Suffolk County Vector Control & Wetlands Management Long Term Plan & Environmental Impact Statement

Task 3 Literature Review
Book 1: Long Island Mosquitoes

Prepared for:

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SUFFOLK COUNTY VECTOR CONTROL AND WETLANDS MANAGEMENT LONG - TERM PLAN AND ENVIRONMENTAL IMPACT STATEMENT

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EXECUTIVE SUMMARY

Forty-one native species and one recently introduced species of mosquitoes have been observed in Suffolk County, Long Island, New York, and are assumed to be resident in 2004. Twelve of these species are considered to be of concern with regard to impacts on human lifestyles due to biting habits and/or actual or potential status as a vector of human disease. These species are:

- *Ochlerotatus sollicitans*
- *Aedes vexans*
- *Culex pipiens*
- *Culex restuans*
- *Culiseta melanura*
- *Ochlerotatus cantator*
- *Ochlerotatus taeniorhynchus*
- *Coquillettidia perturbans*
- *Ochlerotatus trivittatus*
- *Ochlerotatus canadensis*
- *Ochlerotatus triseriatus*
- *Ochlerotatus japonicus*

One way to classify mosquitoes is by their mode of reproduction. Mosquitoes that breed in a similar manner frequently have other similarities, such as larval lifestyles. Control measures are best directed at the larval stage, meaning that these groupings can have practical applications. Some species reproduce once a year (univoltine), while others lay eggs that hatch at various times throughout the year (multivoltine). All mosquitoes require damp to wet conditions to lay their eggs. Some mosquitoes require that their eggs remain in water, whereas, desiccation tolerant mosquitoes require that their eggs dry out prior to further development. Desiccation tolerant mosquitoes tend to hatch in "broods," as environmental conditions result in eggs developing at approximately the same time. Desiccation intolerant mosquitoes may not hatch at one discrete time, but rather in a more diffuse manner. Some mosquitoes need organically polluted water as breeding sites, and others can tolerate or need salt water. Some mosquitoes overwinter as adults, but others overwinter as eggs or larvae.

All mosquitoes follow the same developmental pattern. After hatching from an egg, each individual lives in an aquatic environment as an air-breathing larvae, and undergoes metamorphosis through four stages (instars) prior to becoming a non-feeding pupa. After the pupal stage, a fully developed adult emerges.

Males and females tend to feed on plant nectars to fulfill daily energy needs; however, in almost all mosquito species the female requires a blood meal for her eggs to mature. Most species have general preferences of prey for blood (such as warm or cold-blooded animals), and some preferences are quite specific (so much so that *Anopheles gambiae*, the primary African vector of malaria, almost exclusively feeds on people).

Female mosquitoes can transmit diseases to humans when they bite to obtain a blood meal. Mosquitoes are considered to be disease vectors because they can transmit diseases, via a blood meal, from an infected host to a human target. The first blood meal transmits the disease-bearing organism to the mosquito (usually, the mosquito is not affected by the disease), and the second results in its transfer to a new organism. Mosquitoes use secretions of various kinds to prevent blood clotting and make the target organism less aware of a bite and the feeding process. Diseases are transmitted in the injected secretions. Thus, diseases can only be spread when a mosquito feeds for a second time. Particular diseases are transmitted by various aspects of the feeding process, in that some viruses or parasites are associated with secretions released early in the meal, and others are associated with secretions released at other stages.

Birds and other animals are the primary carriers of arboviruses (viral diseases transmitted by arthropods), such as eastern equine encephalitis (EEE) or West Nile virus (WNV), while humans are the primary carriers of arboviruses, such as yellow fever and malaria. The arbovirus is transferred from a primary carrier or host (i.e., birds or humans) to the mosquito and, finally, it is transferred to the recipient or terminal host (i.e., humans). In this chain of events the mosquito is often referred to as the bridge vector.

The behavior of particular mosquitoes determines their capacity as vectors, and their ability to upset human lifestyles through aggressive biting. In addition, their developmental biology also determines how they can be controlled.

Ochlerotatus sollicitans is a multivoltine, salt water and desiccation tolerant mosquito. It is a persistent and aggressive feeder on humans. It has been shown to be a carrier of EEE and WNV, although not yet in Suffolk County. Salt marshes can produce very large broods of *Oc. sollicitans*, usually after a higher than normal tide in summer. The female's range for a meal has been reported as 10 miles or more, but is usually within two miles, of her hatching point, and generally does not cross water bodies. After her first meal, this range is generally restricted to half a mile. This species will bite day or night, further increasing its tendency to bite. Control of this mosquito is intended to reduce major impacts on the outdoors lifestyle of residents in shoreline communities, and to ensure it does not become a bridge vector for EEE and WNV. Control measures include salt marsh water management, larvicides, and adulticides.

Aedes vexans is a multivoltine, fresh water, desiccation tolerant mosquito. Although classified as a freshwater mosquito, it will breed in salt marshes, although it prefers less salty water than *Oc. sollicitans* does. *Ae. vexans* is an aggressive biting mosquito that also can fly large distances from its breeding place. It broods tend not to emerge as frequently as *Oc. sollicitans* broods do, and occur in response to rainfall or river flooding. It is a potential vector for EEE and WNV, and can cause be a significant nuisance to humans. Its salt marsh habitats can be addressed through water management; larvicides and adulticides are also used to control it.

Culex pipiens and ***Culex restuans,*** *despite being different species*, are difficult to differentiate, and so are often grouped as "*Culex spp.*" These mosquitoes are multivoltine, fresh water (polluted water required), desiccation tolerant mosquitoes. They are not aggressive feeders on humans, and apparently prefer to feed on birds. They breed primarily in backyard environments, and do not travel far. They will also breed in drainage structures, septic ditches, and organically polluted ponds or puddles. *Culex spp.* is thought to be the prime WNV vector in Suffolk County, and may be a vector for EEE. Control of these mosquitoes is best addressed by eliminating its habitat. Larvicides can be effective when the larval habitats can be identified, but not removed; however, these sites are frequently too numerous to ensure that all, or most, are treated. Aerial insecticide applications are another viable control option.

Culiseta melanura is a multivoltine, freshwater, desiccation intolerant mosquito whose larvae overwinter in cedar and red maple swamps. This mosquito only feeds on birds. It is an important amplifier of EEE in bird populations, such that the rate of infected birds becomes high enough to increase the likelihood that a bridge vector mosquito will transmit the disease to humans. These mosquitoes are difficult to control through larvicides, due to their larval habitat being among tree roots and frequent association with protected species. They are controlled with adulticides when the threat of EEE is particularly high.

Ochlerotatus cantator is a multivoltine, salt water and desiccation tolerant mosquito. Its largest broods generally emerge from the upland edge of a salt marsh in the springtime. Therefore, it is unlikely to be a vector for EEE, and it may not be an effective transmitter of WNV. It is an aggressive human feeder, and has a substantial range. Control measures for *Oc. sollicitans* generally address this species.

Ochlerotatus taeniorhynchus is a multivoltine, salt water and desiccation tolerant mosquito. Its broods can be large enough, and it is aggressive enough of a human feeder, that it can cause more of a nuisance than *Oc. sollicitans* at certain times. It appears to be capable of being a vector for EEE or WNV. Control measures for *Oc. sollicitans* generally address this species.

Coquillettidia perturbans is a univoltine, fresh water, desiccation intolerant mosquito. Its larvae attach themselves to the roots of emergent vegetation, making larval surveillance and control exceptionally difficult. The mosquito overwinters in various stages of larval development. It appears to generate broods, but multiple emergences from freshwater swamps signal the timing associated with the different instars of the overwintering larvae. This species is an aggressive human biter, and is the typical bridge vector for EEE. It can travel several miles in search of a blood meal. Its habitat characteristics dictate control by larvicides or adulticides.

Ochlerotatus trivittatus has a life-style akin to *Ae. vexans*, and so is a multivoltine, desiccation tolerant mosquito. It breeds in freshwater environments, and is especially common in recharge basins that retain water intermittently. It is thought to be a potential vector of WNV, but not of EEE. It is an aggressive biter of people, but has a short flight range. It can be controlled through water management, fish stocking, and larvicide applications in the recharge basins.

Ochlerotatus canadensis emerges in early spring, but may have additional broods in the summer; it is a freshwater, desiccation tolerant mosquito. It does not venture far from its larval habitat, but has been described as a fierce biting mosquito. Its indiscriminant feeding habits make it a potential late-season EEE vector, although its early emergence usually mitigates this. It is largely controlled by larvicide applications, but it is targeted with adulticides if EEE is a concern.

Ochlerotatus triseriatus is a multivoltine, freshwater (prefers polluted water), desiccation tolerant mosquito. It typically uses abandoned tires (the anthropogenic equivalent to natural tree holes) as habitat. It is an aggressive daytime biter, and so is not caught in traps. It does not fly far from its breeding points. It is a potential EEE and WNV vector. Elimination of habitat is the primary means of control.

Ochlerotatus japonicus is an invasive species that shares many lifestyle characteristics with *O. triseriatus*. It has been found with WNV and is capable of transmitting the virus. It is difficult to sample and does not appear to be particularly aggressive, but it is widespread in Suffolk County. Its importance, or lack thereof, as a vector is not yet understood. It is not known to be an EEE vector.

1. Classification of Mosquitoes

Mosquitoes are classified in the Insect Order Diptera, commonly known as the true flies. The mosquitoes comprise the family Culicidae within that order and are considered by many as the most important insects on earth, based on disease potential (Clements, 1992). There are currently more than 3,000 mosquito species in the world grouped in 39 genera and 135 subgenera (Eldridge and Edman, 2000; Reinert, 2000; Reinert, 2001). Table 1-1 illustrates the taxonomic breakdown for this important group of insects that directly impacts human health and recreation in Suffolk County, NY. Carpenter and LaCasse (1955) is the classic publication for the identification of both larval and adult mosquitoes found in North America, north of Mexico. Darsie and Ward (1981) is an updated version that is used by the majority of mosquito identification specialists in the US.

1.1. Characteristics of the Order Diptera

Mosquitoes, like all members of the Order Diptera, undergo complete metamorphosis during their developmental stages and possess one pair of membranous fore wings when they become adults. Functional hind wings have been lost in this group, which significantly improves flight capabilities. The remnants of the hind wings in the True Flies are represented by halteres, which function as gyroscopic balancing structures that allow the insects to maintain their attitude with the ground. Unlike most other insect Orders, true flies can hover, bank and land on the ceiling with ease. The mosquitoes share these characteristics with other Diptera and, although fragile, are capable of acrobatic flight.

1.2. Suborder Nematocera and Family Characteristics of the Culicidae

The Family Culicidae is grouped in the suborder Nematocera which gives the developing stages in their life cycle a number of unique characteristics. The larval stages of all Nematocera have a sclerotized head capsule that contains antennae, bristles, hairs and sutures that are useful for identification to species. Nearly half of the taxonomic characters used to identify mosquito larvae are based on features found on the head capsule. Most of the remaining characters are found on sclerotized regions on the terminal segments including the siphon, saddle and comb scale area.

The larval stages of all Diptera possess chewing mouthparts composed of mandibles that commit the young to solid foods. With few exceptions, the Culicidae have modified their chewing mouthparts for filter feeding by adding maxillary brushes that sweep suspended food particles from the water into the mouth opening. The combination of mouth brushes and mandibles allows mosquito larvae to feed on a wide range of particle sizes. They can filter feed on suspended particles, graze on algae when it is abundant, and gnaw chunks from larger substrates when other foods are scarce. Larvae of the genus *Psorophora* prey on other small aquatic organisms, and larvae of the genus *Toxorhynchites* even prey on other mosquito larvae.

The pupal stage of the Nematocera is, in general, free swimming which makes mosquitoes unique compared to most true flies. In most insects, the pupal stage is sedentary and capable of nothing more than minor movement. Mosquito pupae are expert swimmers and each one remains active right up to the time that the adult emerges. The mosquito pupa has a large caudal fin that allows it to dive with ease when danger approaches. Mosquito pupae have trapped air pockets under their developing wing flaps, which cause them to bob to the surface whenever they stop swimming. This stage in the life cycle breathes through two trumpets on the cephalothorax, which, in the vast majority of species, break the meniscus each time the insect rises to the surface.

Adult Culicidae are separated from other Diptera by:

1) mouthparts contained in a long proboscis;
2) scales on the body; and,
3) scales that emanate from the wing veins.

