

Branchiopoda (Anostraca, Notostraca, Laevicaudata, Spinicaudata, Cyclestherida)

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Introduction

The extant members of the class Branchiopoda are arguably the most primitive living crustaceans. Strictly for purposes of convenience with absolutely no basis in taxonomy, they are divided into the so-called ‘large branchiopods’ (fairy shrimp, clam shrimp, and tadpole shrimp) and the cladocerans (often called water fleas) (Table 1). Morphological, paleontological, and molecular data suggests that the Cladocera split off from the Spinicaudata early in the group’s history, as paedomorphic clam shrimp. The moniker ‘large’ branchiopod is a misnomer, in that, many so-called ‘large’ branchiopods are smaller than some cladocerans (Figure 1).

The large branchiopods are found in temporary and saline inland aquatic habitats on all continents including Antarctica. The Anostraca and most clam shrimp are part of the planktonic component of temporary pools, playas, and salt lakes. Notostraca and some clam shrimp are typically found at or near the bottom of temporary pools, lakes, and playas. These crustaceans are used as indicators of aquatic ecosystem health, several species are afforded protection under environmental law, and some species are economically important. As obligate aquatic macroinvertebrates, large branchiopods are important links in the aquatic food chain of ephemeral wetlands. Their presence and persistence in ephemeral wetlands (sometimes occurring in the hundreds per cubic liter of water) can serve as a biological indication of aquatic ecosystem health, which ultimately reflects on land-use practices from a larger landscape perspective.

Taxonomy

The class Branchiopoda contains the fairy shrimp, tadpole shrimp, clam shrimp, and water fleas. Molecular and morphological studies support the monophyly of the class, subclasses, and orders. Strong sexual selection has resulted in most anostracan species being well-defined morphologically, whereas the remaining groups with hermaphrodites, parthenogens, and gonochory have converged morphologically, making species difficult to define.

The Branchiopoda is divided into two extant subclasses: Sarsostraca and Phyllopoda (Table 1). Sarsostraca contains the single extant order Anostraca with around 300 species (fairy shrimp and brine shrimp),

separated into the suborders Artemiina and Anostracina (Table 2). Artemiina contains two halobiont monogeneric families: Artemiidae and Parartemiidae, commonly called ‘brine shrimp.’ Anostracina has six primarily freshwater families commonly referred to as ‘fairy shrimp’: Branchinectidae (monogeneric), Thamnocephalidae, (six genera), Streptocephalidae (monogeneric), Branchipodidae (six genera), Tanymatigidae (two genera), and Chirocephalidae (ten genera). Male genitalic morphology defines the anostracan genera. Due to their soft bodies, anostracans are nearly unknown from fossil records; the only definitive fossils are from the Miocene. Fossils of now extinct near relatives are known from the Devonian (the order Lipostraca) and the Cambrian (*Rebbachiella*).

Molecular phylogenetic studies have been conducted on anostracans, primarily defining the families and genera. Recent revisions include the Streptocephalidae, Thamnocephalidae, and portions of the Chirocephalidae.

Phyllopoda comprises three orders: Notostraca, Laevicaudata, and Diplostraca (Table 3). The Notostraca (tadpole shrimp, shield shrimp, helmet shrimp) contains one family with two (possibly three) genera. The genus *Lepidurus* has 12 described species and subspecies, and the genus *Triops* has five. *Triops cancriformis* may represent a separate genus, and preliminary molecular analyses suggest the presence of many cryptic *Triops* species. The Notostraca have been called ‘living fossils’ due to their minimal overall morphological variation since their divergence over 250 Ma. The associated lineage Kazakarthra, typically treated as a distinct order from the Notostraca, became extinct sometime in the late Jurassic.

The Laevicaudata are a unique order of clam shrimp, containing one family (Lynceidae) with three genera and 37 species. Laevicaudata has been treated as a suborder of the Diplostraca, although evidence indicates that the group represents a unique order. The Laevicaudata, Spinicaudata, and Cyclestherida are commonly referred to as ‘clam shrimp’ and often as the ‘Conchostocraca,’ although this term has lost all taxonomic meaning and has not been considered valid since the 1980s.

Molecular analyses and morphological cladistic analysis place the Laevicaudata as a lineage older than the remaining diplostracans, more closely allied to the Notostraca. No molecular analyses have been conducted within the Laevicaudata.

