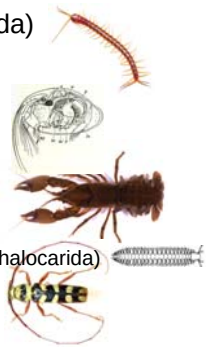
Main arthropod clades (Regier et al 2010)

- Trilobita
- Chelicerata
- Mandibulata
  - Myriapoda (Chilopoda, Diplopoda)
  - Pancrustacea
    - **Oligostraca** (Ostracoda, Branchiura)
    - **Altocrustacea**
      - **Vericrustacea**
        - » (Branchiopoda, Decapoda)
      - Miracrustacea
        - » Xenocarida (Remipedia, Cephalocarida)
        - » Hexapoda

Crustacean phylogeny…?

"It can be concluded that crustacean phylogeny remains essentially unresolved. Conflict is rife, irrespective of whether one compares different morphological studies, molecular studies, or both."

Jenner, 2010: Arthropod Structure & Development 39:143–153

Phylum Arthropoda

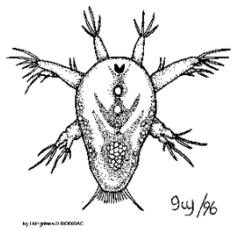
Subphylum (or Class) Crustacea

Mostly aquatic, with calcified exoskeleton.

Head derived from acron plus next five segments- so primitively has 5 pairs of appendages:

-2 pair antennae
- 1 pair of jaws
- 2 pair of maxillae
- usually a median (cyclopean) eye and one pair of compound eyes

Tagmosis of trunk varies in different taxa



Nauplius

- first larva stage of most crustaceans.
- three pairs of appendages
- single median (naupliar) eye

Appendages:
- 1st antennae
- 2nd antennae
- mandibles

Crustacean taxa you should know

Class Remipedia

Class Branchiopoda

- **Notostraca –**tadpole shrimp
- **Anostraca-**fairy shrimp
- **Cladocera-** water fleas
- **Conchostraca-** clam shrimp

Class Maxillopoda

- **Ostracoda-** ostracods
- **Copepoda-** copepods
- **Branchiura-** fish lice
- **Cirripedia-** barnacles

Class Malacostraca

"Peracarida"-marsupial crustacea

- **Isopoda-** isopods
- **Amphipoda-** amphipods
- **Mysidacea-** mysids

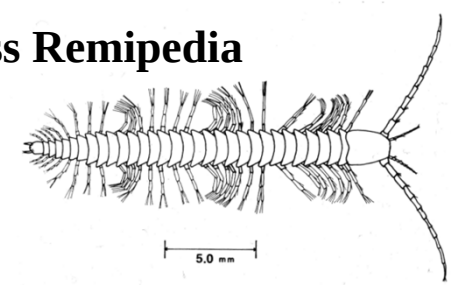
"Eucarida"

- **Euphausiacea-** krill
- **Decapoda-** decapods- ten leggers
  - **Penaeoidea-** penaeid shrimp
  - **Caridea-** carid shrimp
  - **Astacidea-** crayfish & lobsters
  - **Brachyura-** true crabs
  - **Anomura-** false crabs

"Stomatopoda"– mantis shrimps

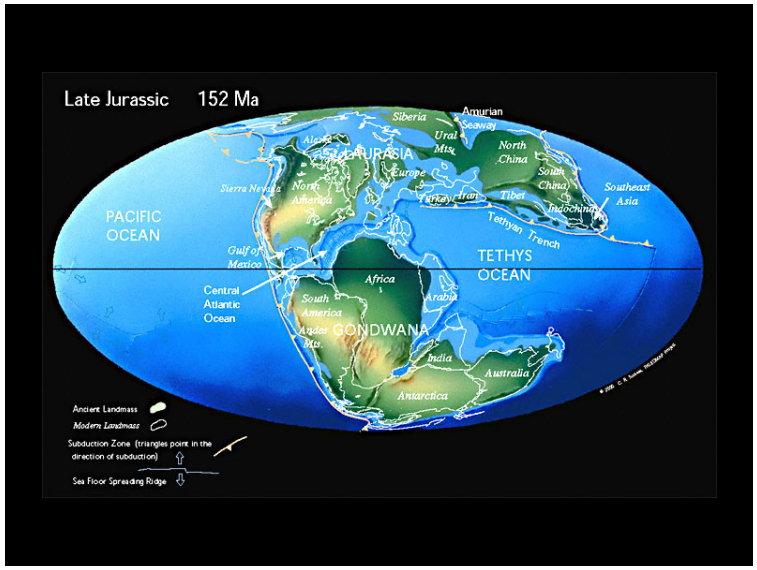
Remipede habitat: a sea cave "blue hole" on Andros Island. Seven species are found in the Bahamas.

