Diversity and Adaptations of the Aquatic Insects

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Abstract

Aquatic insects make up only 3-5 percent of all insect species, but are very taxonomically diverse (Daly et al, 1998). There are insects in the orders Ephemeroptera, Odonata, Plecoptera, Megaloptera, Neuroptera, Coleoptera, Diptera, Lepidoptera, Trichoptera, Hemiptera, Orthoptera, and Hymenoptera that spend at least some stage of their lives underwater. The Parainsecta order Collembola also has species that are closely associated with the water. Many of these insects have both economical and ecological value. The aquatic lifestyle of these insects has required many adaptations including specializations in osmoregulation, locomotion, and respiration (Daly et al, 1998; McCafferty, 1981).

Introduction

Freshwater habitats from puddles to rivers to lakes, including both lentic (still water) and lotic (running water) habitats, can be home to various species of aquatic insects. There are almost no insects found associated with the marine environment (Cheng, 1985; Daly, 1998; Glausiusz, 1997). The diversity of insects in lentic waters tends to increase with increased nutrients (Daly, 1998). Nutrient rich waters are known as eutrophic and nutrient poor waters are called oligotrophic. Most aquatic insects are found in the littoral zone (Daly, 1998; McCafferty, 1981). This consists of shallow, nearshore waters where the light reaches the bottom. The limnetic zone consists of

offshore, open water to the depth of light penetration. The profundal zone is the deep, offshore waters below the penetration of light. There are few insects that inhabit the limnetic and profundal zones (McCafferty, 1981).

Aquatic insects are important for several reasons. In the fishing industry many lures are designed to mimic various aquatic insects, especially in fly fishing (McCafferty, 1981). Aquatic insects form an important link in many food chains. They consume other invertebrates, small fish, aquatic plants, algae, detritus, and decaying matter. Aquatic insects are also an important food source for birds, fish, reptiles, and amphibians. Aquatic insects are also often used to determine water quality based on type and number of species present. Many aquatic insects of the order Diptera, such as mosquitoes, gnats, blackflies, and biting midges, are biting pests to both humans and other animals (Daly, 1998; McCafferty, 1981; Lehmkuhl, 1979). Some Dipterans, most notably mosquitoes, are also vectors of diseases, which include malaria, encephalitis, and yellow fever (McCafferty, 1981). Adult Odonata can greatly reduce adult mosquito populations (Daly, 1998), and predaceous diving beetles and several other predatory aquatic insects can help reduce mosquito populations by feeding on their larvae (McCafferty, 1981; Lundkvist et al, 2003). Midges feed on algal mats and sediments in sewage treatment facilities, which helps to keep them running properly (McCafferty, 1981). Moth flies feed on the algal film in the trickling filter systems of sewage treatment facilities to keep them from clogging (McCafferty, 1981). Some herbivorous aquatic insects have the potential to be used as biological control of invasive aquatic plants (McCafferty, 1981).

The aquatic insects of the orders Ephemeroptera, Odonata, Plecoptera, Hemiptera, Megaloptera, Neuroptera, Coleoptera, Trichoptera, Lepidoptera, and Diptera and the Parainsecta order Collembola will be discussed in this paper.

Adaptations for osmoregulation in aquatic insects include a waxy epicuticle; producing urine more dilute than the hemolymph; active and passive ion transport mechanisms (such as chloride cells, chloride epithelia, rectal gills, and papillae); excretion of nitrogenous wastes as ammonia; and drinking excess water (Daly, 1998; McCafferty, 1981). The details of some of these adaptations can be complex and will not be discussed further. Respiration in aquatic insects is aeropneustic (oxygen obtained from air), hydropneustic (oxygen obtained from water), or a combination of both. Specific adaptation for respiration and locomotion will be discussed for each group. Only the aquatic stages of each group will be discussed.