The Diplostraca is divided into three suborders: Spinicaudata, Cyclestherida, and Cladocera. The Cladocera are treated separately and are often combined with the Cyclestherida into a taxon called the

‘Cladoceromorpha.’ The diplostracan carapace typically has an umbone and growth lines, and exuviae and fossils have been misidentified as true clams. The Cyclestherida contains two species (one is probably an immature form of the type species), from the tropical and subtropical regions of the world, occurring in permanent and temporary waters.

The Spinicaudata has around 200 described species, however, the group is in need of revision. The Spinicaudata has three families; Cyzicidae, Leptestheriidae, and Limnadiidae. However, the only character separating the Leptestheriidae and Cyzicidae is the presence of the leptestheriid rostral spine. This spine is present in some cyzicids, so the two families may be united at some point in the future. Cyzicidae contains four described genera, Leptestheriidae contains three, and Limnadiidae contains five. The Spinicaudata are found on all continents, except Antarctica.

Table 1 Higher classification of branchiopod Crustacea

Class Branchiopoda
Subclass Sarsostraca
Order Anostraca
Suborder Artemiina
Suborder Anostracina
Subclass Phyllopoda
Order Notostraca
Order Laevicaudata
Order Diplostraca
Suborder Spinicaudata
Suborder Cyclestherida (Combined with the Cladocera into the ‘Cladoceromorpha’)
Suborder Cladocera

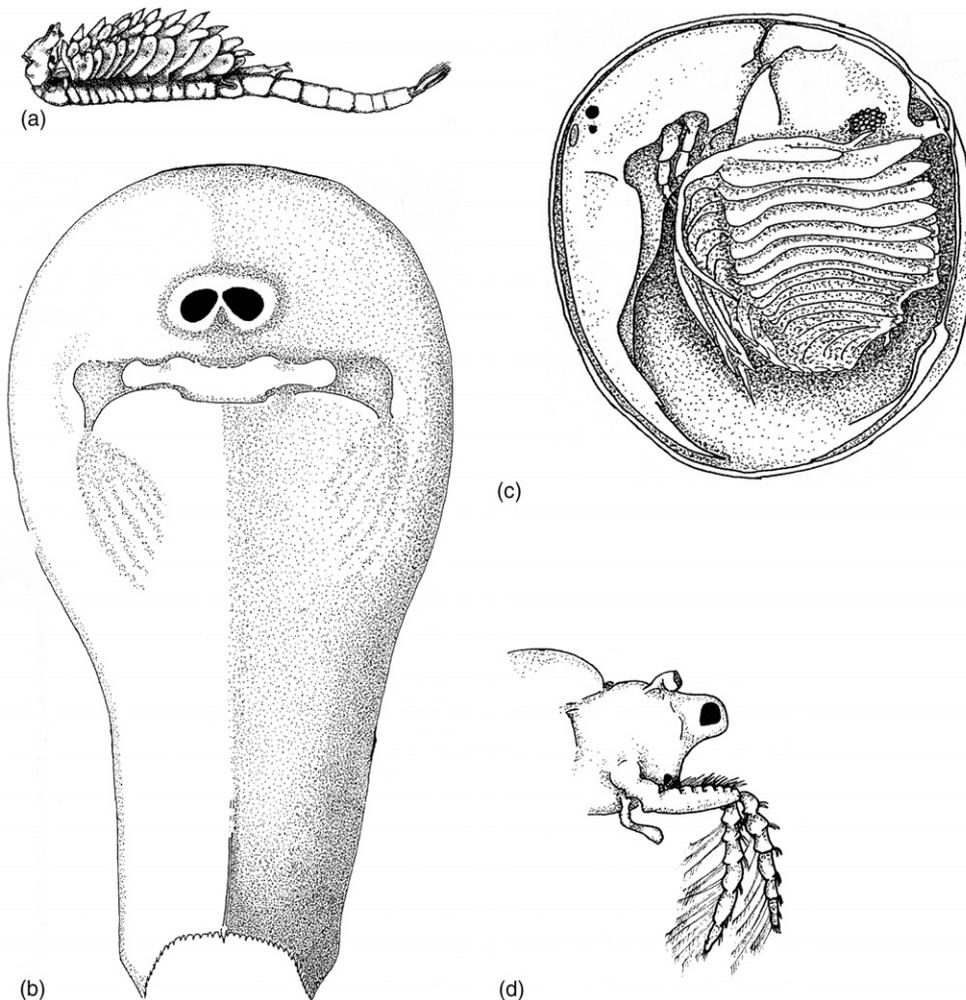


Figure 1 Representative ‘large’ Branchiopoda. (a) Anostraca, ‘fairy shrimp’ *Branchinella buchananensis* lateral view of entire animal; (b) Notostraca, ‘tadpole shrimp’ carapace of *Lepidurus viridis*; (c) Laevicaudata, ‘clam shrimp’ lateral view of entire animal, with left half of carapace removed; (d) Diplostraca, Spinicaudata, ‘clam shrimp’ lateral view of head.