Class Remipedia



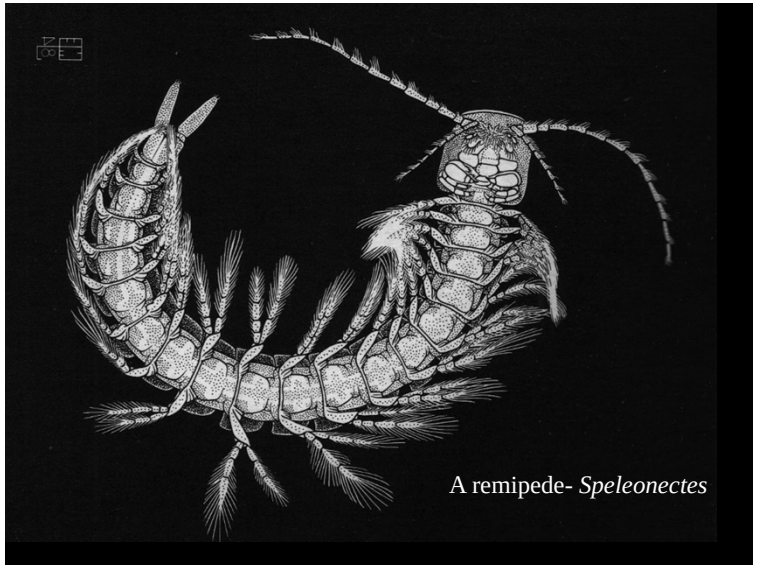
- Primitive class of crustacea? (11 species)
- Discovered in 1981 by Jill Yager, sport diver and high school teacher, now professor at Antioch College
- Long trunk of similar segments, each with a pair of biramous appendages

Remipides found only in sea caves in the Caribbean, the Canary Islands, and Western Australia (see pink below). These areas were last linked as coastline ~150 million years ago, around Tethys Sea, during breakup of Pangea



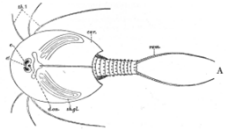
Class Branchiopoda

- About 900 species in 4 orders, mainly in ephemeral freshwater and brackish water
- Thoracic appendages flattened and similar, usually no abdominal appendages
- Telson usually has paired caudal cerci (forked "tail")
- Carapace shield-like posterior and lateral extension of head exoskeleton, present in all but one order.
- Embryos of many branchiopods are capable of anhydrobiosis



Branchiopod orders

Notostraca
" tadpole shrimps"

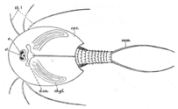


Anostraca
"fairy shrimps, brine shrimp"

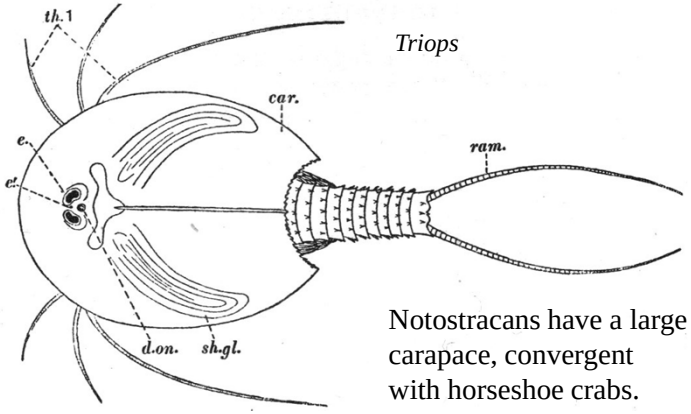
Cladocera
"water fleas"