Order Ephemeroptera - Mayflies

Ephemeroptera are exopterygotes and hemimetabolous. The mayflies are all aquatic as naiads (Daly, 1998). This order gets its name from the mayfly's ephemeral nature. The naiads may live for up to a year underwater, but the adults usually live only for a day and at most a few day. Mayflies are the only insects to molt after reaching the winged form. This stage is called the subimago. There are over 600 species of mayflies in North America (Lehmkuhl, 1979). The naiads are usually 3-20 mm long (excluding tails), however a few species may reach 30 mm or more (McCafferty, 1981). The naiads have large compound eyes, short multiarticulate antennae, and mandibulate mouthparts. The abdomen usually ends with three elongate tails, which consist of two cerci and a caudal filament. Each leg ends with a claw for clinging to the substrate in

lotic water. Most mayfly naiads have seven pairs of gills on the abdomen for absorbing oxygen from the water. This number of gills is one way to differentiate mayflies from other types of naiads (Kellogg and Kellogg, 1994). Most naiads feed on live and decaying vegetation and detritus. A few species are carnivorous (McCafferty, 1981; Lehmkuhl, 1979). Mayfly naiads are found in almost all natural and many artificial aquatic habitats as long as they have sufficient dissolved oxygen (4-10 ppm) (Kellogg and Kellogg, 1994; McCafferty, 1981; Lehmkuhl, 1979). However, the greatest diversity and abundance is found in streams and rivers. Naiads have a wide range of form including burrowers, filter feeders, swimmers, clingers, and sprawlers (Lehmkuhl, 1979). Mayflies are common and important food source for trout. It is for this reason that the mayfly serves as the basis for the sport and technique of fly fishing and fly tying (McCafferty, 1981).

Order Odonata – Dragonflies and Damselflies

The Odonata are hemimetabolous exopterygotes. Nearly all Odonata naiads are aquatic (Daly, 1998). The order Odonata contains two suborders: Anisoptera, the dragonflies, and Zygoptera, the damselflies. There are approximately 450 species in North America (McCafferty, 1981). All Odonata are predatory in both the immature and adult forms (Daly, 1998; Lehmkuhl, 1979). Naiads are 10-60 mm long (McCafferty, 1981). Odonata naiads are found in most freshwater habitats, but are most common in ponds, marshes, lake margins, and shallow areas of streams (McCafferty, 1981). Both the dragonfly and damselfly naiads have a characteristic feeding method. The labium is hinged in two places and ends with a pair of spiked jaws or grasping pincers. When not in use the labium is held under the head. It is extended (shot out) to grasp prey, which

includes mollusks, other insects, crustaceans, worms, and small fish. Both damselfly and dragonfly naiads are usually brown or green to camouflage them from predators and for ambushing prey (Kellogg and Kellogg, 1994). Dragonfly naiads have gills located inside the abdomen. Water that is drawn into the abdomen for the gills can also be forced out to propel the naiad through the water. The abdomen of dragonfly naiads has five anal appendages: a pair of dorsolateral cerci, a pair of paraprocts, and an epiproct (Richardson). Dragonfly naiads can be divided into three main groups: claspers, sprawlers, and burrowers. Claspers or climbers are usually found among aquatic vegetation where they stalk prey or lie in ambush for prey to pass. Sprawlers are usually long legged and are sluggish movers. These forms are ambush predators that will often accumulate silt on their bodies from remaining motionless. Burrowers lie beneath the mud, silt, or sand to ambush prey. The eyes and the tip of the abdomen remain above the surface so they can see prey and respire while the rest of the body is buried (Richardson, unknown). Dragonfly naiads tend to have a wide and oval or wide and elongate abdomen, while damselfly naiads have a narrow body (Kellogg and Kellogg, 1994). Damselfly naiads do not have gills in their abdomen, but instead have three gills at the end of the abdomen that have a tripod formation.