Table 2 Anostracan families and genera

Subclass Sarsostraca		
Order Anostraca		
Suborder		
Artemiina		
Family	Artemiidae	<i>Artemia</i>
	Parartemiidae	<i>Parartemia</i>
Suborder		
Anostrocina		
Family	Branchinectidae	<i>Branchinecta</i>
	Thamnocephalidae	<i>Thamnocephalus</i>
		<i>Carinophallus</i>
		<i>Phallocryptus</i>
		<i>Gurneya</i>
		<i>Dendrocephalus</i>
		<i>Branchinella</i>
	Streptocephalidae	<i>Streptocephalus</i>
	Branchipodidae	<i>Australobranchipus</i>
		<i>Branchipus</i>
		<i>Branchipodopsis</i>
		<i>Metabranchipus</i>
		<i>Pumilibranchipus</i>
		<i>Rhinobranchipus</i>
	Tanymastigidae	<i>Tanymastix</i>
		<i>Tanymastigites</i>
	Chirocephalidae	<i>Branchinectella</i>
		<i>Artemiopsis</i>
		<i>Parartemiopsis</i>
		<i>Chirocephalus</i>
		<i>Galaziella</i>
		<i>Eubranchipus</i>
		<i>Dexteria</i>
		<i>Linderiella</i>
		<i>Polyartemia</i>
		<i>Polyartemiella</i>

The earliest fossil spinicaudatan clam shrimp come from marine sediments in the Devonian. Also from the Devonian is a fossil branchiopod called *Castracollis wilsonae*, with a morphology that is intermediate between Spinicaudata and Notostraca.

Morphology

The Branchiopoda are separated as a distinct class of Crustacea based primarily on the form of the larvae, which eclose as a nauplius or metanauplius. The larvae have reduced, undifferentiated first antennae, the second antennae are elongated and used for swimming, and the mandible is uniramous. One or more segments and limb pairs are added with each molt.

Branchiopods range in size from a few millimeters to 17 cm. Anostracans are typically 1–5 cm in length, however, *Dendrocephalus alachua* and *Branchinella nana* are both around 6 mm in length, while *Branchinecta gigas* and *Branchinecta raptor* may reach 17 cm. Notostracans range from 1 to 10 cm in length

Table 3 Phyllopod families and genera

Subclass Phyllopoda		
Order Notostraca		
	Family Triopsidae	<i>Triops</i>
		<i>Lepidurus</i>
Order Laevicaudata		
	Family Lynceidae	<i>Lynceus</i>
		<i>Lynceiopsis</i>
		<i>Paralimnetis</i>
Order Diplostraca		
Suborder		
Spinicaudata		
	Family	
	Limnadiidae	<i>Limnadopsis</i>
		<i>Limnadia</i>
		<i>Eulimnadia</i>
		<i>Metalimnadia</i>
		<i>Imnadia</i>
	Family	
	Leptestheriidae	<i>Leptestheria</i>
		<i>Maghrebestheria</i>
		<i>Eoleptestheria</i>
	Family Cyzicidae	<i>Cyzicus</i>
		<i>Eocyzicus</i>
		<i>Baikalolkhonia</i>
		<i>Sewellestheria</i>
Suborder		
Cyclestherida		
	Family	
	Cyclestheriidae	<i>Cyclestheria</i>
Suborder		
Cladocera		

as adults and laevicaudatans range from 4 to 14 mm. Cyclestheridians are never more than 7 mm, and spinicaudatans are typically 4–10 mm, although the genus *Limnadopsis* may reach 3 cm.