Conchostraca
"clam shrimps"

Order Notostraca (tadpole “shrimps”)



- Extensive carapace
- Two living genera- *Triops, Lepidurus.* Both are known as fossils from the Triassic period (245 to 208 million years ago Notostracan carapaces date to Carboniferous (360 to 286 million years ago)
- Popular novelty item- the new and improved sea monkeys. Detritus from ephemeral lakes in California contains dormant eggs of these and other Branchiopods.
- California vernal pool species *Lepidurus packardi* (and a couple of anostracans) listed as endangered



Triops

Notostracans have a large carapace, convergent with horseshoe crabs.

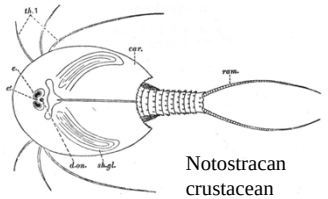
Cosmopolitan- I once found *Triops* in a rain pool on top of a desert mountain range in California.

Morphological convergence in four benthic arthropods

Trilobite

Modern isopod crustacean

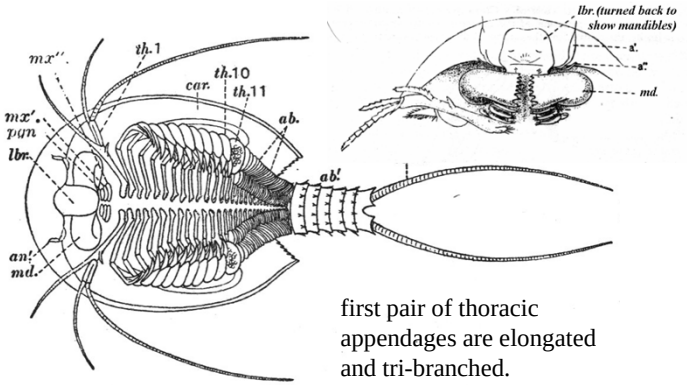
Chelicerate *Limulus*



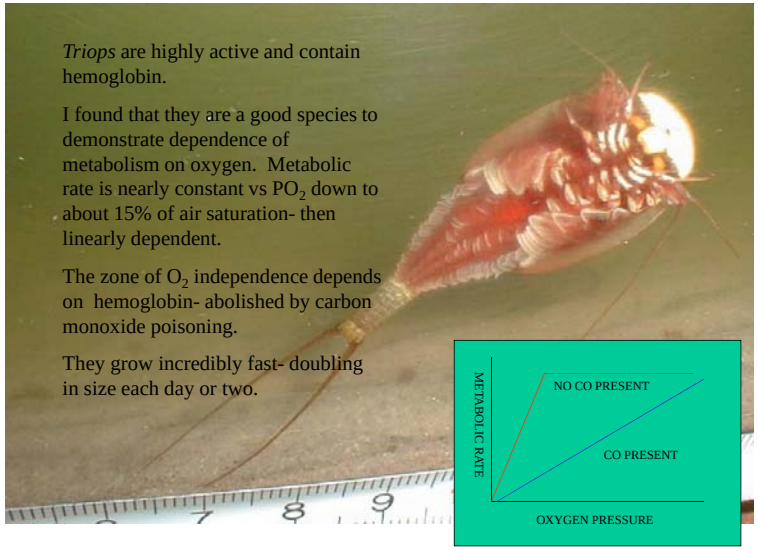
Notostracan crustacean

Notostracan anatomy

The jaws (*md.*) are partly hidden behind a large labrum *(lbr.)*– analogous to the hypostome of trilobites.



first pair of thoracic appendages are elongated and tri-branched.