The mouthpart structure gives a female mosquito access to blood and forms the basis for their disease importance. The scales on the body create light and dark banding patterns that are useful for species identification. The scales on the wings, which also exhibit color patterns, range from narrow to broad, providing additional criteria for species identification in this exceptionally large group of insects. Mosquito species that are brightly banded have the ability to rest in open areas because the body scales reflect light. Many of these are opportunistic feeders and bite readily if blood meal hosts enter their resting sites during daylight hours. Unbanded mosquito species tend to rest in more shaded areas to avoid heat absorption during the middle of the day. Most unbanded mosquito species remain inactive during daylight hours and have host-seeking rhythms that are driven by decreased light intensity.

1.3. Subfamily Characteristics and Mosquito Genera

Table 1-1 shows that the Family Culicidae contains three Subfamilies:

- the Anophelinae (anophelines)
- Toxorhynchitinae (toxorhynchitines)
- Culicinae (culicines).

Taxonomic differences among the three Subfamilies are most evident in the larval stages. Anopheline mosquito larvae lack an air tube and rest parallel to the surface to obtain atmospheric oxygen. Toxorhynchitines and Culicines possess air tubes in the larval stage and hang at a 45 degree angle from the surface when they breathe. Toxorhynchitine larvae are predators and grow considerably larger than the larvae of the other two subfamilies.

The subfamily Anophelinae is represented only by the genus *Anopheles* in Suffolk County. The genera *Bironella* and *Chagasia* are anopheline genera found only in tropical regions. The subfamily Toxorhynchitinae contains the single genus, *Toxorhynchites*. Although most of the species in this genus are tropical, one Toxorhynchitine does occur in Suffolk County. The subfamily Culicinae contains 39 different genera worldwide and includes a very diverse group of insects. Eight genera of Culicinae are found in Suffolk County.

Anopheline larvae possess characteristics that enable them to rest at the surface and obtain food directly from the surface film. They have a head capsule that rotates 180 degrees giving the mouthbrushes contact with the meniscus while the larva remains in the breathing mode. They also possess palmate hairs on their abdominal segments that function as floats keeping the insect parallel to the surface unless they purposely dive. Anopheline adults differ morphologically from the other subfamilies of mosquitoes. The body is more slender than culicines and the abdomen lacks scales. Abdominal banding is widely used for culicine species identification. The absence of abdominal scales in anophelines forces mosquito identification specialists to focus on other characters. Light and dark wing scales are clustered in anophelines forming patterns and spots that are frequently used for species identification. In some regions of the country, keys to the anophelines rely solely on wing scale patterns. The maxillary palps of the female anopheline form the most striking characteristic of the subfamily. The paired palps are as long as the proboscis, giving the appearance of three beaks in the female insect. Adult anopheline mosquitoes rest at a 45 degree angle to the substrate holding the head, thorax and abdomen in one plane. When anophelines are resting, they look very much like splinters. This behavioral trait easily separates the group visually from the other subfamilies of Culicidae. Members of the genus *Anopheles* function as the sole vectors of human malaria. Malaria was once a major problem in North America but was eradicated from the US in the 1950s. Sporadic cases of human malaria occur each year in North America, mainly amongst travelers who acquire infection abroad or from use of shared needles contaminated with the blood of an infected person. Two cases of local malaria in Suffolk County were reported in 1999; although the parasite was not isolated from any trapped, local mosquitoes, it was inferred from circumstances surrounding the infections that *Anopheles* mosquitoes in or near a Boy Scout camp in Bating Hollow were the vectors, leading to adulticide control there.

The Subfamily Toxorhynchitinae comprises the giants of the mosquito world. The members are predacious as larvae and are flower feeders as adults. The subfamily contains a single genus, *Toxorhynchites*, which is largely tropical in distribution. A single species, *Toxorhynchites rutilus*, is temperate and the subspecies *Toxorhynchites rutilus septentrionalis* is found as far north as Connecticut in the northeastern US. The species *Tx. r. septentrionalis* has been collected in Suffolk County (Guirgis and Van Ostrand, 1976) but is considered to be rare. The combination of predacious larva and flower feeding adult makes the toxorhyncitines ideal tools for biological control purposes. Numerous attempts have been made to exploit that trait but none have succeeded to date. Toxorhynchitines are container breeders, which limit the number of associate species they can control. They are slow to develop and occur in low numbers, which minimizes their impact, even when available prey is plentiful. Most species in the subfamily are cannibalistic in the late larval instars, which defeats the purpose of propagation for biological control purposes. More research is needed before these interesting natural agents can be utilized for mosquito control purposes.

The Subfamily Culicinae comprises the largest group in the family and includes eight different genera in Suffolk County:

- *Aedes*
- *Ochlerotatus*
- *Psorophora*
- *Culex*
- *Culiseta*
- *Coquillettidia*
- *Uranotaenia*
- *Orthopodomyia*

Since generic differences reflect habitat usage they will be discussed fully in the section on Mosquito Ecology.

Table 1-1 – Taxonomic Classification of Mosquitoes found in Suffolk County

TAXONOMIC HIERARCHY	TAXONOMIC CLASSIFICATIONS	
Phylum	Arthropoda.	
Class	Insecta	
Order	Diptera	
Suborder	Nematocera.	
Family	Culicidae	
Subfamily	Anophelinae Toxorhynchitinae Culicinae	
Genus	Anopheles Aedes Ochlerotatus Psorophora Culex Culiseta	Coquillettidia Uranotaenia Orthopodomyia Toxorhynchites Wyeomyia
Species	41 Native, 1 Invasive Species in Suffolk County	

2. The Mosquito Life Cycle

Mosquitoes pass through four main stages in their metamorphosis, passing from egg to larva to pupa and finally adult (Figure 2-1). The adult is a terrestrial organism; the larval and pupal stages are aquatic. The eggs of most genera are deposited directly on water but a number of Suffolk County's worst pests have eggs that are able, and need, to dry down. The eggs of desiccation tolerant species remain viable on dry substrates but do not hatch until they are inundated by rain or tide following some period of exposure to dry air. The adult mosquito is an insect that gets nutrition by feeding mainly on plant sugars. The females of most species require blood before they can produce fertile eggs. Basic life cycle characteristics for the Culicidae as a group are presented in Table 2-1. Table 2-2 compares life cycle characteristics for important mosquito genera. Detailed information on the biology of mosquitoes is compiled in two separate volumes by A.N. Clements. Clements (1992) includes pertinent information on mosquito development, nutrition and reproduction and Clements (1999) reviews sensory reception and mosquito behavior. Both volumes are completely referenced and serve as a major source of information on mosquito biology. Information on the disease potential and vector status of mosquitoes is available in several Medical Entomology texts. Eldridge and Edman (2000) published the text, *Medical Entomology,* to help fill the void created by the classical Harwood and James text that is now out of print. Beaty and Marquardt (1996) published *The Biology of Disease Vectors,* a text that includes a great deal of important information on insect-borne pathogens.

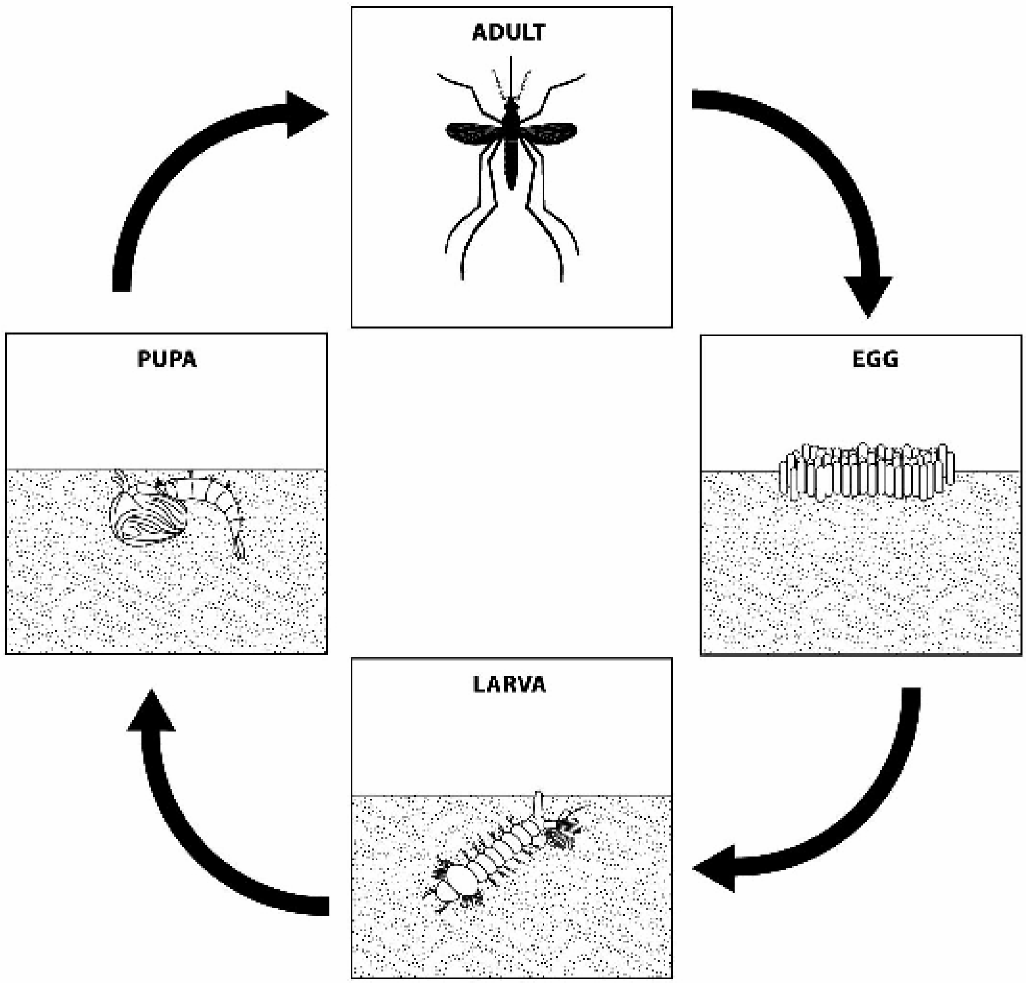

Figure 2-1 - Mosquito Life Cycle (NYCDOH, 2001)

2.1. Eggs

Mosquito eggs generally measure less than one mm and vary from spindle shaped to nearly round. Many have elaborate ornamentation on the exterior surface and can sometimes be identified to species. Mosquito eggs have three layers:

- an outer layer (exochorion)

- an inner layer (endochorion)
- a third layer (serosal cuticle) produced by the embryo after oviposition.

Differences in the structure of the three layers produce two basic egg types among the genera found in Suffolk County, which directly reflect human biting potential of the species involved.

Desiccation tolerant eggs have a re-enforced inner layer and a permeable outer layer. The design releases pressure under drought conditions and permits the egg to dry completely without collapsing. Three genera of Suffolk County mosquitoes (often referred to as the Aedine genera) have desiccation tolerant eggs, *Aedes*, *Ochlerotatus* and *Psorophora*. The Aedine genera occur in large numbers and are Suffolk County's worst pests. Females deposit desiccation tolerant eggs on moist surface in low-lying areas that may subsequently flood. The eggs are capable of hatching weeks, months, or even years after the female deposits them. Desiccation tolerant eggs must remain moist until the embryo produces the serosal cuticle. As a result, the eggs are deposited in rings around transient pools and puddles as the habitat dries down. After the production of the serosal cuticle, the egg must be exposed to dry air for at least 24 hours to finish maturing. Female mosquitoes that deposit desiccation tolerant eggs directly on the ground usually produce spindle shaped eggs with the widest portion located at the midpoint. This egg shape allows the least amount of surface area to touch the ground and the eggs roll to the lowest point when the habitat dries completely. Positioning in the lowest areas of the habitat maximizes inundation after a flooding event. Some female mosquitoes glue desiccation eggs to the sides of a container and rely on rising water levels for flooding and egg hatch. Most container breeding species that glue eggs to a substrate have cigar shaped rather than spindle shaped eggs. The cigar shape provides a broad flat surface for the egg to adhere. Human biting species that oviposit in containers can be monitored with ovitraps (vessels that are designed to attract container breeding Aedines). Mosquitoes glue their cigar shaped eggs to a small paddle that can be removed periodically for egg counts to indicate population densities. The practice is common in the southern United States to monitor the Yellow Fever mosquito, *Aedes aegypti*, and the Asian Tiger mosquito, *Aedes albopictus,* but is not widely used in the northeast.