Order Plecoptera – Stoneflies

Stoneflies are exopterygotes and hemimetabolous. Nearly all Plecoptera naiads are aquatic (Daly, 1998). There are approximately 500 species of stoneflies found in North America (McCafferty, 1981). Stonefly naiads are 5-35 mm long. They are found primarily in cold lotic water, and some are found in cold lakes with lots of wave action. The naiads relatively long antennae and two long cerci. They closely resemble adults

except that they do not have fully developed wings. Respiration is through single gills found under the legs or through the skin (Kellogg and Kellogg, 1994; McCafferty, 1981). The legs end in small hooks (2 claws) for grasping the substrate. The bodies tend to be flattened which allow the naiads to crawl under stones, hence the name stonefly (Kellogg and Kellogg, 1994; McCafferty, 1981). North American stoneflies were previously divided into the suborders Filipalpia and Setipalpia, but this division has been shown to be based on differences that do not always hold. They are now divided into Systellognatha, which have mouthparts adapted for grasping and handling prey and are primarily carnivorous, and Euholognatha, which have mouthparts adapted to feeding on detritus, leaf litter, and algae (Pescador, 2000; McCafferty, 1981). The prey of Systellognatha are small macroinvertebrates.

Order Hemiptera – Water Bugs

Hemiptera are hemimetabolous exopterygotes. All aquatic Hemiptera belong to the suborder Heteroptera. There are about 300 species of Hemiptera in North America that are adapted to living in or on the water (McCafferty, 1981). In contrast with most aquatic insects both the adult and immature stages are associated with water, and they share the same habitat as well as having similar body form (Daly, 1998; Lehmkuhl, 1979). Most aquatic Hemiptera are found in lentic waters, but a few are found in lotic waters (McCafferty, 1981). Several species are found in brackish, intertidal, and marine habitats (Cheng, 1976; Cheng, 1985; Glausiusz, 1997; McCafferty, 1981). The families Notonectidae, Corixidae, Nepidae, Belostomatidae, Naucoridae, Gerridae, and Veliidae will be discussed. All aquatic Hemiptera are predators or scavenger. All aquatic Hemiptera are aeropneustic. Hemipterans have a beak-like mouth that is either

conelike or a more elongated piercing, sucking structure. The abdomen lacks gills, filaments, and cerci. A few species lack wings (McCafferty, 1981). When handled improperly these insects can inflict a painful bite.

Members of the family Notonectidae are commonly known as backswimmers. Backswimmers are 5-16 mm long, and there are approximately 30 species found in North America (McCafferty, 1981). They are found in pond, streams and lake margins, small pools, and intertidal marshes (Daly, 1998; Kellogg and Kellogg, 1994). As would be expected by the common name, backswimmer, the Notonectidae swim on their backs. They have natatorial, or swimming legs. The middle and hind legs are covered with long hairs, and the hind legs are oarlike. The front legs are adapted for holding prey (Lehmkuhl, 1979). Backswimmers trap an air bubble with hairs on the body. This form of respiration is called a plastron. Some aquatic insects have a plastron that allows oxygen from the water to diffuse into it, which is termed a physical gill. Notonectidae generally prey on other insects, snails, and small fish (McCafferty, 1981).

The family Corixidae consists of the insects commonly known as water boatmen. There are over 100 species found in North America (McCafferty, 1981). Adults are 3-11 mm long (Lehmkuhl, 1979; McCafferty, 1981). Water boatmen resemble backswimmers in many respects, and often inhabit the same types of habitats. Some are associated with brackish water, intertidal marshes, and salt pools (Cheng, 1976; Daly, 1998; Kellogg and Kellogg, 1994). As previously mentioned the Notonectidae and Corixidae are similar in several ways including body shape, structure of the middle and hind legs, and use of a plastron for respiration. Two distinguishing characteristics are that water boatman do not swim on their backs, and water boatman have a modified

beak (Lehmkuhl, 1979; McCafferty, 1981). The beak is short, blunt, triangular, and not distinctly segmented. This unique beak design does not restrict to consuming only juices as in most other Hemiptera (McCafferty, 1981). Water boatmen are herbivore-detritivores, omnivores, predators, or scavengers depending on the species (Daly, 1998; McCafferty, 1981).