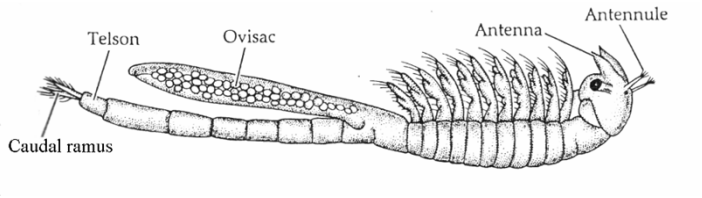
Some selected items from the lake detritus sold as part of a "Triassic Triops" kit.

#1,2,5 are plant seeds. #6 are *Triops* eggs. #7 cladoceran ephippia. #3 oolite. #4??

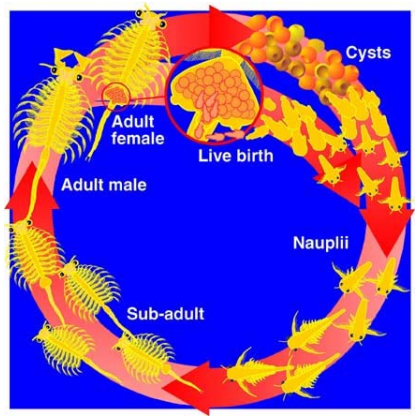
Notostraca are omnivorous.
They can be pests in rice fields by eating seedlings.

Order Anostraca (fairy shrimp, brine shrimp)

- Lack a carapace
- Most are mobile suspension feeders on phytoplankton
- Sexual and asexual populations



***Artemia franciscana* life cycle**



During spring and summer the eggs hatch during release from the female (ovoviparity).

During the fall, cysts form- a dormant stage capable of anhydrobiosis

The *Artemia* Story

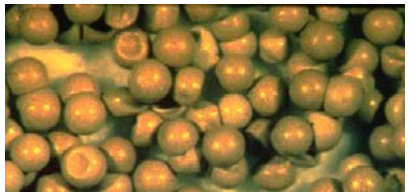
- Brine shrimp live in hypersaline lakes (up to 25% salt). Predators and competitors are few, and algal production is high.
- *Artemia franciscana* lives in Great Salt Lake (above) and San Francisco Bay.
- During summer, eggs hatch during release. In the fall, dormant eggs (cysts) are produced.

Brine shrimp are suspension-feeders on phytoplankton

Artemia nauplii

1980's- *Artemia* becomes big business in Utah

- Cyst harvest at Great Salt Lake became a "gold rush" as shrimp aquaculture expanded worldwide. Mid-1990's Demand pushed cyst prices to $30-40/pound and harvest to 15 million pounds in '95 and '96.
- Primary cyst harvest at Great Salt Lake worth about $50 million annually (>90% of the supply). Small amounts from San Francisco Bay, China, Tibet,.



The *Artemia* Industry

1950-60's

adult *Artemia* were harvested and sold for aquarium fish food.

Cysts were sold as a novelty item.

1970's - present

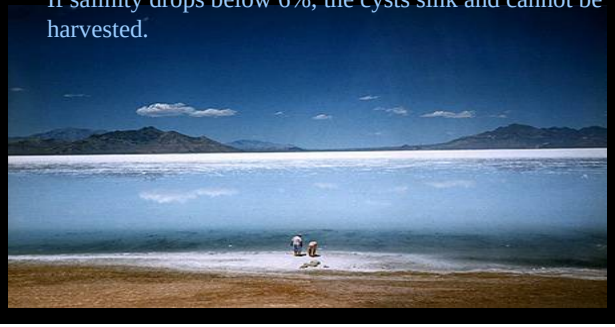
the market shifted to cysts for aquaculture-

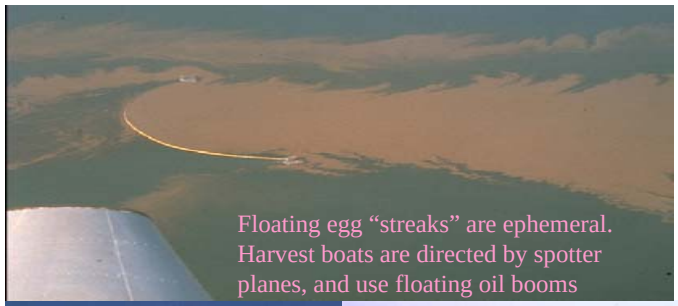
the larvae of penaeid shrimps and some fish are fed on brine shrimp

