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Aquatic insects and their societal benefits and risks

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Abstract
Information on the aquatic insects and their benefits and risks to the society are scanty among the general public, students and the scientific community, when compared with the same on the land forms. In this article, an attempt is made to overcome this deficiency. A brief description is furnished along with the representative photographs of eleven orders of aquatic insects. These orders are Collembola (springtails), Ephemeroptera (mayflies), Odonata (dragonflies and damselflies), Plecoptera (stoneflies), Hemiptera (true bugs), Megaloptera (dobsonflies and alderflies), Neuroptera (songillaflies), Trichoptera (caddisflies), Lepidoptera (butterflies and moths), Coleoptera (beetles) and Diptera (true flies). Detailed information is presented on the beneficial role of aquatic insects in food webs, biomonitoring, fishing and control of noxious weeds. The harmful impacts caused by these animals to the society and the ecosystem by way of general nuisance, transmission of diseases and destruction of crops, are described. The importance of the need for a new generation of aquatic entomologists, is stressed.

Keywords: Aquatic insects, taxonomic orders, benefits and risks, food web and biomonitoring, fishing and noxious weeds, larvae and adult, entomologist

1. Introduction
Insects are invertebrates (animals without an internal skeleton) that belong to the large group of animals given the name Arthropoda, which loosely translates as "joint footed". The "joints" referred to are a feature of animals that have a hard outer shell or exoskeleton, because such armored invertebrates must have joints (like the elbow or knee joints in a medieval suit of armor) in order to move. There are more than 1 million known species of insects on the planet; this is about three-fourths of known species of all animals and about two-thirds of species of all living things (microbes, plants and animals). Everyone is familiar with common terrestrial butterflies, moths, beetles, ants, bees, flies, grasshoppers, and cockroaches, but the many insects that live in water are less often appreciated except by those who explore special places such as puddles, ponds, lakes, water-filled ditches, and streams. Truly aquatic insects are those that spend some part of their life cycle closely associated with water, either living beneath the surface or skimming along on top of the water. There are many different kinds of aquatic insects and almost every type of freshwater environment will have some of the insects living in it [1]. The ocean, on the other hand, is rarely or only marginally inhabited by insects because very few insects have become adapted to survive or to compete with other animals in that environment.

2. Taxonomic orders of aquatic insects
Most aquatic insects are grouped in 11 taxonomic orders [2, 3]. They are (1) Collembola, the springtails; (2) Ephemeroptera, the mayflies; (3) Odonata, the dragonflies and damselflies; (4) Plecoptera, the stoneflies; (5) Hemiptera, the true bugs; (6) Megaloptera, the dobsonflies and alderflies; (7) Neuroptera, the spongillaflies; (8) Trichoptera, the caddisflies; (9) Lepidoptera, the butterflies and moths; (10) Coleoptera, the beetles; and (11) Diptera, the true flies. Other orders (Orthoptera, the grasshoppers and crickets; Blattodea, cockroaches; and Hymenoptera, wasps) also include a few aquatic insects.
A brief description of each of the main orders of aquatic insects is given below:

Order 1: Collembola (Figure 1)
The springtails are very small hexapods (animals with 3 pairs of legs), with fossil remains known from over 345 million years ago. They occur in large numbers near water and on the surface of water where there is vegetation or organic detritus like leaves washed against the shore. They have a jumping device, composed of a spring-like lever (furculum) and a trigger (tenaculum), used to leap many times their own length.

Fig 1: Collembola: Water surface springtails, *Podura aquatica* L. (©Marshall)

Order 2: Ephemeroptera (Figure 2 a, b)

The mayflies are well known to fishermen because the larvae (nymphs) (Fig. 2a) and newly emerged winged adults (Fig. 2b) of this ancient order are among the favorite foods of many fishes. Mayflies spend most of their lives, sometimes several years, as aquatic larvae before leaving the water to transform into winged adults that mate and lay eggs in a few hours or at most a few days. The order got its name from the "ephemeral" (lasting a very short time) nature of the insect's adult life. Mayflies are the only insects known to moult after reaching a winged form. After emerging from the water, they live briefly as winged forms called subimago which soon moult again to the true. adult form.