Non-desiccation tolerant eggs have a thinner inner layer and an outer layer that is impermeable to gaseous exchange. These eggs collapse if they dry and are, therefore, deposited directly on water by the female to assure that the eggs remain moist until ready to hatch. Embryonation is rapid among the Culicidae and the larval stage is ready to hatch within days in both types of eggs. Egg hatch occurs several days after oviposition in those species that deposit their eggs directly on water. Genera that exhibit this egg type emerge continuously over the course of a breeding season. Embryos within desiccation tolerant eggs remain quiescent until inundated by enough water to stimulate egg hatch. Larvae of species with desiccation tolerant eggs hatch fairly synchronously after a flooding event, grow, pupate, and emerge as adults in a distinct brood.

Mosquitoes of the various genera that lay their eggs directly on water often have mechanisms to keep them floating on the water's surface. *Anopheles* produce eggs that have frills on the exochorion that serve as individual egg floats. *Culex, Culiseta, Coquillettidia* and *Uranotaenia* glue their eggs together in a floating mass that resembles a raft. *Toxorhynchites* have eggs that are nearly round with each egg covered by tiny tubercles. The aerodynamic shape of the round egg allows the flying *Toxorhynchites* female to shoot her eggs into container habitats with relatively small openings. The tubercles keep the round eggs floating on the surface until the predacious larvae are ready to emerge. *Orthopodomyia* and *Wyeomyia* deposit their eggs on the water's surface, but have no floating mechanism. These eggs sink to the bottom and the embryos breath from an air film formed over elaborate sculpturing of the exochorionic layer.

2.2. Larvae

Mosquito larvae are essentially free-swimming aquatic maggots that filter the water column for food particles small enough to pass through the mouth opening. They are very active and swim with a writhing motion leading to the common name of "wriggler" for this stage of the life cycle. Although they are aquatic, mosquito larvae breathe atmospheric oxygen and drown quickly if they are denied oxygen for any length of time. Insects that live underwater have a variety of unique modifications that permit survival in an aquatic habitat.

In general, insects breathe through minute holes, called spiracles that are connected to an elaborate tubular network that channels air to their internal tissues. Terrestrial insects possess a pair of spiracles on each abdominal and thoracic segment. They may "breathe" by flexing their bodies; some are able to alternately open and close valves on the spiracles to create a directed airflow through the tracheal system. Mosquito larvae have sealed off all but the terminal spiracles to adapt the system for underwater usage. The terminal spiracles are equipped with valves that enable them to breath at the surface when open and dive when closed. Palmate hairs keep anopheline larvae at the surface with the functional spiracles just above the meniscus. Their ability to rotate the head 180 degrees coupled with rotary action of the mouth brushes allows anopheline larvae to filter feed in the surface film where small food particles occur in great abundance. The single pair of functional spiracles is positioned at the end of an air tube (siphon) in culicines and toxorhynchitines that functions much like a snorkel for those organisms. With few exceptions, mosquito larvae with air tubes hang at a 45 degree angle to the water's surface when they breathe and filter a water column for food particles. Such larvae may also dive to the bottom to feed where food may be more abundant. In most cases, they must resurface regularly, however, to obtain the oxygen they need to survive. Mosquito larvae generally exploit relatively shallow aquatic habitats, such as that found in swamps, bogs, marshes, and containers, as well as transient and permanent pools. Mosquitoes rarely inhabit moving water because of the energy required to remain in place in lotic conditions. As a result, except for relatively calm back eddies, rivers, streams, and any body of water that is moving rarely support development of mosquitoes. Mosquito larvae rarely inhabit water that exceeds three feet in depth. For this reason, lakes and ponds do not produce mosquitoes except for weed-choked edges, which essentially meet their requirements for survival (access to nutrients and protection from predators).

The larval stage of the mosquito lasts from a minimum of four to five days in species with the quickest developmental times to up to a year in the genus *Coquillettidia*. Selection pressure has provided the Aedine genera (those with desiccation tolerant eggs) with the quickest developmental times because they inhabit transient water habitats that dry quickly after flooding. Species with non-desiccation tolerant eggs tend toward longer developmental times with five to seven days being the norm during the warmer times of the year. During this period, the mosquito larva passes through four larval instars, which represent incremental size increases between each of its molts. Immature insects grow by a series of molts that represent a sequence of repeatedly larger duplications of the insect that hatched from the egg. Each molt involves shedding the outer skin (exoskeleton) completely as well as the linings of the tracheae and portions of the fore- and hindgut. The cast skin contains every hair and bristle and may be accurately identified to species in the absence of the insect's body. The sclerotized areas of the mosquito larva's body (head capsule and siphon) are incapable of expansion and remain the same size for the duration of the instar. The thorax and abdomen of a mosquito larva are more supple and do expand somewhat allowing the organism some growth within a given instar. "Big headed" larvae generally represent newly molted insects and "small headed larvae" are ready to molt to the next instar. First instar larvae have just hatched from the egg and fourth instar larvae are ready to pupate. Surveillance data that include the proportion of each instar in field collections provides valuable information for mosquito control decisions. A preponderance of early instars indicates that emergence of the adults will not take place for several days. Populations composed primarily of late instars narrow the window considerably and should be attended to immediately when major pest species are involved.

2.3. Pupae

The pupal stage of a mosquito is nothing more than a mold for the adult. Complete metamorphosis allows for internal development of adult characteristics as early as the second instar. Insects that undergo complete metamorphosis possess two sets of cells. The first produces structures required during the larval stage and are expressed by the time the organism hatches from the egg. The second set of cells contains adult characteristics and will not be expressed until they are needed. Many adult characteristics, however, take time to form and begin developing during the larval stage. Adult structures are formed in imaginal buds, named after the word "imago" which translates to "adult." A chemical substance called juvenile hormone determines which set of cells should be active. Juvenile hormone determines when the next molt is due and the form that the new insect will take. As a result, this chemical regulates the appearance of the pupal stage. The organism molts to an adult when the juvenile hormone is completely depleted. Synthetic formulations of juvenile hormone are available for use as control agents.

Mosquito pupae are called "tumblers" because of their rocking swimming motion. The organisms have the head and thorax fused in the shape of a comma, with the curled abdomen protruding downward to give it the "comma shape." Mosquito pupae possess a flattened tail fin that moves the organism forward by a series of sharp kicks. Trapped air under the developing wing flaps helps produce the rocking motion when the pupa swims. The air bubbles under the wing also keep mosquito pupae at the surface unless they purposely dive. Mosquito pupae have no mouth opening and they do not feed in this stage of their development. Two respiratory siphons on the cephalothorax, usually referred to as "trumpets," provide respiration. The duration of the pupal stage is temperature dependant and lasts from one to four days or more, depending on species. When emergence time nears, the pupa stretches itself out of the comma shape and lays parallel at the surface. The fully formed adult within pumps air, and the resulting pressure splits the cuticle along a pre-determined line of weakness. Continued pumping on the part of the adult forces the adult mosquito up and out of the pupal exoskeleton. Adult mosquitoes usually rest on the water's surface just long enough for the wings to dry and become functional. When the transition is complete, the adult mosquito flies to nearby vegetation to begin the terrestrial phase of its life cycle.

Because the pupal stage of the mosquito is free swimming, it can be collected and used for monitoring purposes. The presence of mosquito pupae in field collections tells mosquito control agencies that an emergence of adult mosquitoes is about to take place. The pupal stage, however, usually only lasts a day or two; thus, the window of opportunity for control is extremely narrow. More importantly, mosquito pupae do not feed; therefore, biorational pesticides designed to be ingested for toxicity (*i.e., Bti*) are ineffective against this stage of the life cycle.

Table 2-1 - The Mosquito Life Cycle (NYCDOH, 2001; Milne and Milne, 1980; Gillette, 1972)

Stages of Development	Habitat	Nourishment	Behavior
Stage 1: Egg	Eggs laid on surface of fresh or stagnant water,* or laid singly on damp soil or vegetation.	Egg does not feed.	Larvae hatch in water.
Stage 2: Larva (wigglers)	Aquatic; use breathing tube (siphon) to obtain oxygen at water's surface. Some have specialized air tube used to penetrate air sacs in vegetation.	Filter feed on particulate matter or scrape material from substrate. Jaws have brushes that create currents to move food into the mouth.	Molt exoskeleton four times (stages between molts called instars). Become pupae after 4th molt.
Stage 3: Pupa (tumblers)	Aquatic; float at surface of water; obtains oxygen through two tubes (trumpets). Some access oxygen from plant air sacs.	Do not feed. Have no mouth.	Take a few days to transform into adult.
Stage 4: Adult	Terrestrial, marshes, woodlands, etc..	Males and females feed on nectar. Females of most species need blood meal for development of eggs. Females bite diverse kinds of vertebrates.	Split pupal case, rest until dry and wings harden, fly to nearby vegetation to begin rest of life cycle.

*Depending on availability of water, eggs may hatch within a few days or lay dormant for years before they emerge as larvae

2.4. Adults

The time from egg hatch to adulthood varies with species and with temperature. One to three weeks is the norm for most of the species found in Suffolk County, but some kinds take much longer. Roughly equal numbers of males and females are produced in most species. The males of many genera exhibit "protandry", a term for a shortened developmental period. Often, males emerge a day or so before the females from the same brood.

Male mosquitoes have a lifespan that lasts only a few days. The biological function of the male insect is to find a mate and pass on its genes before it dies. For some unknown reason, male mosquitoes emerge with their genitalia pointed downward. They cannot mate with a female until the terminal segment of the abdomen rotates 180 degrees. Protandry gives male mosquitoes time to complete the rotation process. It also allows time for the male to establish mating territories. Abundant male mosquitoes (relative to that of females) in trap collections indicate the impending emergence of the females. Males also tend to have very short flight ranges. Mosquito control agencies use large male mosquitoes trapping counts as a warning that adult control may be warranted in those areas within several days. The information is also used to locate the source of the problem and monitor the habitat to prevent unexpected emergences of adult mosquitoes in the future.

Male mosquitoes locate females in a variety of different ways. Some species share common resting sites and rely on weak pheromones for male/female attraction. In other species, the males form swarms which attract receptive females. In many species, males are attracted to females of their own species by the wing beat frequency of the female. Male mosquito antennae contain numerous long fibrils that, when held erect, resonate in response to a specific harmonic produced by the wing beat frequency of the female of that species. They have the ability to pursue and mate with females of their own species that enter their territory. The mating act is relatively quick in most mosquito species, and may occur while in flight or while resting on a surface. The male clasps the female in a front-to-front position and thrusts his aedeagus (sexual organ) into the female's vagina.

As with most insects, female mosquitoes mate only once in their lifetime. Sperm are stored indefinitely in internal storage organs known as "spermathecae." Once mated, the female mosquito can lay fertile eggs for the rest of her lifetime. During the summer months, a female mosquito may live for up to one month or so, and lay one to three batches of eggs, all from the same insemination. Mosquitoes of species that overwinter in the adult stage would generally have already mated before entering hibernaculae. They emerge the following spring to seek a host and lay eggs. The lifespan of these mosquitoes approaches eight months in many cases. Sperm from the virgin mating, however, remain viable during the months spent in torpor.

Table 2-2 - Life Cycle Characteristics for Various Mosquito Genera (AMCA website, Rutgers University)

Mosquito Genera	Egg Laying	Larval Behavior	Adult Feeding Behavior
Culex	Lay egg rafts on fresh or stagnant water at night; female may lay raft of eggs every third night during life	Larvae perpendicular to surface	• Feed at dusk and after dark • May enter dwellings for blood meals • Prefer domestic and wild birds over man and other mammals (e.g., cows, horses) • Generally weak fliers, do not move far from breeding grounds; however, are known to fly up to two miles • Live only a few weeks during warm summer months • Females that emerge in late summer search for sheltered areas where they “hibernate” until spring
Anopheles	Lay eggs singly on water	Larvae parallel to surface; do not have breathing tube	• Mosquitoes that may transmit malaria to people. • Adults rest with entire body at a 45^0 angle to the substrate. • Most pest species enter dwellings to feed.
Aedes, *Ochlerotatus*	Lay eggs on damp substrates	Larvae perpendicular to surface	• Painful, persistent biters • Day and night feeders • Some enter dwellings • Some prefer to bite humans rather than other mammals • Short flight ranges for domestic and woodland species; many miles for many floodwater and salt marsh species
Culiseta	Lay egg rafts	Larvae perpendicular to surface	• Moderately aggressive biters • Some kinds rarely attack humans • Feed in evening hours or in shade during daytime
Mansonia, Coquillettidia	Lay egg rafts on marshes or lakes	After hatching, larvae descend below surface and insert air tubes in stems or roots of aquatic plants	• Take one full year to develop from egg to adult • Adults rarely host seek until after dark • Feed on birds, as well as, mammals • Reach greatest numbers near permanent swamps with abundant vegetation.
Psorophora	Lay eggs on ground	Appear in larval habitat after heavy summer rains and develop to the adult stage much quicker than other transient water species.	• Extremely aggressive human biters. • Some species are predacious as larvae, preying on the larvae of transient water breeders that share habitat. • Predacious species represent the largest mosquitoes in North America.