~35 companies in 1996-

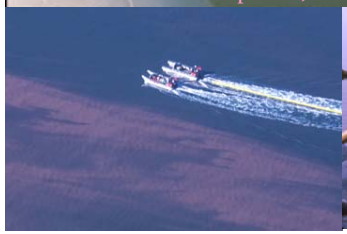
Why Great Salt Lake?

- Big- 2,500 square miles in area. A remnant of Pleistocene Lake Bonneville.
- Salinity usually high ~10-25% (seawater is 3.3-3.5%)
- Ideal salinity for food organisms and *Artemia* is ~12%. If salinity drops below 6%, the cysts sink and cannot be harvested.





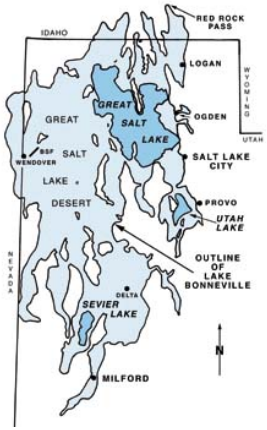
Floating egg "streaks" are ephemeral. Harvest boats are directed by spotter planes, and use floating oil booms



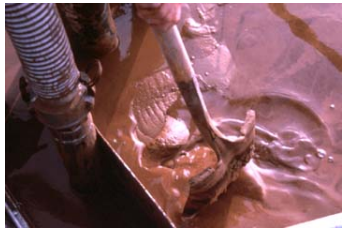
Lake Bonneville

Occupied the lowest, closed depression in the eastern Great Basin

At largest extent (1400-3200 years ago) it covered ~20,000 square miles of western Utah and smaller portions of eastern Nevada and southern Idaho.



Harvest is regulated by Utah DWR. Season is October-January



Order Cladocera

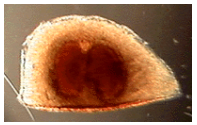
- water “fleas” 80 genera, 400 species.
- Freshwater zooplankton- important food for larval fish. (Unlike most branchiopods, which can’t coexist with fish!)
- Extensive carapace forms a bivalve shell
- Single compound eye
- The antennae provide propulsion.
- Feed mainly on phytoplankton- therefore an important trophic link in freshwater

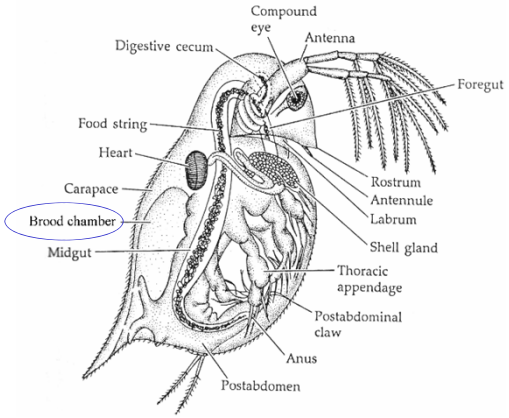
Cladoceran eggs are laid in a brood chamber between carapace and trunk.

Favorable conditions- amictic diploid eggs (parthenogenesis)

Limiting conditions- mictic haploid eggs. If unfertilized, become males. If fertilized, become resting eggs.

Resting eggs are within a case called an ephippium





A cladoceran (*Bosmina*) from the Chesapeake Fish Hatchery solar pond.