The branchiopod cuticle is thin and is comprised of proteins and lipids impregnated with chitin, with no calcification, and little sclerotization. Adult branchiopods retain the reduced first antennae of the larvae, however, the second antennae are only used for propulsion in adult Diplostraca. In anostracans, the second antennae are robust, and in males are secondarily divided into two antennomeres, variously ornamented, and modified into claspers to amplex the female prior to copulation. In notostracans and laevicaudatans, the second antennae are reduced, sometimes lost entirely in the Notostraca.

The head is proportioned to the body in anostracans, notostracans, and spinicaudatans, but is massive in the laevicaudatans, and may be larger than the rest of the animal. A rostrum is absent in anostracans and notostracans. Both the Notostraca and Laevicaudata have a cephalic pore adjacent to the eyes.

The nauplii have a single median eye, which is reduced in most adult large branchiopods, but in the

Notostraca becomes a large tubercle on the nuchal organ, behind the eyes. The adult compound eyes are fused in laevicaudatans and spinicaudatans, but are separate and borne on stalks in anostracans.

The nuchal organ or dorsal organ may be involved in ion transport. This organ lies on the dorsal surface of the head, although in the spinicaudatan family Limnadiidae it is borne on a short stalk.

A head shield of some sort is present in the larvae, although in anostracans it is lost in the post naupliar stages. Notostracans have a broad carapace covering the head and thorax, armed posteriorly (and occasionally dorsally) with stout spines. The Laevicaudata have a broad carapace as juveniles similar to the Notostraca, but this eventually divides into a true bivalved carapace, with a dorsal, grooved true hinge that does not form an umbone, and covers the entire animal. Growth lines are never present, and the carapace is subspherical in shape. In the Diplostraca, the carapace folds over the body, never developing a true hinge. With each molt, spinicaudatans and cyclestheridians add a growth line to the carapace margin.

A labrum lies over the mouth, which contains a pair of rolling type mandibles, which may also bite in predatory anostracans. Some taxa have a reduced mandibular palp. Posterior to the mandibles are the first and second maxillae, although the second maxillae may be reduced or lost in anostracans. Functioning maxillary glands are present in larvae and most anostracans.

The thorax is elongated and has the thoracopods and external reproductive organs. In anostracans, there are 11 pairs of thoracopods (reduced to 10 in most female *Parartemia*, and increased to 17 in *Polyartemiella* and 19 in *Polyartemia*). Posterior to the last pair of locomotor thoracopods, are limbs modified for reproduction. In males they are modified as paired, semiretractable gonopods, and the females as a single ventral brood pouch.

Notostracans also have 11 segments comprising the thorax, the eleventh pair modified for reproduction, with a modified basis forming a brood pouch in females and hermaphrodites. Notostracans may have from 20 to 80 pairs of trunk limbs.

Laevicaudatan males have 10 thoracomeres and females 12, all bearing thoracopods. Male first thoracopod endites are modified into claspers to amplex the female prior to mating. In the genera *Lynceiopsis* and *Paralimnetis*, the second pair may also be modified, but not as claspers. Females carry the eggs between the enlarged exopods of the thoracopods and a set of lateral lamellae projecting from the trunk. These lateral lamellae are unique to the Laevicaudata.

Spinicaudata and Cyclestherida will vary from 16 to 32 thoracomeres, each bearing paired thoracopods.

As in the Laevicaudata, the male Cyclestherida have the first pair modified as claspers, but in the Spinicaudata the first two pairs are modified as claspers. The claspers are formed from the endites, however, the claspers are formed from different endites than in the Laevicaudata. Females carry the eggs between the elongated exopods of the thoracopods, and the carapace. In the Cyclestherida, the eggs hatch and the larvae undergo partial development in the space between the female dorsum and the carapace, as in the Cladocera.

The thoracopods are lamellar, each bearing a lateral pre-epipodite that has osmoregulatory functions. Branchiopod limbs typically consist of a basal protopod, with one or two pre-epipodites, an epipodite, an exopodite, an endite, and several endopodites, the proximal two being fused in the Anostraca. The name 'branchiopod' literally means 'gill foot,' as it was once thought that the thoracopods were also gills. It is now known that the entire body functions as a gill.

The abdomen is elongate and cylindrical in anostracans and notostracans, ending in a telson with a terminal anus, flanked by a pair of cercopods. The anostracan abdomen is appendageless, but may be ornamented with spines, or protrusions. The notostracan abdomen may bear numerous pairs of serially homologous limbs, with several pairs per body segment. Notostracan abdominal segment chitinized cuticular sections may wrap around the body two or more times, distorting the number of body rings.