Source: American Mosquito Control Association

2.5. Blood Feeding and Gonotrophic Development

Mosquitoes are blood-sucking Diptera and often exhibit some degree of synchrony between blood feeding and egg laying, a phenomenon known as “gonotrophic concordance”. Egg production in the female does not take place automatically, as in most insects. Insects that exhibit gonotrophic concordance need blood to trigger their egg follicles to break from a resting stage. One or more blood meals may be required for each batch of eggs produced during their lifetime. Insects that exhibit gonotrophic concordance partition their reserves. Energy for routine daily activities is derived from carbohydrates. Males and females, alike, obtain energy by feeding on sugars contained in plant juices. Carbohydrates from nectar provide energy as food. Female mosquitoes can survive without blood, but only a few kinds are able to reproduce without a blood meal. The protein from a blood meal is usually a prerequisite for egg laying. This is the reason that only female mosquitoes bite. Male mosquitoes do not produce eggs and, therefore, are incapable of biting. Female insects with gonotrophic concordance have alimentary canals that separate carbohydrate meals from blood. Nectar meals are diverted into pouches on the foregut called "diverticulae". Nectar is introduced into the midgut in doses as needed. Blood goes directly into the midgut. The acquisition of blood stimulates the follicles in the ovaries to develop.

Newly emerged female mosquitoes have the follicles of their ovaries in a resting condition. When blood enters the midgut, messenger hormones signal the ovaries to break from the resting state. Egg development proceeds rapidly and gravid mosquitoes oviposit within a matter of days. Each batch of eggs, however, usually requires one or more blood meals. Nectar feeding takes place on a daily basis for most species to maintain the energy required to survive. Mosquitoes may feed on blood more than once during their lifespan. In general, a mosquito must feed on blood at least twice to transmit an infectious agent (once to acquire the agent, and a second time to transmit that agent).

Mosquitoes of several species have eliminated the need for blood by acquiring enough protein during larval development so that the resulting adult female may produce eggs without the need for a blood meal. Species that have that capability are referred to as "autogenous," a trait that is desirable from an anthrocentric point of view. Autogeny is the ability to lay fertile eggs without blood in a species where blood is normally required. *Wyeomyia smithii*, the pitcher plant mosquito, is an autogenous species on Long Island. The larvae of this scientific curiosity are found only in water that has accumulated within the leaves of the predacious pitcher plant, *Sarracenia purpueia* (Smith, 1904, Mahmood and Crans, 1999). The pitcher plant obtains nutrients by dissolving spiders and insects that drown in the fluid where *Wy. smithii* larvae live. These mosquito larvae obtain sufficient protein to lay fertile eggs by feeding on the carcasses decomposed by the plant. Mosquitoes of the genus *Toxorhynchites* are autogenous, including the Long Island species, *Tx. r. septentrionalis*. This mosquito is predacious in the larval stage and obtains protein by feeding on mosquito larvae, and other small arthropods, that occur in small container habitats where the female *Toxorhynchites* oviposit. *Ochlerotatus atropalpus* is a container breeding Aedine on Long Island that appears to have autogenous strains. Specimens occasionally seek hosts in the wild but are usually capable of producing eggs without blood when brought into the laboratory. In all probability, autogenous and anautogenous (blood-feeding) strains are present in nature, and selection for autogeny is favored by artificial conditions. Mosquito control agencies must have staff who can identify mosquitoes to species both in the larval and adult stage to assure that time, money, and effort are not wasted on the control of autogenous species that pose little human pest or health threat.

2.6. Host Preference

Mosquitoes of each species tend to favor one group of hosts over another as the preferred source for a blood meal. Broad categories of host preference include mammalian feeders, avian feeders, and herptilian (cold blooded animal) feeders. A few odd kinds of mosquitoes feed on certain types of fish (such as mudskippers) when they are partially above water. Blood meal preference studies clearly show that mosquitoes can be classified as fixed feeders (those that feed exclusively on one class of host) and indiscriminant feeders (those that may prefer one class of animal, but are willing to feed on a less desirable host). The cedar swamp mosquito, *Culiseta melanura,* is morphologically and behaviorally adapted to feed mainly on birds. This mosquito has a long, down curved proboscis that allows the female to penetrate through feathers. The mosquito also host seeks high in the canopy, after dark, where sleeping birds are most likely to occur. The frog feeding mosquito, *Culex territans,* is a herptilian feeder that obtains most of its blood meals from amphibian hosts. The mosquito breeds in freshwater swamps where frogs are common and emerges from hibernation earlier than most mosquito species to take advantage of the large populations of frogs that breed early in the year. *Ochlerotatus canadensis* is an example of an indiscriminant feeder. This mosquito is a serious pest to people, frequently feeds on birds, and is often seen feeding on turtles. Mosquitoes that have broad host preference may serve as sporadic vectors of zoonotic pathogens that develop in wildlife but are occasionally transmitted to humans. Eastern equine encephalitis (EEE) and West Nile virus (WNV) are examples of zoonotic pathogens that are occasionally transmitted to people and horses by indiscriminant vectors. Knowledge of the blood feeding habits of the mosquito can be helpful in prioritizing interventions against those kinds of mosquitoes that pose greatest risk as vectors. Such information may also be applied to avoid unnecessary treatment of non-target scientific curiosities, such as the frog feeder, *Culex territans.*

2.7. Overwintering

Mosquitoes that live in temperate areas require a strategy to survive the winter. Insects are cold-blooded animals and most kinds are particularly burdened during periods of cold weather. The mosquitoes found on Long Island overwinter either in the egg, larval or adult stage, depending on species. Mosquitoes are not known to overwinter as pupae, the shortest stage in the life cycle of the Culicidae. Mosquito genera with desiccation tolerant eggs pass the winter in the egg stage. Eggs of single generation (univoltine = one generation per year) aedines enter diapause as soon as they are laid in June, and pass the summer months in low-lying ground depressions that are dry for most of the summer. Inundation by summer rains does not break diapause in eggs deposited that same season. The eggs do not hatch even though they are covered with water suitable for larval development. Cold weather breaks diapause in the embryo within the egg. Larvae hatch when the eggs are again inundated with water, and if water temperatures are above freezing in the spring. The larvae begin to develop in very cold water shortly after the ice melts. The adults are on the wing by early May and lay eggs that enter diapause.

Multiple generation aedines lay their eggs in transient water habitats that may become dry shortly after they are laid. The embryo within a desiccation tolerant egg may not enter diapause, as long as ambient temperatures remain favorable for development. Such eggs may hatch with the next complete inundation and the mosquitoes may complete multiple generations as a function of the frequency of summer floodings. The eggs more likely enter diapause with the onset of cold weather, and these do not hatch until water temperatures rise once again the following year.

Mosquitoes of relatively few species overwinter in the larval stage. Larvae of some swamp inhabiting species burrow into the mud of their habitat and pass the winter in a state of torpor, much like frogs. Similarly, larvae of some container breeding species may overwinter inside their container habitats. Water within certain natural habitats, such as treeholes and plant axels, may contain sufficient flocculent material to depress the freezing point, and consequently, protect overwintering larvae in these sites. Container breeding species that attempt to overwinter in artificial containers often freeze solid and die. The cattail mosquito *Coquillettidia perturbans* is a serious pest on Long island that overwinters in the larval stage. Larvae of this unusual species attach to the roots of aquatic plants and obtain oxygen directly from root vacuoles. The larvae enter a period of torpor during the winter months, but remain attached to the plant roots. Larval development resumes when water temperature rises to a permissive level, allowing larvae to pupate and emerge as adults the following spring. The pitcher plant mosquito, *Wy. smithii,* freezes solid in a block of ice inside the water holding pitcher of the plant. Specimens can be collected in a block of ice during the winter and quickly thawed out at room temperature. The little larvae recover completely and begin swimming as soon as the ice melts.

In general, mosquitoes in Suffolk County belonging to the genera *Anopheles*, *Culex*, and *Uranotaenia*, as well as certain species of *Culiseta*, overwinter as mated females. Diapause is apparently triggered in late season larvae and the adults that emerge in the fall mate, feed on nectar sources to build up body fat, and enter hibernaculae without feeding on blood. Winter is spent in a state of torpor in protected sites such as basements, out buildings, and natural resting sites (such as caves). Females that survive the winter, emerge in the spring, seek hosts, and lay eggs that produce the first generation for the new year.

3. Mosquito Ecology

Mosquitoes may be categorized into two broad groups based on their larval habitats. Transient water species have desiccation tolerant eggs and have a life cycle that requires alternate flooding and drying. Each generation is separated by a period of dormancy that can extend for weeks, months or, during extreme conditions, for years. These species appear in fairly synchronous broods after a flooding event and are broadly grouped as "Floodwater Mosquitoes." Mosquitoes with desiccation intolerant eggs survive solely in habitats that remain moist or wet. As a result, egg laying is continuous and emergence is never synchronous because the generations overlap throughout the summer months. Mosquitoes with this life cycle strategy are broadly grouped as "Permanent Water Mosquitoes."

Floodwater mosquito species lay their eggs in a wide variety of transient water habitats that may be flooded either by either rain or by high tides. Permanent water mosquitoes lay their eggs in bogs, swamps and marshes where water levels remain constant enough to assure that the eggs will remain moist. Both groups of mosquitoes have representatives that lay their eggs in containers. The floodwater species glue their eggs to surfaces inside containers and rely on rising water levels for inundation and egg hatch. The permanent water species oviposit directly on water that is trapped in the container. A limited number of representatives from both groups possess salt tolerance and can breed in saline habitats. Pollution tolerance is rare in transient water breeders, but is relatively common in the permanent water-breeding group.

Differences in overwintering mechanisms, larval habitats, and number of generations each year produce considerable variation within mosquito species that fall into the major floodwater and permanent water subdivisions. Pioneers in the ecological aspects of mosquito biology include Bates (1949), Pratt (1959), and Horsfall (1955). Their work divided mosquitoes into habitat groupings on a worldwide basis as a guide for management and control. The work has considerable scientific merit but is too broad to be useful for a Suffolk County management plan. Crans (in press [b]) recently published a system to classify the mosquitoes of the northeastern United States into ecological groupings. The information is detailed enough to be directly applicable to the Suffolk County Vector Control and Wetlands Management Long Term Plan.

Table 3-1 lists ecological groupings found in the northeast, together with basic life cycle characteristics of representative mosquito species.

Table 3-1 - Primary Ecological Groupings of Mosquitoes found in the Northeast

	FLOODWATER MOSQUITOES		PERMANENT WATER MOSQUITOES
	Univoltine Aedine Life Cycle	Multivoltine Aedine Life Cycle	Culex/Anopheles Life Cycle
Representative Habitats	Woodland Pools Freshwater Swamps Roadside Ditches	Fresh Floodwater Salt Marsh Floodwater Containers	Freshwater Swamps Brackish Water Swamps Standing Polluted Water Containers
Number of Generations	One per Year	Rain/Tide Dependent	Continuous
Overwintering Mechanism	Egg Stage	Egg Stage	Mated Female
Seasonal Distribution	April – May	June – October	May - October

3.1. Univoltine Aedine Life Cycle

Mosquitoes with the univoltine aedine life cycle have a life cycle strategy designed for survival in higher latitude areas of the world. Species that belong to this group have desiccation tolerant eggs that hatch very early in the spring. A single generation of larvae develop in cold water habitats during April or very early May. The water table is fairly high at this time of year, assuring maximum egg hatch. Adults from this group usually emerge just as leaves begin to appear on the trees. Trees that are leafing out draw heavily on available water causing the larval habitats to dry down. Oviposition takes place around the perimeter of the drying larval source. The eggs from this group enter diapause and pass the summer months in habitat that tends to remain dry. Should the habitat re-flood during the summer, the eggs tend to remain in diapause. Genetic defenses for survival in these cold weather habitats prevent egg hatch even though environmental conditions dictate otherwise.