Insects that are commonly referred to as water scorpions belong to the family Nepidae. There are 13 species of water scorpions found in North America (McCafferty, 1981). Water scorpions are 15-45 mm (excluding the breathing tube) long and are either narrow and elongate or broad and oval in form (McCafferty, 1981). Nepidae respire through a long caudal breathing tube, or snorkel. The legs are long and narrow. The fore legs are raptorial (Daly, 1998; Kellogg and Kellogg, 1994; Lehmkuhl, 1979; McCafferty, 1981), while the posterior legs are adapted for walking among aquatic vegetation and debris where they stalk prey (Daly, 1998). Water scorpions are poor swimmers (Daly, 1998; McCafferty, 1981), but they mostly inhabit aquatic vegetation and debris of lentic waters and therefore do not need to be good swimmers.

The group of insects commonly known as the giant water bugs belongs to the family Belostomatidae. There are approximately 20 species of belostomatids found in North America (Lehmkuhl, 1979; McCafferty, 1981). These can be some of the largest aquatic insects and are usually 20-65 mm long (McCafferty, 1981). They are somewhat flattened and oval in form. Giant water bugs obtain oxygen through a pair of retractile strap-like appendages that are located at the tip of the abdomen (Lehmkuhl, 1979). The fore legs are raptorial, and the middle and hind legs are fringed with hairs for swimming. The large raptorial fore legs allow belostomatids to attack prey that can be up to 20 time

larger in size (Kellogg and Kellogg, 1994). Males of the genera *Belostoma* and *Abedus* carry eggs on their backs (females glue them there) until they hatch. Common names other than giant water bugs include fish killers, electric light bugs, and toe biters. The name fish killer refers to the voraciousness of some species that will attack small fishes and other small animals such as ducklings (McCafferty, 1981). The name electric light bug refers to the tendency of dispersing adults to be attracted to lights at night (McCafferty, 1981). The name toe biter refers to the fact that some species are known bit the toes of waders and swimmers (McCafferty, 1981).

The family Naucoridae contains the insects called creeping water bugs. There are approximately 20 species found in North America (McCafferty, 1981). Adults are 6-15 mm long (McCafferty, 1981). Creeping water bugs superficially resemble giant water bugs, but they are more rounded and streamlined in the dorsal aspect (Daly, 1998), lack strap-like respiratory appendages on abdomen (Lehmkuhl, 1979), and lack veins in the membranous area of the hemielytra (McCafferty, 1981). These insects respire through a gas bubble or in some species by a plastron (Daly, 1998). Naucorids are the only Hemiptera that have a physical gill type plastron, which enables them to remain permanently submerged (Daly, 1998). The fore legs are raptorial, and the middle and hind legs may or may not have swimming hairs. The raptorial fore legs are used to capture prey that consists mainly of small arthropods (Daly, 1998). Naucorids are found mostly in quiet water, and some species are commonly found in hot springs and desert pools (Lehmkuhl, 1979; McCafferty, 1981).

The superfamily Gerroidea contains the families Gerridae, Veliidae, Hydrometridae, Hebridae, Mesoveliidae, and Macroveliidae. These are not truly aquatic

insects, but they are found closely associated with the shores and surfaces of aquatic habitats. The families Hydrometridae, Hebridae, and Macroveliidae are more terrestrial species, while the families Gerridae, Veliidae, and Mesoveliidae are more aquatic and are usually found on the surfaces of water (Daly, 1998; McCafferty, 1981). They are commonly called water striders and water treaders. Members of all three of these families contain species that are found in association with intertidal or marine environments (Cheng, 1976). The genera *Halobates* of the family Gerridae contains 5-7 species worldwide that inhabit the open oceans (Cheng, 1976; Cheng, 1985; Glausiusz, 1997). The family Gerridae will be considered in greater detail. There are approximately 60 species of Gerridae found in North America (Lehmkuhl, 1979). Gerrids are usually 3-20 mm long, and some species may lack wings (McCafferty, 1981). As these are not submerged species no special adaptations for respiration are needed, and they simple breathe through spiracles. Some species, especially those that inhabit rough waters, do have hairs that cover their body to form an air bubble to float them back to the surface if they are submerged (Cheng, 1976; Cheng, 1985; McCafferty, 1981). The gerrids have long legs and some species have hair on their legs, which enable them to walk or skate on the surface of the water. These insects feed on insect that fall in the water or capture prey through the surface of the water.