The abdomen of the Laevicaudata is reduced to a single anal somite bearing the anus and paired filaments, but no appendages. In the Spinicaudata and Cyclestherida, the abdomen is represented by a large chitinized telson with a terminal anus, large caudal furcae, and a pair of terminal filaments. No appendages other than the furcae are present.

Ecology

Habitat

Large branchiopod crustaceans are a component of the zooplanktonic community within episodic, ephemeral aquatic habitats, often occurring in densities of 200 individuals per liter of water or more. Most large branchiopods need drought to dry the resting eggs and prevent them from fungusing. Typical habitat for large branchiopods include vernal pools, seasonally ponded areas within vernal swales, seasonal wetlands, tundra pools, alpine pools, rock outcrop ephemeral pools (tinajas, gnammas), clay flats, salt lakes, playas, and alkali flats. The diapausing eggs lay dormant in or on the substrate during the dry and/or frozen stages of

the habitat phenology, hatching when liquid water is present.

Some species occur in pools that never become completely dry (*Streptocephalus sealii*, *Lynceus brachyurus*, *Artemia monica*), occurring in permanent salt lakes, fishless permanent pools, or wetlands that dry to damp soil. In the arctic tundra and on the Antarctic Peninsula, there are pools that never dry, freezing solid in the winter, with anostracans and notostracans hatching when the pools melt each spring. Other large branchiopods live in habitats that may remain completely dry for several years or even decades (*Branchinella*, *Thamnocephalus*, *Triops* sp.).

Pool volume is important to some taxa. Many species are found in larger temporary pools because deeper pools with a large surface area can more easily maintain their dissolved oxygen levels. These habitats may last for several months and are often used by the Chirocephalidae, Artemiidae, Parartemiidae, some lynceid clam shrimps, and the notostracan genus *Lepidurus*. Conversely, some species complete their life cycle (egg to adult with eggs) in habitats that last 3–5 days (Branchipodidae, Branchinectidae, and Streptocephalidae). Most species are found in temporary habitats that last from 15 to 40 days.

Various physiochemical factors have been examined in branchiopod habitats including alkalinity, total dissolved solids (TDS), and pH. However, the importance of many of these parameters may be minimal, as the type and amount of dissolved salts may be a more important habitat requirement. Considering the daily fluctuations in pH of a given habitat, this is to be expected. During the daylight hours, hydrophytes (if present) are photosynthesizing, removing the CO₂ (from HCO₃) from the water, and raising the pH. During the night, the hydrophytes are respiring, increasing the CO₂ (and thereby, the HCO₃) in the water lowering the pH. If there is rainfall, the distilled precipitation will lower the pH, as will winds that cause surface action. When the habitats are drying and losing volume through evaporation, the pH, alkalinity, TDS, and electrical conductivity will increase, just as they decrease when the pools inundate or reinundate. As a result, most large branchiopods are osmoconformers, with salt lake species being hypo-osmotic regulators. Some taxa (some *Branchinecta* and *Branchinella*) are capable of both.

Life History

Large branchiopod eggs are released, deposited, or retained in the body of the parent. Typically, the eggs are subjected to drying, freezing, or both in their environment, often at extreme temperatures. Eggs kept in anoxic conditions for years show no evidence of

oxygen debt. Large heat shock proteins have been isolated from *Artemia* eggs, but the exact role of the protein is not entirely understood. Most large branchiopod eggs are resistant to desiccation, the stomach acids and enzymes of predators, freezing, and prolonged burial, remaining viable even under anoxic conditions for decades, possibly even centuries. Shrimp eggs subjected to boiling water, freezing in liquid nitrogen, and even exposed to the vacuum of space during a U.S. Space Shuttle Mission were still viable.

When habitat occupied by large branchiopods inundates from seasonal rainfall, rising water tables, snowmelt, or runoff, some of the eggs hatch, and the nauplii swim into the upper water column. Beyond inundation of the habitat, the specific cues for hatching are unknown, although temperature and conductivity are believed to play a large role. Rhodopsin is present in the eggshell, and when triggered by an outside energy source after wetting, moves to the embryo, which then becomes active.

Only a fraction of each egg clutch hatches with each pool inundation. This is a ‘bet-hedging’ strategy, in that if all the eggs were to hatch and the habitat dried before the shrimp could reproduce, then the population would be eliminated. Since only a fraction hatches, a given habitat can fill and dry numerous times with a hatch of shrimp each time.