Polyphemus- a predaceous cladoceran

ovoviviparity

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- **Copepoda-** copepods
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"Peracarida"-marsupial crustacea

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  - **Brachyura-** true crabs
  - **Anomura-** false crabs

"Stomatopoda"– mantis shrimps

Class Branchiopoda

Order Conchostraca (=Laevicaudata)

Clam "shrimps"

Not to be confused with Class Ostracoda

Bivalve carapace <u>with growth lines</u>

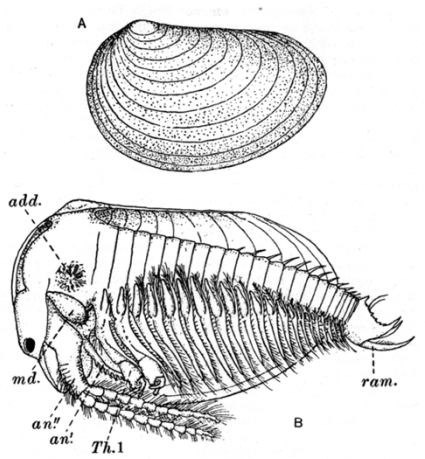


Fig. 243. *Estheria obliqua*. From Calman, after Sars. A, Shell of female, from the left side. B, Male seen from the side after removal of left valve of shell. *add.* adductor muscle; *an.'* antennule; *an.''* antenna; *md.* mandible; *ram.* caudal ramus; *Th.* 1, first thoracic limb.

Class Maxillopoda

- "Short crustaceans" 5-6-4 plus telson
- Abdominal appendages mainly absent
- Unique compound naupliar eye- 3 cups

- Subclasses….copepods, barnacles, ostracods

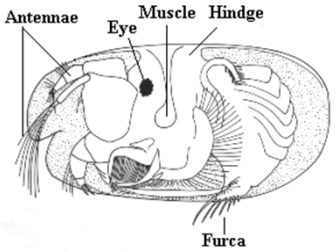
Subclass Copepoda - copepods

- Diverse ~12,000 species in 10 orders.
- Widespread- marine, freshwater, groundwater
- Mostly free-living, but numerous ectoparasitic species
- Highly abundant and significant zooplankton, trophic link from phytoplankton

Class Ostracoda

Diverse- 8,000 living species, marine, freshwater, terrestrial

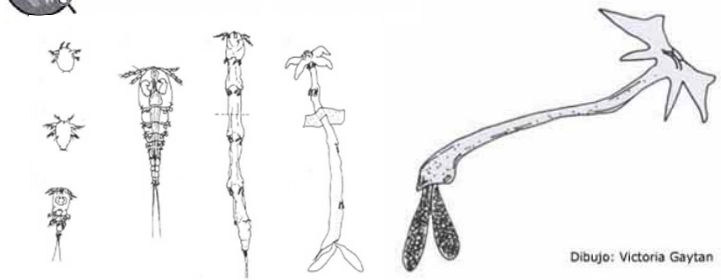
Most ostracods are very small, few are more than 4 mm long.

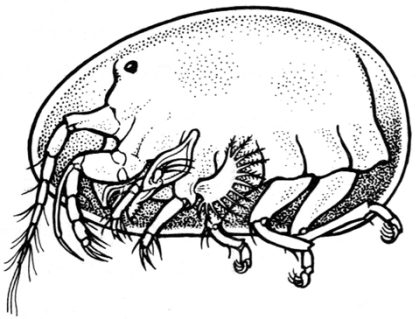


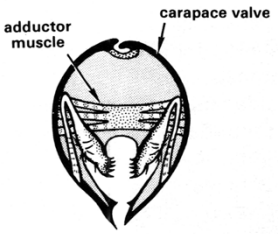
- Bivalve carapace hinges dorsally. No growth rings.
- Segmentation is reduced-
  They have the usual five pairs of head appendages
- The trunk is short, has only 1-3 pairs of limbs, ends in a multi-pronged tail (furca).