Most of the species with this life cycle strategy emanate from leaf-lined depressions in wooded areas termed “woodland pools” by mosquito biologists. A few univoltine aedines lay their eggs within stands of aquatic vegetation in permanent water swamps. Univoltine swamp aedines rely on a high spring water table for inundation and egg hatch. Some univoltine aedines develop in roadside ditches, which mimic the woodland pool habitat. The term "vernal pool" has gained popularity with ecologists and is gaining acceptance in the mosquito control community. A true vernal pool is a woodland resource that supports development of diverse kinds of animals with just one generation per year. Vernal pool/woodland pool habitats that produce amphibians in early spring should be noted by mosquito control agencies so that they may leave such sites untreated, or select methods that would avoid impacting tadpoles or other organisms considered to be of particular ecological risk.

Most of the univoltine aedines have a limited flight range in the adult stage. As a result, complaints regarding human biting from this group generally are most frequent close to these habitats. This life cycle type allows a relatively broad window for larval control because low ambient temperatures slow development of the immatures to more than two weeks. Proper surveillance and knowledge of local breeding habitats usually allows time for intervention before pest species emerge.

3.2. Multivoltine Aedine Life Cycle

Mosquitoes with a multivoltine aedine life cycle produce multiple generations during the warmer months of the year. Species that belong to this group lay their eggs in ground depressions that typically flood after heavy summer rains. Larval development is rapid, and must be completed before the pools dry down, or the larvae and pupae will become stranded and die. Females seek hosts shortly after they emerge, then they deposit their eggs on the perimeter of drying pools. Each rain event produces another generation of larvae and another wave of biting females. Monitoring rainfall amounts allows mosquito control agencies to anticipate a major emergence before it actually occurs.

Immatures of a few species in this group are salt tolerant and lay their eggs in depressions on salt marsh habitats. Eggs of multivoltine salt marsh aedines are usually stimulated to hatch by tidal flooding. Lunar high tides are responsible for predictable broods. Daily tides in salt marsh habitats have minimal impact on mosquito populations, because eggs laid in the lowest areas of the salt marsh do not have enough time to complete the required drying between floods, or these may be flushed out to open water where they become inconsequential. Heavy rainfall or winddriven waters that flood the salt marsh may produce a brood on the high marsh between lunar tide cycles.

Several of the multivoltine aedines glue their eggs to the sides of containers and rely on rainfall for flooding. Treeholes and plant axils provide natural habitat for species with this life cycle type. Artificial containers, in particular, discarded tires, provide additional habitat for pest species.

The flight range of multivoltine aedines varies significantly among species. The majority of species in this group may fly long distances to obtain their blood meals. Most are mammalian feeders and function as serious pests. The flight range of fresh floodwater aedines generally ranges from one to two miles. The flight range of salt marsh floodwater species is considerably further and can exceed 10 miles. Crans et al. (1976) suggested that the flight range of salt marsh species is often exaggerated because it is based on maximum values. The majority of salt marsh mosquitoes in this study bit people at locations less than two miles inland. Multivoltine aedines that deposit their eggs in containers tend to have fairly restricted flight ranges. Most container breeding aedines travel less than 100 yards and may cause annoyance mainly to people in close proximity to these sites. Eggs of container breeding aedines, however, can be accidentally transported considerable distances. Eggs of the Asian Tiger mosquito, *Ae. albopictus,* likely arrived in the US in tire casings (destined for retreading) sent from Southeast Asia (Sprenger and Wuithiranyagool, 1986). Once in the US, the species moved northward at a rapid rate with used tires as the probable transport mode (Crans et al., 1996).

The multivoltine aedine life cycle poses a number of problems for intervention and control. Without proper surveillance and prior knowledge of breeding habitats, large numbers of mosquitoes with this life cycle type can emerge and cause numerous complaints because of feeding. Mosquitoes with a multivoltine aedine life cycle must complete their development and emerge as adults within a relatively short period of time to avoid becoming stranded. Major flooding events create significant breeding problems over a very wide geographic area and the window for intervention is exceptionally narrow during the heat of the summer. Many of the biorational pesticides require ingestion by the larvae, which narrow the window even further because late fourth instar larvae and pupae do not feed. Mosquito control programs must have suitably trained experts and resources available to mobilize quickly and to respond effectively. If agencies do not have the time and resources to accurately target the larval stage, adult control will be required over a much larger geographic area.

3.3. Culex/Anopheline Life Cycle

Culex and *Anopheles* mosquitoes tend to overwinter as adult, mated females, rather than eggs or as subadults. Decreasing photoperiod during the fall months initiates the diapause process sometime during the larval stage. The adults emerge, mate, and build body fat by feeding on carbohydrates, rather than blood. Male mosquitoes are incapable of building body fat reserves and die shortly after mating. Females that enter hibernaculae may survive the winter in a state of torpor. They emerge the following spring, find a blood meal host and lay the eggs that produce the first generation of larvae for that season. Breeding is continuous throughout the summer with overlapping generations produced from desiccation intolerant eggs deposited in permanent water habitats.

Larval habitats for this group of mosquitoes vary from pristine to brackish to foul. Anophelines, in general, exploit clean clear water with emergent vegetation. Certain kinds of *Culex,* tolerate organically polluted waters to the extent that they prefer to develop in such environments.

The seasonal dynamics of the *Culex*/*Anopheles* life cycle differs significantly from either of the aedine types. In general, mosquitoes that overwinter as mated females do not become active until nighttime temperatures allow them to host seek in the spring. As a result, the first generation of larvae does not appear until after the univoltine aedines are on the wing. Mosquitoes with this life cycle type build their populations gradually as the summer season progresses. Because the generations tend to overlap, mosquitoes do not emerge in distinct broods.

4. Mosquitoes Indigenous to Long Island

Trapping records from Suffolk County Vector Control currently show that 41 different native mosquito species actively breed in the county (Table 4-1). Thirty of these are recognized as human biters, but many are so uncommon, or infrequently encountered, that it precludes the need to control them for the prevention of disease transmission to humans. Eight of the species on the Suffolk County checklist are regarded merely as scientific curiosities. A single species (*Tx. rutilus septentrionalis*) is a beneficial predator. Nassau County, which neighbors Suffolk County to the west, has a similar checklist (Table 4-2). Two exotic species from Asia should also be considered when discussing Suffolk County mosquitoes. One, *Ochlerotatus japonicus*, was identified in the county in 1988. The other, *Aedes albopictus*, was reported recently in Nassau County and will probably be found in Suffolk County within the next several years.

Suffolk County has analyzed records from trapping for monitoring purposes. The Department of Health Services identified the mosquitoes so collected. Mosquito species that cause biting complaints from the public and/or have the potential to transmit disease in Suffolk County have been identified as the following species:

- *Ochlerotatus sollicitans*
- *Aedes vexans*
- *Culex pipiens*
- *Culex restuans*
- *Culiseta melanura*
- *Ochlerotatus cantator*
- *Ochlerotatus taeniorhynchus*
- *Coquillettidia perturbans*
- *Ochlerotatus trivittatus*

- *Ochlerotatus canadensis*
- *Ochlerotatus triseriatus*
- *Ochlerotatus japonicus*

(D. Ninivaggi, Suffolk County Vector Control, personal communication).

Breeding habitats that produce these species include:

- salt marsh floodwater
- fresh floodwater
- freshwater swamps
- organically polluted standing water
- woodland pool habitat
- natural/artificial containers.

Table 4-3 summarizes biological information for these species.

Table 4-1 – Mosquito Species of Suffolk County Arranged By Genus

Aedes cinereus *Aedes vexans* ***Anopheles barberi*** *Anopheles bradleyi* *Anopheles crucians* *Anopheles punctipennis* *Anopheles quadrimaculatus* *Anopheles walkeri* ***Coquillettidia perturbans***	***Culiseta inornata*** *Culiseta melanura* *Culiseta minnesotae* *Culiseta morsitans* ***Culex pipiens*** *Culex restuans* *Culex salinarius* *Culex territans*	*Ochlerotatus atlanticus* *Ochlerotatus canadensis* *Ochlerotatus cantator* *Ochlerotatus dorsalis* *Ochlerotatus fitchii* *Ochlerotatus grossbecki* *Ochlerotatus hendersoni* *Ochlerotatus japonicus* *Ochlerotatus riparius* *Ochlerotatus sollicitans* *Ochlerotatus sticticus* *Ochlerotatus stimulans* *Ochlerotatus taeniorhynchus* *Ochlerotatus thibaulti* *Ochlerotatus triseriatus* *Ochlerotatus trivittatus*	***Orthopodomyia alba*** *Orthopodomyia signifera* ***Psorophora ciliata*** *Psorophora columbiae* *Psorophora ferox* *Psorophora howardii* ***Toxorhynchites rutilus septentrionalis*** ***Uranotaenia sapphirina*** ***Wyeomyia smithii***

Crans and McNelly (1997) developed a system for the classification of New Jersey mosquito life cycles to better understand the ecology of local species for surveillance and control purposes. Crans (in press [b]) later expanded that system to include the entire northeastern United States, including Suffolk County. The system is designed to encourage habitat recognition together with seasonal distribution and can, therefore, be used to identify potential habitat for species that are rare and seldom encountered. The system is also designed to train biologists and inspectors of mosquito abatement districts to avoid non-pest species and make responsible mosquito control decisions that are based on science.

Crans (in press [b]) divides mosquito life cycles into the Univoltine Aedine, Multivoltine Aedine and *Culex*/*Anopheles* groupings already discussed in this report. Each is then subdivided into life cycle strategies that reflect differences in ecology based on:

1) where the egg is laid,

2) typical larval habitat,

3) number of generations each year, and,

4) stage of the life cycle that overwinters.

In addition to classifications based on differences in these basic ecological determinants, mosquitoes have also been differentiated to recognize unique life-cycle types. Using these designations, the classification system recognizes 11 shared life cycle types for mosquitoes of the Northeastern United States and three that are restricted to a single species. Each of the subdivisions has been named after a common model species to re-enforce habitat recognition for the inspectors that collect the larval stages in the field. A complete list of life cycle types for this classification system is presented in Table 4-3. Mosquito species found in Suffolk County have been added to the list. Primary pest species are underscored in bold type and non-pest/scientific curiosities are enclosed in parentheses.

4.1. Univoltine Aedine Mosquitoes in Suffolk County

The Univoltine Aedine life cycle type has three variations in Suffolk County:

- univoltine mosquito species that utilize woodland pool habitats;
- univoltine species found in swamps and bogs; and,
- generalist univoltine mosquitoes that may appear more than once during a single breeding season.

The model species include *Oc. stimulans, Oc. abserratus* and *Oc. canadensis*[1] respectively. Each of the model species is indigenous to Suffolk County.

4.1.1. *Ochlerotatus stimulans* Type

The *Ochlerotatus stimulans* Type is characterized by:

- Desiccation tolerant eggs laid in ground depressions in wooded areas
- Larvae that develop in woodland pool/snow pool habitats
- A single generation in early spring
- Overwintering eggs

Ochlerotatus stimulans is the northeastern model species for single generation mosquito species that Pratt (1959) referred to as "Northern *Aedes.*" The larvae are found in a variety of leaf-lined vernal pools in wooded areas that are flooded by a combination of spring rains and snow melt. A lack of aquatic vegetation and a thick layer of leaf litter characterize typical larval habitats. The water is usually quite clear when the eggs first hatch, but tannins from decomposing leaves progressively darken the habitat water as the larvae pass from first to fourth instar. The larvae of species that belong to this life cycle type must complete their development before the

[1] The univoltine status of *Oc. canadensis* has not been accepted by all medical entomologists. Data collected on this species can be interpreted as showing it is both uni- and multi-voltine. There are few practical consequences to this dispute.

surrounding trees break dormancy. Trees that will later shade the habitat draw heavily on ground water as they leaf out, causing rapid dry down of this transient aquatic habitat. During years when the water table is low, trapped larvae often become condensed in the leaf litter in the deepest sections of individual pools. Adult females of this life cycle type deposit their eggs in the band of moist leaves as the pools dry down. As the season progresses, the pools dry completely and become depressions in the forest floor. Like all univoltine aedines, larvae within the eggs enter diapause and do not hatch until the following spring.