The maturation rates of the animal vary extensively depending upon temperature and habitat. Some *Branchipodopsis*, *Branchinecta*, and *Streptocephalus* can mature in 3–6 days, whereas *Triops*, *Lepidurus*, *Cyzicus*, *Artemia*, *Chirocephalus*, and others may take 18 days or longer.

Reproduction may be sexual, parthenogenic, or gonochoric. Spinicaudatan clam shrimp populations commonly have protandrous hermaphrodites. Notostracans are typically parthenogenic or gonochoric, but some species with separate sexes do occur.

In anostracans, sexes are separate, except for a few parthenogenic *Artemia* species and possibly one *Streptocephalus*, in which males are rare or absent. Typical anostracans have a highly coadapted mate recognition system, wherein the male displays his enlarged and ornamented second antennae and antennal or cephalic appendages (if any) to the female. If the female does not swim away, the male approaches the female from beneath and behind, and amplexes the female with the enlarged second antennae. Amplexus occurs either between the last pair of thoracopods and the brood pouch in a specialized amplexial groove, or on the brood pouch itself. Many families (Chirocephalidae, Branchipodidae, Tanyastigidae, Parartemiidae) have a unique, species-specific ‘lock-and-key’ complimentary coupling between the ornamentation of the male second

antennae and the female amplexial groove, the result of sexual selection.

Amplexus may be sustained for a second or two with rapid mating and release (Branchinectidae, Thamnocephalidae), or may last for hours or even days (Artemiidae, Parartemiidae, Chirocephalidae). The female typically sheds her eggs as the shell forms over the fertilized oocytes, and the eggs fall to the substrate, or are retained (*Artemiopsis*).

Predator consumption of branchiopod eggs aids in population distribution. Predators (e.g., birds, amphibians, fish) expel viable eggs in their excrement, often at locations other than where they were consumed. If conditions are suitable, these transported eggs may hatch at the new location and potentially establish new populations. Eggs are also transported by wind, and in mud carried on the feet of animals, including livestock (or biologists) that wade through the habitat.

The vast majority of large branchiopods are omnivorous filter feeders, indiscriminately filtering particles from the water column, including bacteria, unicellular algae, and micrometazoa. Most branchiopods will attempt to consume whatever material they filter from the water column and can fit into their food groove, and do not discriminate based upon taste, as do some other crustacean groups. Anostracans, laevicaudatans, and spinicaudatans will also rasp periphyton from rocks, sticks, stems, and slender leaves. Notostracans will filter feed, but as adults are more typically omnivorous, with a strong preference for animal matter, and will capture and consume live invertebrates, amphibian larvae, or carrion. The Notostraca and some species of Branchinectidae are often predatory, and the anostracan *Branchinecta raptor* is an obligate predator as an adult.

Trophic Relationships

Large branchiopods are typically a component of a larger invertebrate community structure. This invertebrate community includes mostly planktonic Crustacea dependent on temporary wetlands including copepods, cladocerans, and ostracods, as well as turbellarians, and a suite of insect species.

Large branchiopods can occur in high densities and are readily filtered from the water by ducks, flamingoes, avocets, and other wading birds. Herons, storks, and cranes, as well as shrews, amphibians, and temporary water fish (*Galaxia*, Cyprinodontids) will all consume large branchiopods.

Being prey items of birds, large branchiopods are an intermediate host for avian cestodes. Anostracans that are hosting a cestode tend to be bright pink in color. The cestode *Cysticercoides* castrates the anostracan host, causing the shrimp to accumulate

lipids (probably linked to carotenoid pigments) that would otherwise be expended by the host during reproduction.

No specific bacterial, viral, or protozoan diseases have been reported from large branchiopods. Occasionally, specimens with black markings or lesions will appear in collections. These black markings, sometimes referred to as 'black disease,' are actually evidence of the normal immune response of all Crustacea to any bacteria, where any foreign bacteria is infused with melanin to lethal levels. Branchiopod crustaceans are commonly found with phoretic ciliate protozoan colonies, which are abandoned on the exuvium with each molt.