Order Megaloptera – Fishflies, Dobsonflies, and Alderflies

Megaloptera are holometabolous endopterygotes. Only the larval stage of these insects are aquatic (Daly, 1998; McCafferty, 1981), and all species are aquatic in this stage (Daly, 1998). There are approximately 300 species worldwide that are distributed mostly in temperate regions (Daly, 1998); of these only about 50 species are found in

North America (McCafferty, 1981). These insects are most abundant in cool, well oxygenated streams (Daly, 1998), and are commonly found under stones. The larvae, which are commonly called hellgrammites, are 10-90 mm long (McCafferty, 1981). Larvae have well developed chewing mouthparts including large mandibles, filamentous antennae, and poorly developed eyes. Thoracic legs are present. Each abdominal segment contains filaments for respiration underwater, and the filaments of some species have tufts of gills at the base to increase respiration (Daly, 1998; McCafferty, 1981). Some species also have spiracles on a pair of elongate breathing tubes at the end of the abdomen, which are raised above the surface of the water for respiration (McCafferty, 1981). The abdomen ends with two elongate medial appendages or prolegs. Larvae of the Megaloptera are all predaceous, and will attack anything that is small enough to subdue with their large mandibles (Daly, 1998).

Order Neuroptera – Spongillaflies

Only one family of the order Neuroptera has an aquatic stage in its life cycle. This family is the Sisyridae or spongillaflies. Spongillaflies are holometabolous and are also endopterygotes. There are two genera and six species of spongillaflies found in North America (McCafferty, 1981). The larvae are the only stage that is aquatic. The larvae are small, soft-bodied, and bristled in form, and they are usually 3-8 mm long (McCafferty, 1981). Larvae have thoracic legs that each end in a single claw. Respiration is cutaneous, and takes place over the general body surface (McCafferty, 1981). The mouthparts are modified into a needlelike structure that is used for feeding on the cells and juices of freshwater sponges (Lehmkuhl, 1979; McCafferty, 1981).

Order Coleoptera – Water Beetles

There are over 1000 aquatic or semiaquatic species of beetles found in North America (McCafferty, 1981). Beetles are also holometabolous endopterygotes. Members of the families Gyrinidae, Haliplidae, Dytiscidae, Hydrophilidae, Noteridae, Hydraenidae, Dryopidae, Elmidae, Psephenidae, and Amphizoidae are considered to be aquatic (Epler, 1996; Lehmkuhl, 1979; McCafferty, 1981). In some of these families only the larvae are aquatic while in others both the larvae and adults are aquatic. The families Gyrinidae, Dytiscidae, and Hydrophilidae, which are the most commonly encountered water beetles, will be discussed further.

The family Gyrinidae consists of the whirligig beetles. There are over 50 species found in North America (McCafferty, 1981). Both the larvae and adults are aquatic. Whirligig beetles are found in a variety of lentic and lotic habitats, especially ponds and streams (McCafferty, 1981). The larvae are elongate and up to 30 mm long (McCafferty, 1981). The abdomen has lateral filaments for respiration, and terminates in four small hooks (Lehmkuhl, 1979; McCafferty, 1981). The larvae are predaceous. Larvae leave the water to pupate, and make a pupal cell out of mud or plant material (Lehmkuhl, 1979). The adults are oval and somewhat flattened. They are 3-15 mm long (McCafferty, 1981). Adult are found on the surface of the water, but they can dive if necessary. When they dive an air bubble is trapped under the elytra for respiration underwater. The fore legs are relatively long and adapted for grasping prey, and the middle and hind legs are short. They swim in circular, gyrating, and whirling manner, which is why they are called whirligig beetles (Daly, 1998; Lehmkuhl, 1979). The eyes are divided for simultaneous aerial and submarine vision, and it is sometimes said that they have four eyes. Adults often form large groups that may contain several species