Fig 2(a): Ephemeroptera: A mayfly larva (nymph) (©Marshall)

Fig 2(b): Ephemeroptera: A mayfly adult (©Marshall)

Order 3: Odonata (Figure 3 a, b, c, d)

The Odonata, dragonflies and damselflies, are all predators, (feed on other animals) both as larvae (nymphs) (Fig. 3 a, c) and adults (Fig. 3b, d) and can significantly reduce mosquito populations by eating mosquito larvae and adults. Odonata larvae have unusual mouthparts that can be extended to capture underwater prey and adults can scoop flying insects from the air with their basket-like arrangement of legs. Extinct relatives of these ancient insects were around before the age of the dinosaurs. Some Odonata-like fossils from the Carboniferous period had wingspans up to 71 cm; in other words, in the distant past these insects were larger than some modern hawks!

Fig 3(a): Odonata: A dragonfly larva (nymph) (©Marshall)

Fig 3(b): Odonata: A dragonfly adult (©Marshall)

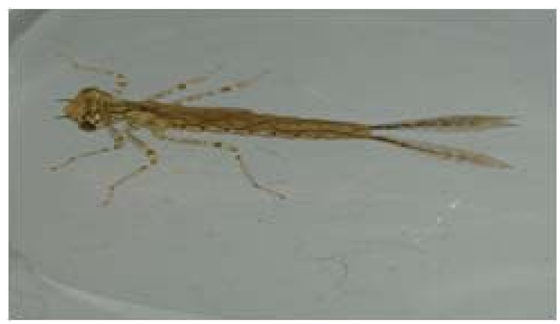

Fig 3(c): Odonata: A damselfly larva (nymph) (©Marshall)

Fig 3(d): Odonata: A damselfly adult (©Marshall)

Order 4: Plecoptera (Figure 4 a, b)

The Plecoptera are called stoneflies, likely because larvae (nymphs) of this ancient order are very common beneath the stones of rivers and streams, especially, colder, fast-running water. The larvae (nymphs) (Fig. 4a) of stoneflies look very much like the adults (Fig. 4b) with the exception of wings, which are absent in larvae (nymphs) but normally present and folded over the back of the adult insect when it is not flying.

Fig 4(a): Plecoptera: A stonefly larva (nymph) (©Marshall)

Fig 4(b): Plecoptera: A stonefly adult (©Marshall)

Order 5: Hemiptera (Figure 5 a, b)

Properly speaking, the Hemiptera are the only true "bugs." They range in size from tiny insects called "water measurers" in the family Hydrometridae to the huge Belostomatidae or "giant water bugs," (Fig. 5a) which can reach 7 cm or more in length and are sometimes enjoyed as human food. Species in most families of aquatic Hemiptera are predators equipped with grasping (raptorial) forelegs and sharp piercing mouthparts that are often capable of inflicting a painful bite if they are handled carelessly. The most formidable of these insects is an oval bug called a "creeping water bug" (Naucoridae) (Fig. 5b). The bite of this bug is very painful. Some other hemipterans one may find in or on water include the "water scorpions," "backswimmers," "water boatmen," and "water striders". These insects are especially common in places where the water is slow-moving and emergent vegetation is present, although a few true bugs are also characteristic of running waters.

Fig 5(a): Hemiptera: An immature giant water bug (©Marshall)

Fig 5(b): Hemiptera: An adult creeping water bug (©Marshall)

Order 6: Megaloptera (Figure 6 a, b)

These insects, commonly known as dobsonflies and alderflies can be quite striking both as larvae and as adults. The immature form of the dobsonfly is called "hellgrammite" (Fig. 6a). These fierce larvae can be over 7.5 cm long and are equipped with strong mandibles with which they consume their prey; they also can deliver quite a pinch if handled carelessly. Some are common in rocky, fast-moving areas of the rivers and others live in lakes and ponds where they live by hunting and eating other aquatic animals. Many of the adult (Fig. 6b) males have grossly exaggerated jaws that seem to be useful for impressing females.

Fig 6(a): Megaloptera: A hellgrammite, or larval dobsonfly (©Marshall)

Fig 6(b): Megaloptera: A dobsonfly adult (©Marshall)

Order 7: Neuroptera (Figure 7 a, b)

The neuropterans, or nerve-winged insects (Fig. 7 b). are mostly terrestrial, but larvae (Fig. 7a) of spongillaflies (family Sisyridae) have needle-like jaws to pierce and consume freshwater sponges. To avoid detection by predators, their larvae often "hide" on their host sponge by attaching tiny pieces of sponge to the spines on their backs.