Three univoltine aedines share this life cycle type in Suffolk County:

- *Oc. stimulans*
- *Oc. excrucians*
- *Oc. intrudens* (Table 4-2)

Although all are described as vicious human biters, none occur in high enough numbers to warrant routine control. Therefore, management of this life cycle type should be conducted only if complaints and follow-up surveillance document a problem.

4.1.2. *Ochlerotatus abserratus* Type

The *Ochlerotatus abserratus* Type is characterized by:

- Desiccation tolerant eggs laid above the water line in saturated soil habitats
- Larvae that develop in swamps and bogs
- A single generation in early spring
- Overwintering eggs

Ochlerotatus abserratus is the northeastern model species for a group of univoltine mosquito species that are found in permanent rather than transient early spring habitats. Although most of the members are aedines, the life cycle type is shared by *Culiseta* species (subgenus *Culicella*) that have winter hardy eggs. The larvae of mosquito species that utilize this life cycle type can be collected from a variety of bog habitats in early spring. Many of the species are adapted to specific swamp habitats such as red maple, cattail, or sphagnum swamps. Only rarely do members with this life cycle strategy share habitat with any of the members of the *Oc. stimulans* type. Many of the mosquitoes in this group deposit their eggs within clumps of aquatic vegetation and rely on the high spring water table for inundation and egg hatch. The larvae become sparsely distributed in heavily vegetated areas of the swamp and are only infrequently collected close to the shoreline. The univoltine mosquitoes in this group appear somewhat later in the season than members of the *Oc. stimulans* life cycle type.

Five species share this life cycle type in Suffolk County:

- *Oc. abserratus*
- *Oc. aurifer*
- *Oc. fitchii*
- *Cs. minnesotae*
- *Cs. morsitans* (Table 4-2)

Trap records suggest that *Oc. abserratus* may occur at high enough levels in some years to cause biting complaints. Overall, however, the mosquitoes that demonstrate this life cycle type in Suffolk County rarely occur in high enough numbers to warrant control.

4.1.3. *Ochlerotatus canadensis* Type

The *Ochlerotatus canadensis* Type is characterized by:

- Desiccation tolerant eggs laid in a variety of transient and permanent water situations
- Larvae that develop in a wide variety of freshwater habitats

- A major generation in early spring followed by sporadic egg hatches later in the season[2]

- Eggs that overwinter

Oc. canadensis is the northeastern model species for a small group of mosquitoes that are listed as single generation but often appear more than once during a single breeding season. Larvae that hatch in early spring make up the bulk of the population, but one or more overlapping cohorts often follow during the spring months. In some years, the species that utilize this life cycle type reappear in numbers if heavy rains re-flood the habitat in late summer and early fall. Matheson (1944) attributed the sporadic hatch to a single generation of overwintering eggs that required more than one flooding.

Three species share this life cycle type in Suffolk County:

- *Oc. canadensis*

- *Ae. cinereus*

- *Oc. sticticus* (Table 4-2).

The model species, *Oc. canadensis,* is among Suffolk County's species of concern and utilizes a wide range of early spring habitats. The mosquito is an indiscriminate feeder (Crans, 1965), increasing its likelihood as a disease vector (albeit only as an occasional bridge vector). This species often bites enough for residents to register complaints. Early spring biting populations do not pose a health threat because they occur too early to make contact with either EEE or WNV, which do not seem to cycle in avian populations until later in the summer (Crans et al., 1997). Late season populations, however, have the ability to function as bridge vectors and should be closely monitored and controlled in Suffolk County.

Oc. sticticus is a severe biter that reaches highest numbers on the floodplains of major river systems. The species is not a major cause of biting complaints on Long Island because of the

[2] This is the behavior that causes the dispute regarding the uni- or multi-voltine status of the species.

lack of suitable breeding habitat. Trap records point toward *Ae. cinereus* as a minor pest in Suffolk County.

4.2. Multivoltine Aedine Life Cycle Types in Suffolk County

The multivoltine aedine life cycle type has three variations in Suffolk County:

- multivoltine aedines that utilize fresh floodwater habitats
- multivoltine aedines with a high degree of salt tolerance
- multivoltine aedines that breed in container habitats.

The northeastern model species include *Ae. vexans*, *Oc. sollicitans* and *Oc. triseriatus*, respectively. All cause biting complaints from the public and are potential disease vectors on Long Island.

4.2.1. *Aedes vexans* Type

The *Aedes vexans* Type is characterized by:

- Desiccation tolerant eggs laid in ground depressions inundated by fresh floodwater
- Larvae that develop in a wide range of transient freshwater habitats
- Multiple generations each year
- Eggs that overwinter

Aedes vexans is the northeastern model species for a group that includes multivoltine mosquitoes in the genera *Aedes, Ochlerotatus* and *Psorophora.* The members of this group rely on summer rains to flood eggs that are deposited in low lying ground depressions, but rainstorms at other times of the year can also stimulate the emergence of broods. This behavior is why they are commonly referred to as floodwater mosquitoes (Horsfall et al., 1973). Flood plains where rivers overflow their banks in most parts of the country generate the highest populations, but significant numbers can be produced from virtually any area where fresh groundwater accumulates on an intermittent basis. The entire group undergoes accelerated larval development and can pupate 4 to 5 days after egg hatch when ambient temperatures are favorable. Some species in this group (*Oc. trivittatus* and *Ps. ferox*) prefer shaded larval habitats and emanate from the same woodland pools that produced univoltine aedines in early spring (Means, 1979). Most members in the group, however, deposit eggs in ground depressions exposed to direct sunlight and rely on high daytime temperatures to accelerate completion of their larval development before the habitat dries down.

Six species from three genera with this life cycle type are found in Suffolk County and most function as major pests (Table 4-2). *Ps. ciliata* and *Ps. howardi* are large mosquitoes that are predacious in the larval stage, but require a blood meal once they become adults. *Ae. vexans, Oc. trivittatus, Ps. columbiae,* and *Ps. ferox* are vicious human biters that require control because of the numbers normally produced, and the subsequent complaints they generate (Pratt and Moore, 1993). These mosquitoes have been repeatedly implicated as vectors of both EEE and WNV. Mosquitoes with an *Ae. vexans* life cycle are among Suffolk County's worst pests. Therefore, considerable resources should be directed to minimizing their impact on residents.

4.2.2. *Ochlerotatus sollicitans* Type

The *Ochlerotatus sollicitans* Type is characterized by:

- Desiccation tolerant eggs that are laid on a substrate periodically flooded by lunar tides
- Larvae that develop in salt marsh pools
- Multiple generations each year
- Eggs that overwinter

Ochlerotatus sollicitans is the northeastern model species for a group of floodwater mosquitoes with a high degree of salt tolerance. Multivoltinism combined with salt tolerance allows these mosquitoes to utilize vast expanses of salt marsh wetlands as larval habitat that is unsuitable to other floodwater species. Eggs are normally deposited in ground depressions on marshland that is high enough to exclude daily tide cycles. Marshes that support large stands of *Spartina patens* produce the largest populations because that grass is limited to the highest areas of the salt marsh. The positioning on high marsh allows eggs to be flooded by lunar tides producing broods at roughly two week intervals during the summer months. Additional broods can be triggered by storm tides or heavy summer rains, provided enough time has elapsed after oviposition for embryonation and formation of the serosal cuticle (Harwood and Horsfall, 1959).

Four species with this life cycle type are found in Suffolk County (Table 4-2). *Oc. cantator* is an early season species found as larvae in greatest numbers on the upland edges of the salt marsh in April and May. *Oc. sollicitans* is regarded as Suffolk County's number one pest species and has long been known to migrate great distances inland to find a blood meal host (Smith, 1904). *Oc. taeniorhynchus* also moves off the marsh in large enough numbers to elicit biting complaints well inland (Provost, 1952). *Oc. dorsalis* is a western species that shares salt marsh habitat on Long Island, but is much too rare to function as serious pest.

Mosquitoes that exhibit the *Oc. sollicitans* life cycle type are Suffolk County's worst pests. They repeatedly occur in large enough numbers to warrant control due to people being repeatedly bitten. Their migratory behavior allows them to impact citizens well inland (Crans et al., 1976).

The members of this group also function as vectors of EEE. Crans (1977) implicated *Oc. solicitans* (in particular) as a vector of EEE on epidemiological grounds following the 1959 outbreak of EEE in New Jersey. Later studies (Crans et al., 1986) documented vector status of this species in the northeast, with virus isolations during an epizootic of EEE in southern New Jersey. WNV has also been isolated in *Oc. sollicitans* in New Jersey (W. Crans, Rutgers University, personal communication, 2004) and in Nassau County on Long Island, within flight range of Suffolk County (G. Terrillion, Nassau County Department of Public Works, personal communication, 2003).

Currently, the professional vector control community is generally of the mind that *Oc. sollicitans* is capable of transmitting WNV to humans. This is because the virus has been isolated in the species, and the mosquito has proven with EEE that it is a capable transmitter of arboviruses to humans. WNV has occurred in areas where the dominant mosquito is *Oc. sollicitans*, but also in areas where *Oc. sollicitans* is absent. It is, thus, clear that this species cannot be the sole vector of WNV. Its exact role as a vector is difficult to isolate, as *Culex spp*. are often found in conjunction with it, and WNV is commonly isolated from *Culex spp.* (Andreadis et al., 2001).

That this mosquito has been shown to be a vector elsewhere indicates that it can similarly transmit disease to humans in Suffolk County, especially considering that the circumstances that result in vector status in New Jersey (Koch's postulates) for EEE are also met on Long Island. That viruses have not been isolated from trapped *Oc. sollicitans* in Suffolk County is not sufficient evidence to eliminate them as vector species for Suffolk County. The number of mosquitoes tested is not a large enough sample to exclude a species as a vector if no viral isolations are made; conversely, potential vector status is shown by a single virus detection. The mobility of most humans infected by arboviruses means that the location they were infected can only be inferred, and so the species of mosquitoes present at the infection site is similarly uncertain. This means that a finding that *Oc. sollicitans* in Suffolk County is not a disease vector is hard to support merely because it has not been definitively shown that the species has transmitted a human disease. Paradoxically, it may be the current level of effort made to control this mosquito species has diminished its ability to transmit disease; its role as a disease vector in the absence of control efforts might be of much greater concern.

Therefore, a rationale is clear to expend considerable resources to target this group of salt marsh mosquitoes, both to alleviate human discomfort and to address potential disease transmission. Larval control can be more effective, and can minimize the requirements for adulticide applications. Water management is used as an acceptable alternative to chemical methods to manage this important group of mosquitoes in most areas of the country (CDC, 1993).

4.2.3. *Ochlerotatus triseriatus* Type

The *Ochlerotatus triseriatus* Type is characterized by:

- Desiccation tolerant eggs laid above the water line in container habitats
- Larvae that develop in a wide range of natural and artificial containers

- Multiple generations each year
- Eggs that overwinter

Ochlerotatus triseriatus is the northeastern model species for a group of floodwater mosquitoes that develop in container habitats. The species within this group deposit their eggs in bands just above the waterline in containers that regularly receive rainwater. Evaporation provides additional oviposition substrate, while rainfall raises the water level stimulating egg hatch. Treeholes, plant axils and rock pools are natural container habitats utilized by members of this group. Discarded tires and a wide array of artificial containers provide additional habitat if the containers hold enough decomposing plant material to mimic natural sites (Means, 1979).

Four species with this life cycle type occur in Suffolk County:

- *Oc. triseriatus*
- *Oc. atropalpus*
- *Oc. japonicus* (Table 4-2)

Ochlerotatus triseriatus, the model species, can be a serious pest to the homeowner, but reaches greatest numbers where discarded tire piles provide abundant breeding habitat. *Aedes albopictus* has not yet appeared in Suffolk County, but the species does occur on Long Island (G. Terrillion, Nassau County Department of Public Works, personal communication, 2003). The species may have been introduced to the United States by the practice of importing used tires for re-treading purposes (Eads, 1972; Sprenger and Wuithiranyagool, 1986). The first record for *Oc. japonicus* in the USA came from specimens collected in Suffolk County (Peyton et al., 1999). All of the members with this life cycle type are day biters and do not enter light traps. As a result, surveillance for this important group is based on bite counts and complaints.