(Daly, 1998; Lehmkuhl, 1979; McCafferty, 1981). They have club shaped antennae that are sensitive to surface film disturbance, which allow them to avoid one another while swimming and to locate insect that fall in the water on which they feed (Daly, 1998). Adult Whirligig beetles will also feed on floating debris and small aquatic organisms. Some species release defensive secretions when they are disturbed or handled (McCafferty, 1981).

The predaceous diving beetles make up the family Dytiscidae. There are over 400 species found in North America (McCafferty, 1981). Both the larvae and adults are aquatic, and can be found in nearly all aquatic habitats. The larvae are 5-70 mm long (McCafferty, 1981). They have slender legs and mandibles that are grooved or hollow for suctorial feeding (Daly, 1998; McCafferty, 1981). The abdomen of some species has lateral filaments. The abdomen is usually strongly tapered at the end and lack terminal hooks (McCafferty, 1981). Fringes of hair on various parts of the body aid in swimming (Lehmkuhl, 1979). A few species can obtain oxygen through lateral filaments, but most species must come to the surface to respire. The voraciousness of the larvae has earned them the common name of water tiger. Pupation occurs on shore above the water line (Lehmkuhl, 1979). The adults are oval in shape, and are 1-40 mm long (McCafferty, 1981). Adults, like the larvae, are predatory. The middle and hind legs are covered with hairs for swimming. Air is trapped under the elytra for respiration underwater. There are several characters that distinguish the Dytiscidae from the Hydrophilidae. These include breaking the surface with the tip of the abdomen, having filiform antennae, and moving the hind legs in unison for swimming (Lehmkuhl, 1979; McCafferty, 1981).

The Hydrophilidae are commonly known as water scavenger beetles. There are approximately 200 species found in North America (McCafferty, 1981). Both the adults and the larvae are aquatic, and are found in nearly all aquatic habitats. The larvae are 4-60 mm long (McCafferty, 1981). The abdomen may or may not possess lateral filaments which may aid in respiration, but most species must surface for air. The mandibles are toothed rather than grooved or hollow as in Dytiscidae. Most larvae are predaceous, but a few feed on algae (McCafferty, 1981). Pupation occurs in damp soil on the shore (Lehmkuhl, 1979). Adults are 1-40 mm long (McCafferty, 1981). They are oval in shape and superficially resemble predaceous diving beetles, but there are several characters that are used to separate the two groups. Water scavenger beetles have clubbed antennae rather than filiform as in the predaceous diving beetles. The Dytiscidae surface with the tip of the abdomen, while the Hydrophilidae surface with head/antennae first. The dytiscids move their hind legs in unison for swimming, and the hydrophilids move the hind legs alternately and crawl more than they swim (Lehmkuhl, 1979; McCafferty, 1981). Adults must surface for air, and an air bubble is trapped under the elytra. The adults are scavenger, detritivores, and predatory depending on the species.

Order Trichoptera – Caddisflies

The caddisflies make up the order Trichoptera. Over 1,200 species are found in North America (McCafferty, 1981). Trichoptera are holometabolous endopterygotes. The larval and pupal stages of caddisflies are aquatic. They are found in almost all aquatic habitats, but they are not very tolerant of pollution (Lehmkuhl, 1979). *Limnephilus affinis* (Curtis) are found in saltmarsh pools off the coasts of Britain, and

