In response to concern regarding mosquito impacts, Ballina Shire Council produced a specific Development Control Plan (DCP) (Development Control Plan No.11 - Mosquito Management) to address the health issues associated with mosquitoes by recommending and requiring various measures to reduce human contact with mosquitoes with respect to existing and proposed residential developments. The plan was prepared in accordance with section 72 of the *Environmental Planning and Assessment Act 1979* and adopted by Council in 2003.

The key component of the DCP is that it is now mandatory that the services of a “competent and experienced medical entomologist” be incorporated into the consultancy team preparing development applications and rezoning requests within the coastal plain and lowlands of the Ballina Shire. The DCP also provides guidance on minimising exposure to mosquitoes in presently developed areas and proposed developments including housing subdivisions, tourist developments and the design of constructed wetlands.

The Northern Rivers Mosquito Focus Group has recently requested a review of the North Coast Regional Environment Plan by DIPNR to include “Mosquito habitat” as an environmental hazard alongside coastal processes, flooding, soil instability, bushfire, contaminated land, sewage treatment works and high tension power lines.

13.3 Buffer zones

Buffer zones between urban developments and mosquito habitats are often raised as a possible management strategy. However, there are no quantitative studies in NSW indicating the appropriate size or vegetation composition of effective buffers. Guidelines developed for preventing biting insect problems in the Northern Territory recommend that no residential developments should be within 1.6km for large uncontrolled mosquito habitat but such considerations can be site and species specific.

For developments close to estuarine wetlands, it has to be recognised that *Ae. vigilax* is known to disperse many kilometres from larval habitats and buffer zones are not practical as a management option. However, pest mosquitoes associated with brackish water habitats such as *Melaleuca* forests, including *Ae. multiplex*, *Ae. procax* and *Ve. funerea* disperse over much smaller distances and buffer zones should be considered as a valuable option.

Where buffer zones are considered appropriate, they should be maintained as clear or sparsely vegetated zones, so as to not provide continuous harbourage sites for adult mosquitoes and act as a corridor for adult mosquitoes moving between the larval habitat and the human community.

13.4 Constructed wetlands

Constructed wetlands are becoming increasingly common in coastal regions of NSW. Freshwater types are usually associated with urban developments and designed for stormwater treatment, waste water treatment and water storage, with side benefits for wildlife conservation, passive recreation, community education and aesthetic appeal. These wetlands are generally small but given their proximity to the community, may increase the relative risk of mosquito impacts. Saline wetlands usually are constructed to maintain local saltmarsh habitat, primarily for its conservation value, and also are generally small but they can provide a significant habitat for saltmarsh mosquitoes.

The management strategies required to address the mosquito risks associated with constructed wetlands are often site-specific. However, there are general design, construction and maintenance principles that can be incorporated into wetland management to minimise mosquito production. Most importantly, the strategies of mosquito management have to be balanced against other requirements such as public safety, habitat and wetland function.

13.4.1 Freshwater wetlands

Surface Flow wetlands may range from small, simple linear wetlands to large complex multi-component systems. Mosquito management in these systems, whether large or small, is often constrained by the essential requirements of the wetlands to meet specific purposes. Wetlands are typically located close to urban areas, contain (or at least receive) polluted water, include large areas of shallow, slow moving water and thick vegetation and have gently sloping banks. To meet these requirements, site-specific compromises must be implemented into the design, construction and maintenance of the wetland.

Mosquito populations are minimised where there are relatively deep, steep sided water bodies supporting natural (preferably native) mosquito predators that contain areas of open water and are sparsely planted with emergent aquatic vegetation. However, while the initial design of water bodies may adhere to these requirements, the ongoing growth of vegetation, bank slumping, physical disturbance, accumulation of rubbish and debris, sedimentation, water quality deterioration, water management problems and general climatic conditions will all influence the production of mosquitoes.