Oc. triseriatus is the most important member of the group in Suffolk County and is recognized as one of the county's most important mosquito pests. The mosquito's reluctance to enter light traps makes adult surveillance difficult and the restricted larval habitat impedes larval surveillance by routine inspections for lack of staff to address the large effort. Tire piles produce the largest populations and should be eliminated whenever possible. Routine used tire collections form a large portion of many mosquito control programs. Most of the complaints regarding bites created by this mosquito are probably related to the artificial container habitats in the residential areas of Suffolk County. Because of the uniqueness of this species' biology, *Oc. triseriatus* poses a challenge to mosquito control agencies in any area where the species is numerous. Similarly, these shared characteristics are making control of the invasive species *Oc. japonicus* a growing problem in Suffolk County.

4.3. Multivoltine Culex and Anopheles in Suffolk County

There are three variations on the *Culex/Anopheles* Life Cycle Type in Suffolk County:

- continuous breeders that utilize pristine freshwater swamp habitats;
- continuous breeders that utilize brackish water habitats; and,
- continuous breeders that thrive in polluted water habitats.

The model species include *An. quadrimaculatus*, *Cx. salinarius* and *Cx. pipiens*, respectively. All occur in Suffolk County and have the ability to function as pests.

4.3.1. *Anopheles quadrimaculatus* Type

The *Anopheles quadrimaculatus* Type is characterized by:

- Non-desiccation tolerant eggs laid directly on water in pristine freshwater habitats
- Larvae that develop in freshwater swamps and bogs
- Multiple generations each year
- Overwintering mated females

Anopheles quadrimaculatus is the northeastern model species for a group of mosquitoes that hibernate as mated females and deposit non-desiccation tolerant eggs in freshwater swamps and bogs. The members of this life cycle type typically replace the bog breeding univoltine aedines in the *Oc. abserratus* life cycle type as the season advances. Typical breeding habitat supports abundant aquatic vegetation at that time of year. Larvae from this group do not appear until nighttime temperatures allow the hibernating adults to exit hibernaculae, seek hosts and oviposit. Larval populations are typically sparse in late spring, build progressively during the summer and do not peak until mid-summer or early fall.

Three species with this life cycle type are found in Suffolk County:

- *An. quadrimaculatus*
- *Cx. territans*
- *Ur. sapphirinna* (Table 4-2)

The model species does not occur in high enough numbers to warrant management. The other two are scientific curiosities that need not be controlled.

4.3.2. Culex salinarius Type

The *Culex salinarius* Type is characterized by:

- Non-desiccation tolerant eggs that are laid directly on water in brackish water habitats
- Larvae that reach greatest numbers in brackish water swamps
- Multiple generations each year
- Overwintering mated females

Culex salinarius is the northeastern model species for multivoltine *Culex/ Anopheles* that exhibit salt tolerance. This life cycle type is the non-aedine counterpart of the *Oc. sollicitans* life cycle type. The eggs, however, are deposited directly on standing water, rather than on moist mud in habitats that are flooded by lunar tides. Although they are often called salt marsh mosquitoes, these mosquitoes do not breed directly on tidal marshes (Dyar and Knab, 1906). Most of these mosquitoes reach greatest abundance in areas adjacent to salt marshes, where fresh water from the upland drains onto coastal habitats producing a brackish water environment. Members of this group are capable of breeding in freshwater habitats, but reach greatest concentrations in areas close to the coast. Slaff and Crans (1982) showed that freshwater impoundments were a major producer of *Cx. salinarius* in coastal areas of New Jersey. Murphey and Burbutis (1964) showed that members of this group were highly attracted to chemical volatiles from infusions created by salt marsh vegetation die off when marshland is flooded with fresh water. *Culex salinarius* is the primary mosquito species in Suffolk County with this life cycle type. *Anopheles crucians*, the other species on Long Island with this life cycle type, is present in Suffolk County but occurs in low numbers.

Culex salinarius is a serious pest and potential disease vector in much of the northeast but lack of suitable habitat reduces its pest status in Suffolk County. Considerable salt marsh habitat is available in the county but the brackish water impoundments that this species prefers are less common and appear to be limiting population abundance. WNV has been isolated from *Cx. salinarius* with some frequency in the northeast (Andreadis et al., 2001) and the species is thought to be the primary bridge vector to humans in New York City (J. Miller, New York City Department of Health, personal communication, 2003). Although *Cx. salinarius* is not regarded as one of the top problem mosquitoes in Suffolk County, it should be closely monitored and controlled as a potential disease vector.

4.3.3. *Culex pipiens* Type

The *Culex pipiens* Type is characterized by:

- Non-desiccation tolerant eggs laid directly on water with high organic content
- Larvae that thrive in polluted water habitats
- Multiple generations each year
- Overwintering mated females

Culex pipiens is the northeastern model for a group of multivoltine *Culex/Anopheles* with pollution tolerance. Typical breeding habitat requires water with high organic content. Rotting vegetation, decaying animal wastes and septic seepage are highly attractive to the mosquitoes included in this group. Catch basins, sewage treatment plants, and landfills provide typical habitats. Members that utilize this life cycle type will also lay their eggs in artificial containers that hold putrid water. The gravid trap developed by Reiter (1983) relies on fermented infusions as an attractant specifically for the members of this group. These are the mosquitoes that breed in untended birdbaths, untended swimming pools, and clogged rain gutters. Decreasing photo period initiates ovarian diapause, and nectar feeding produces body fat in females that enter overwintering hibernaculae (Spielman and Wong, 1973). Four species with this life cycle type are found in Suffolk County:

- *Cx. pipiens*
- *Cx. restuans*
- *Cs. inornata*
- *An. punctipennis* (Table 4-2)

Cx. pipiens and *Cx. restuans* are very common throughout the county and function as the primary amplification vectors of WNV (Nasci et al., 2001; Andreadis et al., 2001; Fonseca et al., 2004; WildPro, 2004). These two species are often grouped with *Cx. salinarius* as the "*Culex* complex" because of problems associated with accurate species identification in field-collected specimens. The entire *Culex* group contains cryptic species, subspecies and/or varieties that require further investigation. Crabtree (1997) is one of many researchers using polymerase chain reaction (PCR) technology to separate genomic differences within the complex. Fonseca et al. (2004) provides a controversial explanation for vector involvement in the WNV cycle based on hybridization within the *Cx. pipiens* complex. Although not widely accepted by the scientific community, the hypothesis underscores how little is actually known about this group of domestic mosquitoes.

The *Culex* complex assumes tremendous importance because of its role in maintaining and transmitting WNV. Although mosquito control agencies try to target the complex, homeowner intervention is needed to get the job done properly. Homeowners can inspect their own properties much more efficiently and must become involved for a complete management program. Public education can be very useful to alert homeowners in this regard. Educational materials regarding this life cycle type should be a priority issue in the final Suffolk County Management Plan. The entire group must remain a primary target for mosquito control efforts because of the overwhelming evidence for disease involvement.

4.4. Unique Life Cycle Types in Suffolk County

4.4.1. *Culiseta melanura* Type

The *Culiseta melanura* Type is characterized by:

- Non-desiccation tolerant eggs laid directly on water
- Larvae that develop in swamps and bogs
- Multiple generations each year
- Overwintering larvae in typical freshwater swamp habitats

Culiseta melanura is the model species for multivoltine freshwater swamp breeders that overwinter in the larval stage. The larvae in this life cycle type become quiescent during the winter months and burrow into bottom sediment to survive periods of cold weather. Fourth instar larvae generally predominate, but earlier instars frequently make up a portion of the overwintering population (Burbutis and Lake, 1956). Frohne and Hart (1949) described this same overwintering mechanism for *An. crucians* in the southern United States.

Cs. melanura functions as the primary amplification vector of EEE in Suffolk County. The species has also been implicated as an amplification vector of WNV (Andreadis et al., 2001). Host preference tests have shown that *Cs. melanura* is a fixed bird feeder with behavioral adaptations to host seek and feed on birds, although others suggest a different behavior (Nasci et al., 2001). Enzootic vector status in the northeast has been fully documented for this species and its role in creating epizootics in nature is well known (Crans et al., 1994; Mahmood and Crans, 1998). Even though the species does not bite humans (or, at least, does so only rarely), *Cs.*

melanura should be closely monitored throughout the season for the purpose of documenting vector status and minimizing the chances of disease transmission.

4.4.2. *Orthopodomyia signifera* Type

The *Orthopodomyia signifera* Type is characterized by:

- Non-desiccation tolerant eggs laid on water in container habitats
- Larvae that develop in natural and artificial containers
- Multiple generations each year
- Overwintering larval stage

Orthopodomyia signifera is the northeastern model species for multivoltine container breeders that overwinter in the larval stage. The eggs are deposited directly on the water's surface (Horsfall, 1955). Breeding is continuous during the summer months. Lake (1954) showed that the larvae burrow into the bottom sediment during the winter and pupate the following spring. The life cycle type appears to be adapted for treehole habitats where the flocculent bottom sediment provides protection from freezing. Specimens that attempt to overwinter in artificial containers usually freeze solid and suffer extensive winter mortality. Four species from three genera share this life cycle type in Suffolk County (Table 4-2). All are biological curiosities that need not be controlled.

4.5. Monotypic Life Cycle Types

Suffolk County has three mosquito species (*Coquillettidia perturbans*, *Anopheles walkeri,* and *Wyeomyia smithii*) with biological characteristics that make them the only representatives of a distinctive life cycle type.

4.5.1. *Coquillettidia perturbans* Type

The *Coquillettidia perturbans* Type is characterized by:

- Non-desiccation tolerant eggs laid directly on water

- Larvae that attach to the roots of aquatic vegetation in freshwater swamps
- One extended generation each year
- Overwintering larval stage

Coquillettidia perturbans is a mosquito with larvae and pupae that possess a unique respiratory apparatus that enable them to extract oxygen directly from the roots of submerged aquatic plants (Bosak and Crans, 2002). This species lays its eggs in rafts (Hagmann, 1953) that are somewhat similar in structure to those of *Culex*, *Culiseta,* and *Uranotaenia*. Overwintering takes place in the larval stage in any instar trapped by the onset of winter. The life cycle is unique because they take one full year to complete a single generation in the northeastern US. Adult emergence appears to occur in broods over the course of the summer but actually represents cohorts of larvae that passed the winter in different instars. The adults move from their freshwater swamp-breeding habitat to woodland areas in quest of a blood meal (Bosak et al., 2001). The first cohort emerges in early July and is often the primary cohort in terms of potential to elicit complaints from biting. Cohorts that emerge later in the season frequently make contact with EEE and WNV and have the ability to function as disease vectors.

Cq. perturbans was suspected as a vector of EEE for many years before vector status could be documented with virus isolations. Studies conducted after an epizootic in horses in New Jersey (Crans and Schulze, 1986; Crans et al., 1986) clearly showed the importance of this species as a disease vector and the need to monitor its abundance as both larva and adult. *Cq. perturbans* is a serious pest and significant potential vector of disease in Suffolk County. Specialized surveillance and control is needed because of the unique life cycle.

4.5.2. *Anopheles walkeri* Type

The *Anopeles walkeri* Type is characterized by:

- Non-desiccation tolerant eggs laid directly on water
- Larvae that develop in freshwater swamp habitats

- Multiple generations each year

- Overwintering in the egg stage

Anopheles walkeri is a multivoltine anopheline that over winters in the egg stage. Hurlbut (1938) showed that the species possessed a winter hardy egg that differed from summer eggs by having enlarged floats that nearly cover the dorsal surface of the exochorion. Overwintering in the egg stage extends the seasonal cycle of this species by allowing it to pass through one full larval generation before ambient temperatures allow hibernating females of other anophelines to become active. The first generation shares freshwater swamp habitat with bog breeding univoltine aedines when early spring vegetation is still sparse. Because *An. walkeri* is multivoltine, it remains after the swamp becomes weed choked and shares habitat with members of the *An. quadrimaculatus* life cycle type. Although the adults bite readily, trap records suggest that the species is a minor pest in Suffolk County.