Fig 7(a): Neuroptera: A spongillafly larva (©Marshall)

Fig 7(b): Neuroptera: A spongillafly adult (©Marshall)

Order 8: Trichoptera (Figure 8 a, b, c)

The English common name of Trichoptera is "caddisflies," which is thought to refer to itinerant cloth merchants of Medieval England ("caddis men") who often wore on their clothes many small examples of their wares as they traveled from town to town. Many of these insects build and cover themselves with portable cases (Fig. 8b) from various materials they find in the river such as stones, twigs, leaves or sand [4]. Others spin silken retreats and often also silken nets with which to filter food from moving water. Still others are predators that chase and consume other small animals. Eggs, larvae (Fig. 8a), and pupae (Fig. 8b) live in the water, but adults (Fig. 8c), which resemble moths, often hide on shore side vegetation during the day or fly above the water seeking mates or laying eggs.

Fig 8(a): Trichoptera: Stenopsychidae Caddisfly larva (©Marshall)

Fig 8(b): Trichoptera: Limnephilidae Caddisfly larva, cases and pupae (©Marshall)

Fig 8(c): Trichoptera: Hydropsychidae Caddisfly adult (©Marshall)

Order 9: Lepidoptera (Figure 9 a, b)

There are only a few Lepidoptera, the (butterflies and moths), that are truly aquatic; all butterflies and most moths are fully terrestrial. Some moths occur in lakes and rivers where they are found live as eggs, larvae (Fig. 9a), and pupae on the leaves and in the stems of aquatic plants, or under silken tents on rocks. As is true for the related order Trichoptera or caddisflies, aquatic Lepidoptera leave the water as adults (Fig. 9b) and fly nearby.

Fig 9(a): Lepidoptera: Crambidae: Aquatic snout moth larva (©Marshall)

Fig 9(b): Lepidoptera: Crambidae, Nymphulinae: Aquatic snout moth adult (©Marshall)

Order 10: Coleoptera (Figure 10 a, b, c)

The name Coleoptera loosely translates as "sheath-wing," reflecting the way that adult beetles have the front wings modified into hardened covers that shield the rear wings from damage while folded at rest. Flying beetles mostly use just their rear wings to fly. There are more species of beetles (Fig. 10 b, c) in the world than there are of any other group of animals or plants. To date, more than 350,000 species of beetles have been described. The aquatic beetles are very diverse and interesting. Predaceous diving beetles, some nearly 2.5 cm long, are common in weedy ponds, some nearly 2.5 cm long. The whirligig beetles are very common and can often be found swimming together on the surface of calm water in large groups. Most whirligig species are "four-eyed," with one pair of eyes seeing above the water and the other below. Other beetles that might be found in rivers are elmid or riffle beetles, psephenid or water-penny beetles, and the little heart-shaped haliplids or crawling water beetles. Larvae (Fig. 10a) of most of these families also live in the water, but some beetle families have terrestrial larvae and aquatic adults.

Fig 10(a): Coleoptera: Water scavenger beetle (Hydrophilidae, Hydrobius larva) larva (©Marshall)

Fig 10(b): Coleoptera: Hydrophilidae Water scavenger beetle adult (©Marshall)

Fig 10(c): Coleoptera: Diving beetle (Dytiscidae) adult (©Marshall)

Order 11: Diptera (Figure 11 a, b)

The order name Diptera means "two wings", referring the defining character of adult true flies, which have only a single pair of wings means "two wings" and this name refers to the true flies. Some of the least favorite insects are those aquatic Diptera, mainly the ones that like to feed on our blood. These include the tabanids (horseflies and deerflies), the culicids (mosquitoes), the ceratopogonids (punkies or biting midges), and the simulids (biting black flies). Since many of these insects transmit diseases like malaria and dengue fever, much effort has gone into research for controlling them. Some of the interesting adaptations flies have used to colonize the aquatic habitat include breathing tubes, silken tunnels and ventral suction cups. Non-biting midges can be especially abundant in freshwater ecosystems and form the primary food for predators in these waterways. Non-biting midges (Chironomidae), both larvae and adults (Fig.11 a, b) are the most abundant and diverse of all aquatic insect families.