From a mosquito management perspective, the most important feature of the constructed freshwater wetlands is the macrophyte zone. This area of a wetland is typically shallow and as vegetation increases and/or accumulated debris or filamentous algal growth restrict water movement, suitable conditions for mosquito production may occur. As vegetation is often a crucial component of constructed wetlands, the incorporation of macrophyte zones can be designed to minimise mosquito populations by locating them in areas surrounded by deeper water or separating sections of dense vegetation by areas of deep water.

There is limited information available on the associations between specific vegetation types and the suitability for mosquito breeding. More structurally diverse stands of vegetation assist the minimisation of mosquito populations by promoting a greater diversity of macroinvertebrates. The plant species of greatest concern are the *Typha* spp. and *Phragmites* spp. that are prone to wetland invasion and exhibit rapid and dense growth. These species may “clog” wetland systems with both actively growing and fallen decaying material that creates refuge and provides enhanced nutrition for mosquito larvae. In wetlands where these species are present, it is important that vegetation is maintained in a healthy state and regularly maintained to reduce plant density and the accumulation of dead plant material.

Concern for public safety around wetlands is an important consideration and often results in the incorporation of gently sloped wetland banks. To discourage access to wetlands, spiky, thorny or otherwise impenetrable terrestrial vegetation can be planted, but this strategy is not always desirable. The recommended bank slope of wetlands to minimise mosquito breeding is from 2.5H:1V to 4H:1V, and slopes should not be vegetated with grasses that may trap water and provide habitat for mosquitoes (alternatively, grasses should be regularly cut to minimise habitat available). Steep slopes can restrict the density of vegetation, and reduce the area of shallow water, minimising suitable mosquito habitat by maximising the access of predatory fish and exposing larvae to surface water disturbance that may increase larval mortality. If the recommended bank steepness cannot be maintained for safety or other considerations, a vertical ‘lip’ between 100 - 300mm may be used at the water margin, allowing more gradual slopes above and below the vertical edge.

The manipulation of water levels in the wetlands can be a useful tool for managing mosquito populations, but it is important to note that while the life cycles of major pest species such as *Cx. annulirostris* and *Cq. linealis* may be interrupted, populations of species that prefer habitats prone to temporary drying (e.g. *Aedes* spp.) may be increased.

13.4.2 Estuarine wetlands

There is an increasing trend to include saltmarsh habitat in coastal urban developments but the risk of creating additional habitat for *Ae. vigilax* should be a major concern. Such constructed wetlands are usually small, but their proximity to residential and/or recreational areas increases the relative impact of mosquito populations.

The most important design consideration for constructed saltmarsh is that areas of pooling water following inundation are minimised. While consideration must also be given to the most appropriate conditions for the establishment of saltmarsh plants, having a relatively steep sloping marsh where water can flow away freely will greatly reduce the opportunity for mosquito breeding. A proposed saltmarsh slope of 3% would be sufficient (although as little as 1% may be effective) to ensure adequate drainage of tides and rainwater from the saltmarsh, given an even grade to the sediment and sufficient compaction to resist erosion and slumping.

The frequency of tidal inundation will also influence the suitability of the saltmarsh for mosquito breeding. If the saltmarsh is inundated by only the highest tides of each month, the saltmarsh will dry out between inundations (allowing mosquitoes to lay eggs at the base of vegetation), and restrict the colonisation of mosquito predators (fish and macroinvertebrates) in pools. More frequent inundation is less likely to create suitable conditions for *Ae. vigilax*, but consideration must be given to the impact such a tidal regime will have on the survivorship of saltmarsh vegetation.

There is a strong relationship between *Ae. vigilax* and plant species associated with the ‘lower’ (frequently inundated) saltmarsh, such as *S. quinqueflora* and *S. virginicus*, as these plants provide suitable oviposition and larval refuge sites when associated with pools and depressions that retain water. Plants of the 'upper' (only occasionally inundated) saltmarsh, such as *S. australis* and *J. kraussii*, are not normally associated with suitable mosquito habitat. However, if water pools around the base of this vegetation, mosquito breeding may occur.