4.5.3. *Wyeomyia smithii* Type

The *Wyeomyia smithii* Type is characterized by:

- Non-desiccation tolerant eggs deposited in pitcher plants

- Larvae that develop only in leaves of the pitcher plant, *Sarracenia purpurea*

- Multiple generations each year

- Overwintering larval stage

Wyeomyia smithii is an interesting tiny mosquito that breeds only in the eggs of pitcher plants, *Sarracenia purpuria*. Adult females deposit rhomboid shaped eggs in the water filled pitchers beginning in early spring and multiple generations of larvae feed actively on the carcasses of insects that are trapped and dissolved by the predacious host plant (Istock et al., 1975). Larvae remain in the plant during the winter months, often frozen within a solid block of ice (Smith, 1902). Larval growth and development is suspended during the winter months and resumes with the advent of warmer weather. The adult mosquitoes are autogenous and pose no threat as pests.

Table 4-2 - Mosquitoes of Suffolk County Classified by Life Cycle Type

Univoltine Aedine Life Cycle Types	Multivoltine Aedine Life Cycle Types		Culex/Anopheles Life Cycle Types	Unique Life Cycle Types	Monotypic Life Cycle Types
Oc. stimulans **Type** *Oc. stimulans* *Oc. excrucians* *Oc. intrudens*	***Ae. vexans*** **Type** ***Ae. vexans*** *Oc. flavescens* ***Oc. trivittatus***	***Ps. columbiae*** *Ps. ciliata* ***Ps. ferox*** *Ps. howardii*	***An. quadrimaculatus*** **Type** ***An. quadrimaculatus*** *(Ur. sapphirinna)* *(Cx. territans)*	***Cs. melanura*** **Type** ***Cs. melanura*** ***An. crucians***	***Cq. perturbans*** **Type** ***Cq. perturbans***
Oc. abserratus **Type** *Oc. abserratus* *Oc. aurifer* *Oc. fitchii* *(Cs. minnesotae)* *(Cs. morsitans)*	***Oc. sollicitans*** **Type** ***Oc. sollicitans*** ***Oc. cantator*** *Oc. dorsalis* ***Oc. taeniorhynchus***		***Cx. salinarius*** **Type** ***Cx. salinarius***	***Or. signifera*** **Type** *(Or. signifera)* *(Or. alba)* *(An. barberi)* *(Tx. rutilus septentrionalis)*	***An. walkeri*** **Type** *An. walkeri*
Oc. canadensis **Type** ***Oc. canadensis*** *Ae. cinereus* *Oc. sticticus*	***Oc. triseriatus*** **Type** ***Oc. triseriatus*** *Oc. atropalpus* ***Oc. japonicus***		***Cx. pipiens*** **Type** ***Cx. pipiens*** ***Cx. restuans*** *Cs. inornata* *An. Punctipennis*		***Wy. smithii*** **Type** *(Wy. smithii)*

Primary pest species and potential vectors in Suffolk Co. are underscored in bold type. Non-pests and scientific curiosities are enclosed in parentheses.

Table 4-3 - Biological Summary for Key Mosquito Species of Suffolk County

Species	EEE status	WNV Status	Feeding habits*	Flight range	Larval habitat	Larval control
Ae. vexans	Known vector	Field positive, poor transmitter	Aggressive nuisance	5-10 miles	Fresh floodwater, upper salt marsh	Water management, aerial and ground larvicide.
Cq. perturbans	Known vector	Field positive, poor transmitter	Aggressive nuisance	1-2 miles	Fresh emergent marsh	Granular, pellet Altosid, Vectolex
Cx. restuans	Positive pipiens/restuans pools	Field positive, Moderate transmission	Bird biter	1-2 miles, usually much less	Fresh permanent water, containers	Sanitation, ground larvicide
Cx. pipiens	Positive pipiens / restuans pools	Field positive, moderate transmission	Not very aggressive, but may transmit to humans	1-2 miles, usually much less	Fresh permanent water, containers	Sanitation, water management, aerial and ground larvicide
Cx. salinarius	Unlikely	Field positive, Moderate transmission, likely bridge vector	Aggressive, not a big nuisance here	1-2 miles	Fresh and brackish habitats	Water management, aerial and ground larvicide
Cs. melanura	Epiornitic vector	Field positive	Bird biter	5 miles	Red maple and white cedar swamps	Granular, pellet Altosid
Oc .sollicitans	Known vector	Moderate transmitter, field positives	Aggressive nuisance	5-10 miles or more	Salt marsh, our major salt marsh species	Water management, aerial and ground larvicide
Oc. canadensis	Potential vector	Potential vector	Indiscriminant and agressive	Short	Woodland pools	Ground larvicides
Oc. cantator	Unlikely	Field positive, Poor transmitter	Aggressive nuisance	5-10 miles	Salt marsh, brackish areas and springtime	Water management, aerial and ground larvicide
Oc. japonicus	Not known	Field positive, good transmitter	Moderately aggressive to humans	Short	Containers, tree holes, drainage areas	Sanitation
Oc. taeniorhynchus	Capable, not believed important	Moderate transmitter, field positives	Aggressive nuisance	5-20 miles or more	Salt marsh, dominant at times. Increase due to warming?	Water management, aerial and ground larvicide
Oc. triseriatus	Possible but not documented	Field positive, Moderate vector	Aggressive	Short	Containers, tree holes	Sanitation
Oc. trivittatus	Unlikely	Field positive, transmission likely	Aggressive nuisance	Short	Fresh floodwater, especially recharge areas	Water management, ground larvicide

*Species referred to as “aggressive nuisance” species are those that commonly trigger complaints about biting mosquitoes. Chart prepared by Suffolk County Vector Control.

5. Exotic Species Found on Long Island

Two mosquito species found on Long Island are exotic species that were accidentally introduced into the United States from Asia. *Aedes albopictus*, the Asian Tiger mosquito, was discovered in a tire pile near Houston, Texas in 1985 (Sprenger and Wuithiranyagool, 1986). The appearance of an exotic from Asia caused health officials to voice concern. *Aedes albopictus* functions as the primary vector of Dengue Fever in that region of the world and importing a known disease vector raises a number of potential health issues. Dengue Fever is fairly common in the Caribbean region, but has been kept from entering the United States by aggressive surveillance programs, coupled with differences in standard of living and house construction that thwart disease transmission in this country (eg., screens and air conditioning, which minimize human exposure to mosquitoes). The mosquito was monitored closely by the Centers for Disease Control over the next several years with no evidence of disease involvement. The species was, however, found to be moving northward at a fairly steady pace. A hypothetical northern boundary was set across the country with a line that passed just south of Suffolk County (Nawrocki and Hawley 1987). The mosquito was detected in northern New Jersey in 1995 (Crans et al., 1995) and exceeded the hypothetical boundary about four years later. The mosquito has since moved northward at a slow pace and entered Long Island quite recently. *Aedes albopictus* has become a major pest in most of New Jersey since its introduction to the northeast in 1995. The results of a 2003 questionnaire show the species to be ranked in the top 10 mosquito pests in southern New Jersey (Crans, in press [a]). Although not yet reported from Suffolk County, *Ae. albopictus* will probably become part of the local mosquito fauna within the next several years.

The exotic mosquito species, *Ochlerotatus japonicus,* was discovered in Suffolk County in 1998 (Peyton et al., 1999), the first record in the western hemisphere. The species is native to Northeastern Asia, occurring predominately in Northern Japan and Korea. *Ochlerotatus japonicus* is multivoltine and prefers to breed in containers located in the shade of trees or manmade canopies that cover water. Discarded tires, buckets, or other basins are its favored breeding grounds. Adult mosquitoes are not attracted to light and are difficult to detect even when abundant. Scott et al. (2001) showed that gravid traps could be used to collect small numbers of specimens for virus isolation attempts. Scott and Crans (2003) found that small pieces of polystyrene floated on the water's surface provide an attractive oviposition site for *Oc. japonicus*, which can indirectly be used to measure adult populations.

Ochlerotatus japonicus has an exceptionally long breeding season, appearing in larval habitats that are still covered with ice. Although it prefers container habitats, the species will breed in surface water and is highly attracted to isolated pockets of water in rocky streams when they dry down during periods of drought. Movement for this exotic has been westward; the westward spread of WNV has roughly duplicated the migration of this mosquito at first, but the area affected by WNV is much greater than the range of *Ochlerotatus japonicus*. *Ochlerotatus japonicus* may prove to be a troublesome human biting species and possibly a new vector for disease. The sudden appearance of this mosquito in the northeast just before West Nile virus was discovered raises questions on its possible role in the epidemiology of this newly introduced pathogen.

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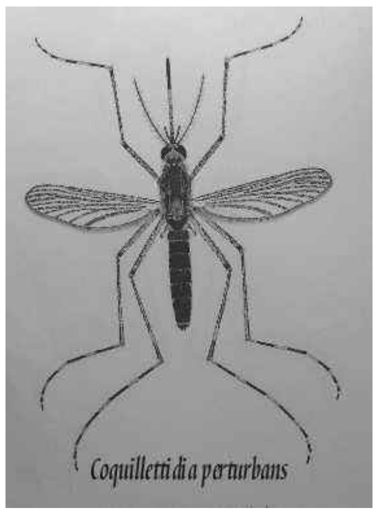
Appendix

A Selection of Mosquitoes Found on Long Island

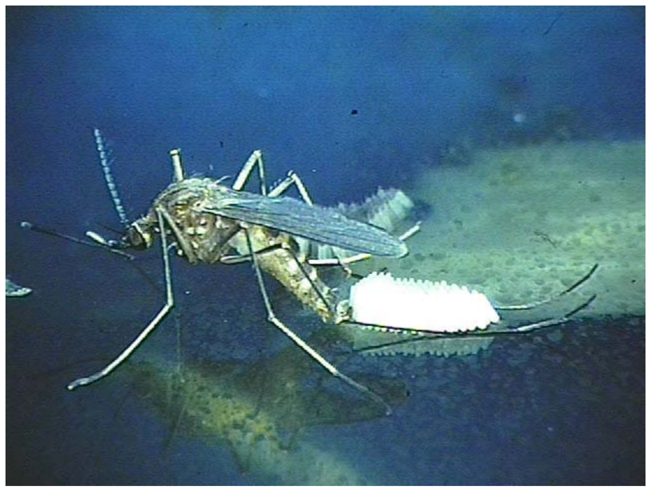
Ochlerotatus sollicitans

Aedes vexans

Coquillettidia perturbans

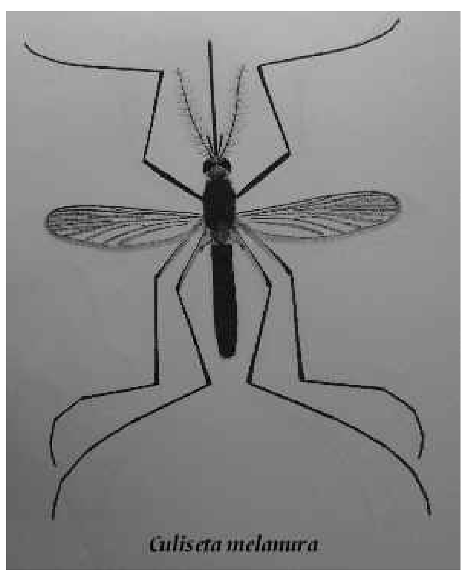


Culex pipiens

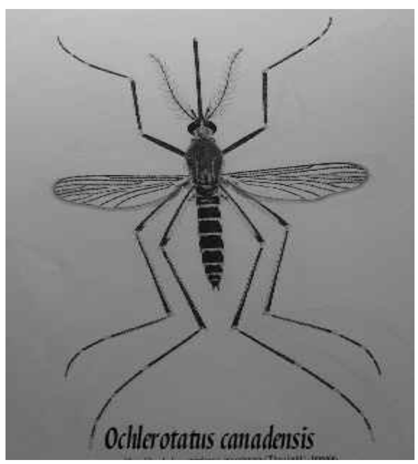


Culex restuans

Culiseta melanura

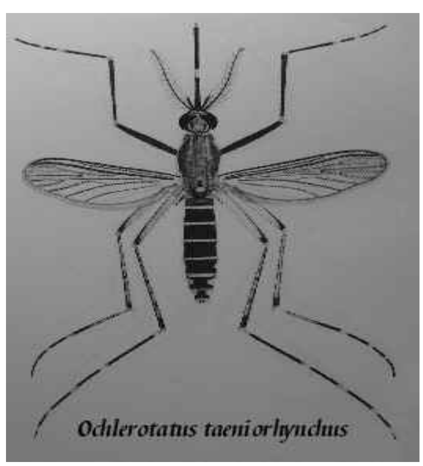


Ochlerotatus canadensis



Ochlerotatus japonicus

Ochlerotatus taeniorhynchus



Ochlerotatus triseriatus