Fig 11(a): Diptera: Midge (Chironomidae) larvae (©Marshall)

Fig 11(b): Diptera: Midge (Chironomidae) adult (©Marshall)

3. Societal benefits of aquatic insects

A high diversity of aquatic insect species is of value to humans and animals for a variety of reasons, out of which four are particularly important. They are the role of these insects in (1) food webs, (2) biomonitoring, (3) fishing, and (4) controlling noxious weeds.

1) Food webs: In food webs, aquatic insects capture, use and make available to other freshwater organisms nutrients that otherwise would be unavailable. In general, they do this by processing nutrients from coarse particulate organic matter (CPOM) and from fine particulate organic matter (FPOM).

CPOM occurs in freshwater ecosystems in the form of both living and dead vascular plants and larger animals. Dead plant material is especially abundant, but cannot be consumed by many animals because it is either too large or mostly indigestible. The nutrients from detritus (fragmented organic particles) often come indirectly from CPOM, having been consumed first by communities of bacteria and fungi - in other words, much of this material must first be "microbially conditioned" by colonizing fungi and bacteria before it can be assimilated (absorbed into the body). Aquatic insects functioning as shredding herbivores (feeding on plants), shredding detritivores (feeding on pieces of dead plants and animals), and predators, fragment CPOM and release smaller organic particles as feeding scraps and feces; their own' bodies assimilate nutrients from CPOM and become available to many predators and parasites.

FPOM occurs in freshwater ecosystems as tiny particles of both living and dead plant and animal material or as flocculated dissolved organic matter (DOM). FPOM is abundant, but cannot be consumed by many animals because it is too small for efficient consumption, and cannot be used by plants because its nutrients are not in solution. Among the aquatic insects, many collecting gatherers and suspension filterers proficiently consume these materials and their bodies become prey for freshwater and terrestrial predators [5].

Aquatic insects are, thus, important links in food webs to assure that nutrients are passed to other members of the community. Higher diversity and abundance of aquatic insects help these nutrients pass more efficiently to other animals, thereby retaining the nutrients in the ecosystem longer, helping to assure the health of the overall ecosystem.

A high abundance (or density) of aquatic insects helps assure the processing of large amounts of nutrients. A high diversity (or taxa richness) of aquatic insects helps assure diversity of resources and ecosystem services (e.g., nutrients, habitats) and effective use of all available resources in both space and time.

2) Biomonitoring: Historically attempts have been made to monitor water pollution by chemical analyses. However, scientists in many countries, especially more developed countries, have been using communities of freshwater macro (big enough to see) invertebrates, especially insects, as a more effective and efficient method to monitor the water biologically (bioassessment or biomonitoring) [6]. These animals 'sample' the water continuously and 'test' for all biologically relevant substances. Moreover, they respond more meaningfully to the combined (synergistic) effects of these substances. Bioassessment/biomonitoring reflects the ecological integrity of freshwater ecosystems and is less expensive than chemical/toxicity testing. The status of living organisms also is of direct interest to the public as a measure of a pollution-free environment. Biomonitoring is the only practical means for evaluating freshwater ecosystems where potential pollution sources are widespread or where criteria for specific ambient effects do not exist.

Biomonitoring efforts that use aquatic insects and other macroinvertebrates have a number of benefits. They are good indicators of localized conditions, because, unlike fish, they do not migrate appreciably to avoid ecological problems. They integrate the effects of short-term environmental variations more effectively than do algae because they usually have much longer life-cycles. Degraded conditions can be detected by experienced biologists with cursory examination because of ease of identification of these animals to family or lower taxonomic levels, unlike for algae. There are usually many insect species in a given waterway, each with its own ecological requirements, so that collectively the species exhibit a wide range of trophic levels and pollution tolerances, unlike fish. Sampling of insects is relatively easy and inexpensive. In comparison with fish, insects are more abundant and diverse in most streams and lakes, permitting computation of statistically reliable results. Now, several developing countries are drafting protocols for using insects in freshwater biomonitoring.