Major estuarine wetland rehabilitation projects also have the potential to significantly change the mosquito fauna in some areas. The use of seawalls and floodgates to restrict the landward movement of tidal waters in order to reclaim land for agriculture or mitigate the effect of coastal flooding has had a significant impact on local ecosystems. Re-establishing tidal flow to these areas is thought to assist the creation and rehabilitation of locally, and often internationally,important estuarine wetlands. However, such project may result in an overall increase in mosquito populations and, consequently, increase pressure on local authorities to initial a broadscale mosquito control program.

Major wetland rehabilitation programs, such as the Hexham Swamp Rehabilitation Project, are being designed to minimise the risk of increased mosquito populations. It is crucial that for projects such as these, mechanisms to regulate the inflow and outflow of tidal and rainwater from the site are incorporated into the project's design. Achieving a balance between the needs of the estuarine wetland's flora and fauna and minimising risk of mosquito population increase is difficult. However, manipulation of the temporal frequency of tidal flooding may provide the most effective strategy for mosquito population management without reliance on mosquito control agents.

The production of mosquitoes from tidally influenced habitats within rehabilitated wetlands may be regulated by the manipulation of tidal inundation via the tide/flood gates. The restriction of daily tides to limit the volume of water entering the wetland will limit the extent, as well as the duration, of inundation, and subsequently minimise mosquito production. To increase the salinity of the wetlands to encourage the growth of saltmarsh vegetation while minimizing opportunities for mosquito production, limiting the number of tides in each month may ensure that water flooding ground pools and depressions dries or soaks into the soil in less than 5 days, limited the opportunity for mosquitoes to complete development. However, regulation of tidal flows is likely to be governed by many different wetland management objectives that consider the well being of plants and animals and compromises may be required to balance mosquito management and the overall objectives of rehabilitation and wetland management strategies.

The regulation of mosquito populations following rainfall is more difficult and the composition of species and relative abundance following exposure to salt water is difficult to predict. In some cases, during periods of above average rainfall, production of *Ae. vigilax* may be reduced but following major rainfall events it should be expected that there will be an increase in mosquito activity. During periods of above average rainfall, many habitats within estuarine wetlands remain inundated for long periods, under these conditions, productivity of *Ae. vigilax* generally declines but populations of other saline species, specifically *Cx. sitiens*, may increase. It is, however, interesting to note that, even though under favourable conditions the wetlands can support exceptionally large populations of *Cx. sitien*s, this species rarely causes major pest impacts as it is primarily a bird feeding species.

An additional consideration is that, while the introduction of tidal flows may create favourable conditions for estuarine mosquito species, conditions for existing freshwater pest mosquitoes, such as *Cx. annulirostris* and *Cq. linealis*, may be made unfavourable. Productivity of these species are primarily driven by seasonal rainfall. However, in some cases, there may be no net increase in pest mosquito activity from rehabilitated wetlands.

Overall, there is going to be seasonal changes in the abundance of pest mosquitoes resulting from differences in tidal heights, rainfall and temperature. These changes will be difficult to predict and mosquito populations may themselves influence habitat productivity in subsequent seasons (e.g. high mosquito populations in one season may result in greater densities of 'eggs' that hatch the following season). Given the relatively dramatic changes that will occur following the reintroduction of tidal flows to rehabilitated wetlands, seasonal variations in mosquito populations make predictions of mosquito productivity difficult.

14 COMMUNITY EDUCATION

14.1 Mosquitoes and the community

One of the most important aspects of mosquito management is the engaging of the community in the program. As well as the dissemination of information on the public health risks associated with mosquitoes and strategies to reduce those risks, it is crucial that the community is educated on the place of mosquitoes in the local environment and the reasons why specific management strategies have been employed in the region.

There is often a lot of misinformation within the community regarding mosquitoes. A lack of understanding of the diversity of mosquito species, their life cycle and habitat associations is common. Concise, accurate information regarding the local mosquito populations can not only provide important public health messages but garner a greater interest in the ecology of local wetlands and the importance of environmentally sensitive mosquito management. The provision of public displays in shopping centres or at community events will provide an ideal opportunity for public education.