Philanisus plebeius (Walker) is found in rock pools on the coasts of New Zealand and Australia (Cheng, 1976). This group is closely related to the Lepidoptera, but the adults have hairs on their wings rather than scales as in Lepidoptera. The scientific name Trichoptera means hair wing, and the common name "caddis" means case bearer (McCafferty, 1981). The larvae generally consist of two types: eruciform (cruciform) and campodeiform (Daly, 1998; Lehmkuhl, 1979). Both types of larvae are elongate and are 2-40 mm long (McCafferty, 1981). They have small, simple eyes and reduced antennae. Most respiration is cutaneous, but some species may have abdominal gills (Kellogg and Kellogg, 1994; McCafferty, 1981). Eruciform larvae build cases out of various types of materials. The anal prolegs are fused and end in a claw for holding the larvae in the case (Daly, 1998; Lehmkuhl, 1979). Case building forms are often scavengers or grazers (Daly, 1998). Campodeiform larvae are usually free-living or spin silken nets, and in these form the anal prolegs are not fused (Lehmkuhl, 1979). Most of these forms are predatory (Daly, 1998). There are many intermediate larval forms (Daly, 1998). Pupation is almost entirely aquatic (McCafferty, 1981), and occurs in the larval case or in retreat where a pupal case is built (Daly, 1998).

Order Lepidoptera – Aquatic Caterpillars

There are approximately 150 aquatic or semiaquatic Lepidoptera found in North America (McCafferty, 1981). Lepidoptera are holometabolous endopterygotes. This order contains the butterflies and moths. The families Cosmopterygidae, Nepticulidae, and Noctuidae contain species that are considered to be semiaquatic (McCafferty, 1981). Nearly all of the truly aquatic species are found in the Subfamily Nymphulinae of the family Pyralidae (Lehmkuhl, 1979; McCafferty, 1981). The subfamilies Crambinae

and Schoenobiinae have some species that are considered to be aquatic. These caterpillars are stem burrowers in aquatic rushes or grasses (Lehmkuhl, 1979). The aquatic larvae of Nymphulinae have been divided to two types: the plant feeders (Nymphulini) and the rock feeders (Argyractini) (Lehmkuhl, 1979). The Nymphulini contains 10 genera and 23 species. These caterpillars build cases or tubes of leaves, have short mandibles, and usually lack gills (Lehmkuhl, 1979). The Argyractini contains 4 genera and 20 species. These species usually live in silk galleries on rock, have long mandibles, usually have long lateral gills, and graze on diatoms and algae in lakes and streams (Lehmkuhl, 1979). Many aquatic Lepidoptera larvae also pupate underwater (McCafferty, 1981).

Diptera – Midges, Mosquitoes, Aquatic Gnats and Flies

There are over 3,500 species of aquatic or semiaquatic Diptera in 20-30 families (Daly, 1998; McCafferty, 1981). Dipterans are holometabolous endopterygotes. Larvae and some pupae are considered to be aquatic. The family Chironomidae has more aquatic species that any of the other orders of aquatic insects (McCafferty, 1981). The larvae are 1-100 mm long (McCafferty, 1981). They are usually elongate and maggotlike. The larvae of aquatic Diptera can be found in all aquatic habitats. Feeding methods include filter feeding, scraping and grazing, scavenging, and being predatory (McCafferty, 1981). The larvae are often active swimmers with side to side wiggling movements of the body. Some larvae float on the surface, and others remain on the bottom during the day but come to the surface at night with migration through the water column may be aided by using a special tracheal bladder as a hydrostatic organ (McCafferty, 1981). Aquatic pupae may be active or quiescent (McCafferty, 1981). Two

of the most common families, the Chironomidae and the Culicidae, will be considered in greater detail.