Conservation Issues

Of the nearly 500 described species of large branchiopods, more than one-fourth are known only from their type localities, and several species have only been collected once or twice. Many species are on the International Union of Conservation of Nature and Natural Resources' Red List, and 20 or so are listed as rare, threatened, or endangered at either state or federal levels in the United States. Australia, Austria, and other nations have species protected under law as well. The first large branchiopod preserve was established in Austria in the 1990s to protect the Anostracan *Chirocephalus shadini*. Similar preserves have developed in the United States and Brazil.

Habitat occupied by large branchiopods typically exists on level open ground. This geomorphic setting tends to be the most desirable for agricultural, urban, or industrial development. The greatest threat to ephemeral wetland invertebrates is the elimination or modification of their habitat by development. The filling of ephemeral wetlands or modification of the watershed that supports those pools either eliminates the habitat or disrupts the pool ecosystem to where it is overcome by opportunistic species that out compete the obligatory ephemeral wetland species.

Damage to the watershed that supports temporary wetlands will impact temporary wetland invertebrate communities. Elimination of the watershed will not allow the wetlands to pond properly and will curtail the movement of nutrients into the wetland. Road runoff entering the watershed and conveyed to occupied habitat through the watershed may carry petroleum by-product residue or sediment from vehicles, paving, or road maintenance activities. Furthermore, pesticide, herbicide, fertilizer, and sediment runoff from agricultural activities may enter the watershed and be conveyed to the occupied habitat and may be injurious to seasonal pool invertebrates. Ground

disturbance from development activities may loosen soil that could enter the watershed and be conveyed to habitat as sediment.

Nonnative invasive species are a threat to temporary wetland invertebrate communities. Invasive *Artemia* populations are becoming established in Western Australian salt lakes, competing with the endemic *Parartemia*. In addition, people may introduce nondiscriminating predatory fish into temporary wetland to control perceived local mosquito problems.

Habitat fragmentation is a threat to wetland invertebrates in that the development surrounding small temporary wetland complexes may prevent waterfowl or shorebirds from feeding at the pools, thereby preventing genetic flow between occupied habitats. Furthermore, small pool complexes surrounded by development will not be buffered against the runoff from developed areas and concomitant changes in the watershed hydrology.

Additional threats to the temporary wetland invertebrate community structure include off-road vehicle use of temporary wetland habitat, conversion of temporary wetlands into permanent livestock waterholes that do not dry, and draining of temporary wetlands. The monobasic genus *Rhinobrachhipus* has only been collected from a single pool in the Thomas Baines Nature Reserve, Republic of South Africa. This pool was altered by the Reserve from a temporary pool into a permanent pool, stocked with fish, and had a bird observatory built next to it.

Economic Importance

Large branchiopods are important to the commercial aquaculture industry. The Anostracan genus *Artemia* is used as a rapidly growing food source for farm fish, mollusks, and shrimp. The eggs are collected in bulk from salt lakes and shipped dry to aquaculture farms. The eggs can be stored dry until needed and then easily hatched in bulk as live food. Because *Artemia* does not differentiate the particles it ingests, antibiotics, medications, or vitamins are suspended in droplets of fat and fed to the shrimp. The shrimp, then, become 'living pills' are easily fed to the aquacultural livestock. This form of medicating the fish is advantageous, as previously these materials dumped into the tanks were removed by filtration, with little chance of the fish obtaining an accurate dosage, and then often discharged into the local environment. In addition to *Artemia* as an aquaculture feed, *Dendrocephalus brasiliensis* and *Eulimnadia colombiensis* are used in Brazil, and *Parartemia* is being investigated for use in Australia.

In the pet industry, *Artemia* is used worldwide as an aquarium fish food, both live and dried, and the clam

shrimp *Leptestheria compleximanus* is used as a pet food in México. In Thailand, local peoples consume paste made from the fairy shrimp *Streptocephalus sirindhornae* reared in aquaculture.

Artemia is frequently sold by the pet industry as 'Sea Monkeys' and the tadpole shrimp *Triops* is sold as a 'living fossil.' As a result, large numbers of pet owners who keep *Artemia* or *Triops* have formed clubs and internet chat rooms. Unfortunately, some have begun shipping eggs overseas to other collectors, raising the possibility of new invasive species concerns. Conversely, this trend has raised public awareness of the animals and promoted their conservation, resulting in increased public knowledge of basic temporary wetland ecology, and working to preserve these habitats in their regions.

See also: Cladocera; Egg Banks; Role of Zooplankton in Aquatic Ecosystems.

Further Reading

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