The public health message regarding mosquitoes dominates most community education programs. However, benefits could be gained by the inclusion of biological and/or ecological facts and figures associated with the local mosquito fauna (e.g. the mosquitoes that don't feed on humans, the specific habitat associations of some common mosquitoes, those mosquitoes that have predatory larvae). Even more so, the incorporation of mosquito information into overall environmental education programs will further promote the understanding that mosquitoes are an integral part of the ecosystem and should not be viewed in isolation.

Public education campaigns often involve the production of posters, fact sheets, stickers and videos, usually undertaken by local government or health authorities (Figure 23). The content, formatting and distribution of this material will be determined by the intended target of the education campaign (e.g. whole community, primary or secondary school, wetland visitors etc).

14.2 Nuisance biting complaints

When mosquitoes are abundant, local authorities may receive phone or email complaints regarding nuisance biting in residential or recreational areas. These complaints may provide information on areas where mosquito impacts are greatest. However, the tolerance of individuals to mosquitoes varies greatly and the number of complaints within and between seasons may not be directly related to actual mosquito populations. There are a number of factors that will influence an individual's sensitivity to mosquitoes and also their likelihood of making a complaint to local authorities.

When assessing the effectiveness of mosquito control programs, it is important that ongoing mosquito monitoring data is used as the measure of pest mosquito activity, not the number of complaints to local authorities (unless the two can be statistically associated). The quantity and frequency of complaints may, at times, be due to factors such as increased publicity regarding mosquitoes and arboviruses in the media or within local actions groups, and not an actual substantial increase in mosquito abundance. However, if some significant linkage can be established, then a public complaint 'threshold' can be a useful trigger for further investigation/ intervention.

When a complaint is made, it is important that it is directed to a person supplied with information on the region's mosquito surveillance and management program, and able to provide appropriate information on reducing nuisance-biting impacts. A database of complaints should be kept and, if time and resources allow, an adult trap could be operated overnight in the local area to determine the mosquitoes likely to be causing the nuisance impacts. These short investigations also provide an excellent opportunity to connect the local community with the mosquito management program.

14.3 Dealing with the media

The various media regularly include mosquito stories during the summer months, often instigated by action groups within the community lobbying for greater levels of mosquito control or in response to health warnings by local authorities (or sometimes just because it is that time of the year).

Dealing with the media is an important component of community education because it provides an opportunity for the dissemination of accurate information on mosquitoes and personal protection strategies, as well as opportunities to publicise the local mosquito management program.

It is crucial that representatives of local authorities dealing with media have appropriate training and/or resources to answer questions regarding general mosquito biology, locally important pest mosquitoes, personal protection strategies and background on the local mosquito surveillance and management program.

While the majority of mosquito related articles in the media relate to pest and/or public health issues, opportunities to promote mosquitoes as an important component of the local environment should be pursued. There are many interesting aspects to mosquito biology and ecology that will provide the basis of radio, newspaper or television segments that have a wide appeal to audiences.

14.4 Personal protection strategies

In the Lower Hunter and Mid North Coast region, regardless of proximity to wetlands, it should be expected that at least some mosquitoes will be active during the summer months and information on personal protection measures should be made available to the community as a primary objective of community education.

During the warmer months, considerable recreation time is spent outdoors during the morning and late evening, pursuing a range of activities. In addition, many occupations require outdoor work and protection of employees against nuisance biting and potential arbovirus infection is an important consideration in occupational health and safety programs.

14.4.1 Avoiding mosquito habitats

Mosquito populations will be greatest in these areas during the two to three week period following high tides and/or major rainfall events. Mosquitoes are also more likely to be active during warm, calm and humid conditions.