Lernaea (“anchorworms”)

Copepod parasites of freshwater fish- female is highly modified for attachment

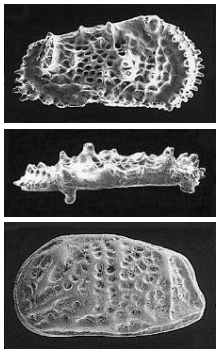


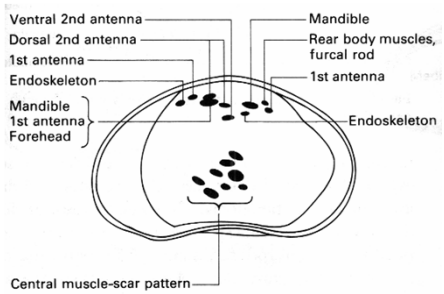


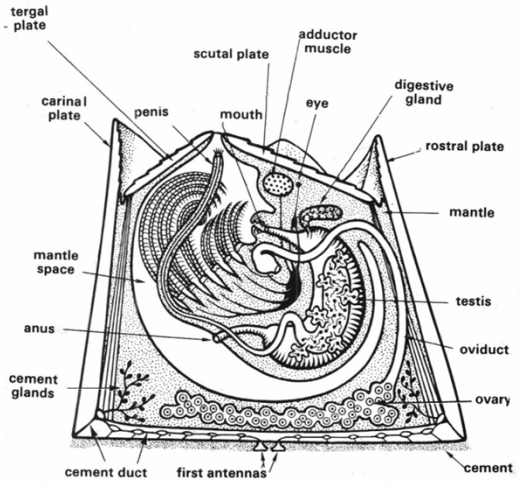


Fossil Ostracods are abundant and diverse- important stratigraphic indicators

Ornamentation and internal muscle scars are used for identification.







Cirrepedia – barnacles

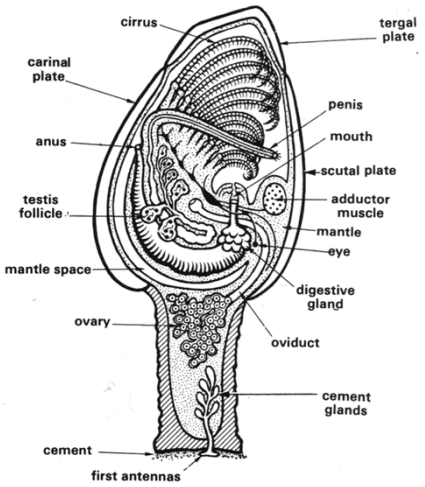
Adult body modified for life as an attached suspension-feeder (or in some, parasitism)

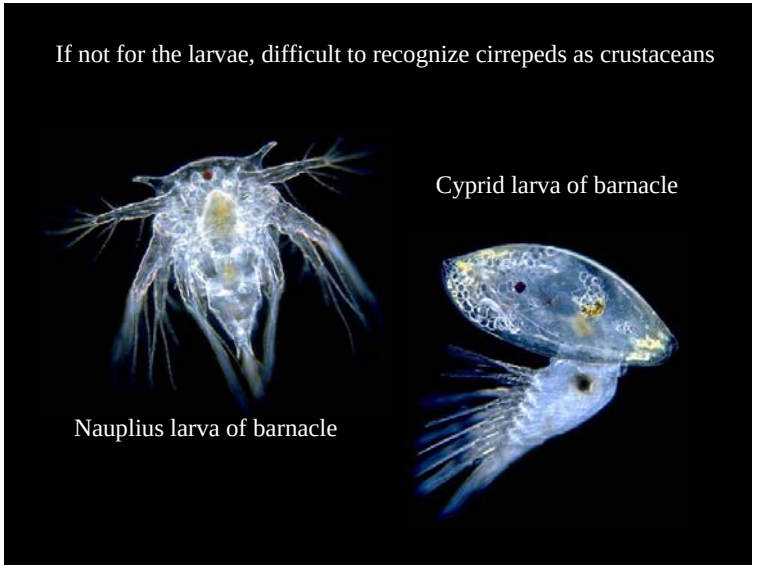
Barnacles (Order Thoracica) use feathery thoracic legs to suspension-feed.