The Chironomidae, or midges, are usually the most abundant macroinvertebrate group, both in numbers of species and individuals, in freshwater aquatic habitats (Epler, 1995). There are over 100 genera and perhaps as many as 2,000 species in North America (McCafferty, 1981). Midge larvae are usually 2-20 mm long (McCafferty, 1981). They are slender and usually cylindrical and slightly curved. The body has one pair of prothoracic legs and one pair of terminal prolegs (Kellogg and Kellogg, 1994; McCafferty, 1981). Many species have larvae that are bright red due to hemoglobin in their blood. This allows them to respire in water with a low oxygen content, and it gives them the common name of bloodworm (Daly, 1998; McCafferty, 1981). Feeding types include carnivores, herbivores, case builders, net spinners, and free-living form (Lehmkuhl, 1979). A few species are phorectic (ride on) on mayflies and stoneflies (Lehmkuhl, 1979). The remains and fecal pellets of midge larvae may form an organic ooze on the bottom of some aquatic habitats (Kellogg and Kellogg, 1994; McCafferty, 1981). Some species can live in highly polluted water, while others need cool clear water. There are over 50 species of midges in 12 genera that are found in marine waters, but only a few are found in the open ocean (Cheng, 1976). The midges *Pontomyia sp.* and *Chironomus oceanicus* (Packard) have been found in 30 or more meters of water in marine environments (Daly, 1998). One species of midge larvae was found in over 1,300 m of water in Lake Baikal of Russia (Daly, 1998). The pupae may live within cylindrical or conical cocoons or be free-swimming (McCafferty, 1981).

The family Culicidae consists of the mosquitoes. There are approximately 150 species of mosquitoes found in North America (McCafferty, 1981). Both the larvae and pupae are aquatic. The larvae are found in almost all lentic habitats, including many that are only temporary. Several species are found in intertidal areas (Cheng, 1976; McCafferty, 1981). They have a swollen thoracic area and have no prolegs, which usually make the larvae easy to recognize from those of other families (Lehmkuhl, 1979; McCafferty, 1981). The larvae breathe through a sclerotized siphon (respiratory tube or snorkel). A few species have a modified respiratory siphon, which they use to pierce the stems of aquatic plants for air (Lehmkuhl, 1979; McCafferty, 1981). Most mosquito larvae feed on floating or suspended microorganisms and detritus with sweeping motions of their mouth brushes (McCafferty, 1981). Larvae are often called “wrigglers.” The pupae fused head and thoracic area that are greatly enlarged, which is distinctive of mosquitoes (McCafferty, 1981). The pupae respire through thoracic respiratory horns (McCafferty, 1981). The pupae are commonly called “tumblers.”

Order Collembola – Springtails

The order Collembola contains organisms commonly known as springtails. These are not true insects, but they are closely related to the insects. They belong to the class Parainsecta. Over 50 species have been reported from various freshwater habitats in North America, but only 10-15 species are regularly associated with the surface of freshwater (McCafferty, 1981). These species are found in the families Isotomidae, Poduridae, and Smithuridae (McCafferty, 1981). The families Onychiuridae, Hypogastruridae, Neanuridae, Isotomidae, and Actaletidae contain species that are associated with marine habitats in different parts of the world (Cheng,

1976). Springtails are ametabolous and entognathous. They are usually less than 3 mm long (McCafferty, 1981). Springtails have one pair of antennae and three pairs of legs. They may or may not have eyes. They lack wings, wing pads, and cerci (Daly, 1998; McCafferty, 1981). The furculum/furca (spring) and retinaculum (holds spring in place) allow these organisms to jump up to 0.2 m through the air, hence the name springtail (Daly, 1998; Lehmkuhl, 1979; McCafferty, 1981). They feed on algae, fungi, spores, lichens, living and dead plant material, or dead animals (Lehmkuhl, 1979). Little is known of the special adaptations of apterygotes, including Collembola, to aquatic environments. They superficially resemble nonaquatic species (Cheng, 1976).

Discussion/Conclusion

As is evident by the information above, the aquatic insects may not have a great number of species in total, but they are a very taxonomically diverse group. They are also diverse in their forms. They have invaded nearly every freshwater aquatic habitat. These include lotic habitats such as river and streams and lentic habitats from lakes and ponds to puddles. Several species have been successful in living in intertidal areas, and a very few species have been successful in invading the open oceans. Living in aquatic habitats has required these insects to evolve various adaptations in osmoregulation, locomotion, respiration, and feeding. This group is not only interesting, but they are both economically and ecologically important.

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