Avoidance of mosquito refuge areas (e.g. bushland, wetlands, etc.) during the peak periods of mosquito activity (i.e. dusk and dawn) will minimise exposure to mosquitoes. If visiting these areas, it is important to wear loose, light coloured clothing with long sleeves and pants where possible, and apply a suitable insect repellent (see Section 14.4.2).

14.4.2 Mosquito repellents

The use of personal insect repellents is highly recommended when undertaking activities near known mosquito habitats or during the periods of peak mosquito activity. These products are available in a wide range of formulations, including aerosols, creams, lotions, pump sprays and sticks. Regardless of the formulation, the most effective products are those that contain at least 20% DEET (diethyl toluamide or N,N-diethyl-3-methylbenzamide) or Picaridin, two chemicals known to be effective insect repellents.

There are pros and cons to every type of formulation and the decision of which is most appropriate is probably best made by the individual. The key point to remember is that, for complete protection, the entire surface of exposed skin must be covered. For this purpose, sprays are often effective for arms and legs while creams and towelettes are good for the face. Some repellents are available as patches or plastic wrist bands but these only offer limited and localised protection (i.e. if any protection is provided, it is generally only immediately around the product). However, when used in combination with other repellents (or long-sleeved shirts), wrist bands may be worth a try for those wanting to avoid getting repellent on their hands.

DEET was originally released to the public in 1957, and has been shown to be effective in repelling many species mosquitoes in both laboratory and field trials worldwide. The chemical repels mosquitoes by confounding their sensory organs and inhibiting their host seeking stimuli. When applied according to manufactures recommendations, there are no side effects to the use of DEET. Picaridin was developed more recently and it also has shown similarly good repellency against a range of mosquitoes and other biting insects, and is widely available in various formulations.

Increasingly, manufacturers are looking to combine insect repellents with other cosmetics including sunscream and skin moisturizers. Studies have shown that the combination of sunscreen with repellents does not reduce repellency. However, there can often be confusion over the recommended use of these products with sunscreen requiring reapplication every 2 hours, a higher reapplication rate than would otherwise be recommended for some repellents with a high DEET concentration. In most circumstances, the reapplication of a low dose DEET-based repellent combined with sunscreen every 2 hours will offer the best protection against both UV radiation and biting insects without unnecessary or excessive applications of repellent.

There is a large quantity of repellents available that contain ‘natural’ compounds derived from plants, including eucalyptus, tea-tree, catmint and citronella extracts. While such products are available for individuals wishing to avoid so-called ‘chemical’ repellents, it should be recognized that they also are chemicals and some persons will find they cause skin irritations. More importantly, however, they generally offer substantially lower protection times when compared to those containing DEET. Laboratory trials have shown that while natural products may only offer 15 –30 mins protection, DEET based products may offer protection against mosquitoes for more than 6 hrs.

A range of live plants (e.g. *Citronella geranium*, *Leptospermum* spp., *Chrysanthemum* spp.) are often marketed as mosquito repellents, with claims they are suitable for keeping mosquitoes away from outdoor areas where they have been planted. The basis for these claims is that these plants contain strongly aromatic oils that may have some mosquito repellent qualities, but studies have shown that these plants offer no useful protection from mosquitoes.

14.4.3 Coils, burners, buzzers and other devices

For information on commercial mosquito traps, see Section 11.2.3

In addition to mosquito repellents that can be applied directly to the skin, there are a range of products including to coils, sticks and other ‘burner’ devices that purport to repel mosquitoes. These products are impregnated with an insecticide (usually a pyrethroid) that is released when heated, either by burning (coils and sticks) or heated by a small electrical unit (vaporising mat). These products are generally designed for indoor or sheltered outdoor areas and should be used as directed. Prolonged use in confined spaces should be avoided as some respiratory problems may result.

Some products are available that contain citronella (or other plant extracts) and while offer short periods of repellency, they do not offer the same protection as those products impregnated with insecticide.