The advantages of biomonitoring with insects can be realized only if the natural fauna of the region is known. Where the species diversity of freshwater insects is poorly known, biomonitoring is possible only at relatively crude taxonomic levels such as order or family. In other words, before monitoring can be most effective, background knowledge of the insect biodiversity at the genus and species levels must be obtained from the wide variety of freshwater habitats of the region.

Government regulatory agencies in most developed countries now have well-established protocols for monitoring the quality of surface water by sampling and identifying aquatic insects. Common impediments for using insect biodiversity in freshwater biomonitoring in many parts of the world include limited scientific knowledge of the fauna, few or no training opportunities, limited equipment and literature, and poor understanding of the benefits. This picture is slowly changing with more collaborative research in the field between expert scientists globally so that a new generation of indigenous taxonomists is emerging to continue the process of describing their native faunas, and indigenous freshwater ecologists are being trained to implement modern biomonitoring methods in their respective countries.

3) Fishing: Aquatic insect biodiversity is of considerable interest to society because these animals are so important in the diets of many fish species, including species that are commonly consumed by humans for food. People who fish with natural or artificial baits have long had particular interest in them. Anglers for centuries have attempted to imitate the form and colour of various aquatic insects on hooks (or angles) in the hope of tricking fish to swallow them and become snagged. Mayflies, caddisflies, stoneflies and non-biting midges have been groups whose species are most commonly imitated. Larvae, pupae and adults are imitated and presented to the fish in ways intended to replicate the behaviour of those forms as they grow on the bottom substrate, drift in the current, emerge from the water surface, or return to the water as egg-laying females or dying adults. A high diversity of these insects in a particular stream, each with its own specific emergence time, assures that food is available to the fish through much of the year and through different times of day [7].

4) Control of noxious weeds: Several species of noxious, invasive weeds have become problems in parts of the world where they out-compete native species, clog otherwise navigable waters and water-intake structures, and exclude food-fish species. Herbicides often are employed to control these weeds, but some success also has resulted from the introduction of insect herbivores. For example, in the USA, alligator weed (*Alternanthera philoxeroides)*, an invasive species from South America, has been controlled successfully by three important herbivores: alligator weed stem borer, alligator weed flea beetle and alligator weed thrip. Another example is the successful control of common water hyacinth *(Eichhornia crassipes)* an invasive species from Brazil, by two imported species of weevils (Coleoptera: Curculionidae) and one species of imported moth. Studies can be attempted to discover species of aquatic insects that may help reduce or eliminate weeds.

4. Societal risks of aquatic insects

Several species of aquatic insects are a nuisance to people, annoying them by biting them, landing on them, or simply flying about. Adults also foul automobile windshields and wet paint, and when present in large numbers, can make highway bridge surfaces dangerously slick. Caddisfly larvae with filter nets can clog water-intake structures of hydropower plants. Adults of various aquatic Diptera (especially mosquitoes, black flies and sand flies) transmit some of the world's most serious diseases to humans and their domesticated animals. Hairs of adult caddisflies or other aquatic insects can cause allergic reactions.

Among the aquatic insects, agricultural pests on rice include the rice water weevil, the white stem borer and yellow stem borer, and some species of caddisflies. Also, various species of Lepidoptera, Coleoptera and Trichoptera are pests of commercial watercress.

5. Need for a new generation of aquatic entomologists

There is a trend for young people today to spend less time in rural forests, ponds, and streams, and more time indoors learning about the natural world indirectly through electronic media. As a result, they seem less inclined to follow careers in biodiversity discovery or working in natural environments. Biological teaching and research in secondary schools/ colleges/universities/research institutions are more focused on molecular principles and methods, with less emphasis placed on the recognition and study of living organisms in nature. A result of these trends is fewer professional entomologists capable of recognizing species of aquatic insects or interested in discovering their biological characteristics, practical value, and methods for controlling pest species. As we have observed, this capacity for discovery of species is declining at the very time in history when there is greatest need for biodiversity discovery, before many more species become extinct. A significant change in direction toward increased emphasis on biodiversity education and research for today's youth and toward improved employment opportunities in biodiversity discovery is urgently needed. This change will most likely occur as we come to appreciate the value of a biologically diverse world and as we gain a greater understanding of ways to manage the challenges a few species present us.

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