While there is demand from the community for repellents, particularly alternatives to topical creams and lotions, entrepreneurs will always be looking to make a quick dollar or two. While not always common in Australia, products often pop up that purport to use sound to repel mosquitoes. These gadgets can range from key ring sound emitters and plug in "sonic" devices to mobile phone ring tones and wrist watches. There is no scientific evidence that these devices work and many have been forced from retail outlets overseas as a result of their false claims. T general principal is that female mosquitoes are repelled by sound of the male mosquito wing beats as they avoid multiple matings. However, there is no scientific basis to these claims and scientific trials have repeatedly shown that these units are not effective and, in some countries, legal action has been taken to recall the items from sale and prosecute the vendors.

14.4.4 Backyard mosquitoes

It is important to educate the community on the importance of "backyard" mosquitoes as, in many instances, these mosquitoes will be the most common cause of nuisance biting in residential areas.

The container breeding mosquito, *Ae. notoscriptus,* can be a serious pest and is closely associated with water holding containers in residential areas. The production of mosquitoes can be reduced by emptying, covering or removing all containers (such as cans, old tyres, buckets), filling pot plant saucers with sand to absorb standing water, ensuring tarpaulins covering boats or trailers don't collect water, and emptying/refilling bird baths regularly. Water holding or storage structures around the house should be regularly maintained, including roof guttering where leaves and other debris should be removed, and all openings to rainwater and septic tanks should be properly screened with wire gauze.

Backyard ponds and ornamental water features should be checked for mosquito larvae. Fountains and other water cycling devices can assist in reducing mosquito production. The introduction of native fish is also suitable and can be effective in these habitats. In the case of ponds created specifically for frogs where the introduction of fish may not be suitable, there may be some mosquito production but, overtime, insect predators (such as water beetles and dragonfly larvae) will colonise these pools and minimise mosquito populations.

While some mosquito activity should be expected in outdoor areas, the entry of mosquitoes into buildings can often have significantly greater nuisance impacts. Fly screens should be fitted to windows and doors where possible. It should also be ensured that there are no entry points via air conditioning ducts, ventilation structures or other connections between indoor and outdoor areas.

14.5 Living with Mosquitoes: "Mozzies suck so cover up"

In conjunction with the launch of the first edition of the "Living with Mosquitoes" document, a range of educational material was produced to assist in raising the awareness of mosquitoes, mosquito-borne disease and personal protection strategies in the local community.

A sub-group of the original "Living with Mosquitoes" group, together with consultant graphic designers, developed the "Mozzies suck so cover up" slogan and accompanying logo and images. Brochures, fridge magnets and bin stickers were initial produced following by primary school book stickers and a modified tidal chart (Figure 6).

Each of the different formats targeted a different group within the community to provide a regular reminder of the local mosquito-borne disease risks and the measures available to minimise individual risk.

Figure 6. An example of the “Mozzies suck so cover up!” awareness material produced by the Living with Mosquitoes group.

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16 USEFUL WEBSITES

The Department of Medical Entomology, ICPMR & University of Sydney
http://medent.usyd.edu.au/

NSW Arbovirus Surveillance & Mosquito Monitoring Program
http://www.arbovirus.health.nsw.gov.au/

Mosquito Control Association of Australia
http://www.mcaa.org.au

American Mosquito Control Association
http://www.mosquito.org/

NSW Health
http://www.health.nsw.gov.au/

Australian Pesticides and Veterinary Medicines Authority
http://www.apvma.gov.au/

Native Fish Australia
http://www.nativefish.asn.au/

Department of Infrastructure Planning and Natural Resources
http://www.dlwc.nsw.gov.au/

Government of New South Wales Legislation home page
http://www.legislation.nsw.gov.au/

Hunter Central Rivers Catchment Authority
http://www.hcmt.org.au/

Hunter and Central Coast Regional Environmental Management Strategy
http://www.hccrems.com.au/

The Kooragang Wetland Rehabilitation Project
http://www.hcmt.org.au/kooragang/

Australian Quarantine and Inspection Service
http://www.affa.gov.au

Australian Entomological Supplies
http://www.entosupplies.com.au/