Carapace is modified into a soft mantle that secretes hard, external, calcareous plates (analogous to mollusc mantle/shell)

"stalked" vs "stalkless" barnacles

Rhizocephalans (Order Rhizocephala) are highly modified internal parasites of decapods



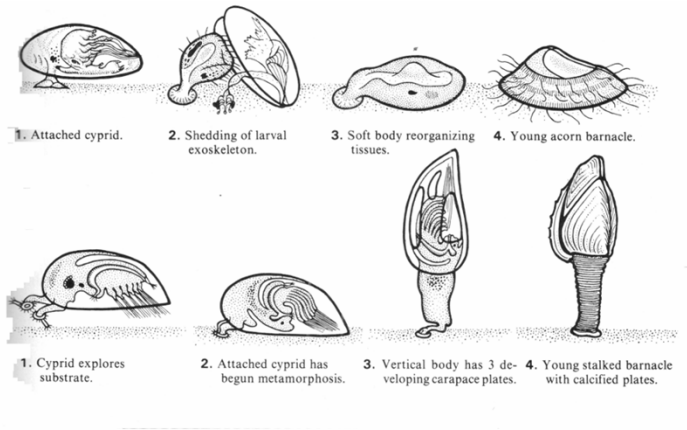


Barnacle feeding appendages

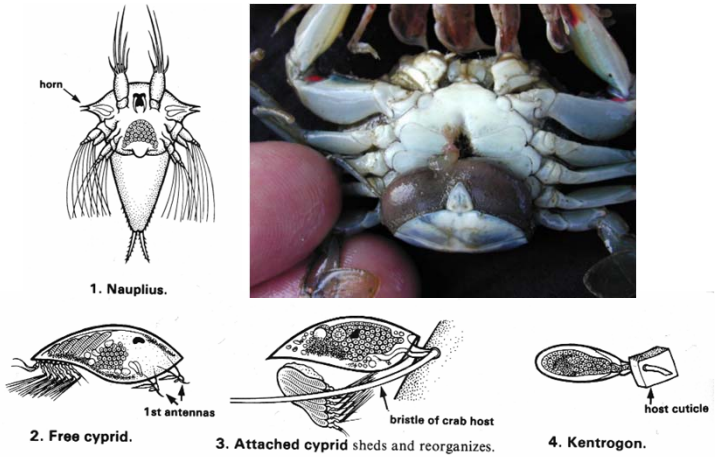
Remember- arthropods have no cilia for moving water during filter feeding.

Barnacles sweep their limbs through the water.

Metamorphosis of cyprid larva in acorn and gooseneck barnacles



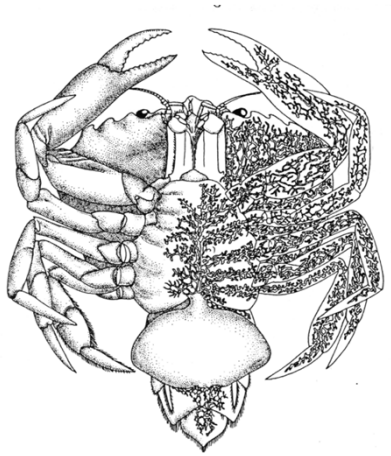
The rhizocephalans- life stages of *Sacculina carcina*



Sacculina carcinus is a serious pest of blue crabs (a commercially important species)- it causes host sterility.

The picture shows the internal part of the parasite (the "interna") ramifying throughout the host body.

The "externa", under the crab's tail, is the parasite's gonad



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"Stomatopoda"– mantis shrimps

Class Malacostraca

The largest class of crustacea- 20,000+ species

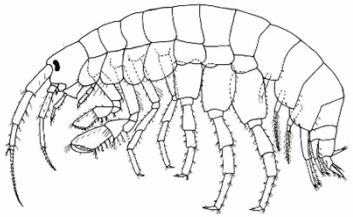
Tagma: 5-8-6

5 segment cephalon (plus the acron)
8-segment perion (thorax)
6-segment pleon (abdomen) (plus telson)

Includes peracarids (amphipods, isopods, mysids), hoplocarids (mantis shrimps), euphasiids (krill) and decapods (crabs, shrimps, lobsters, crayfish,

Peracarida

Order Amphipoda



Very diverse group~ 6,000 species- marine, freshwater, few terrestrial.

Laterally flattened.
Can crawl with pereopods or swim with pleopods

The name “amphipod” refers to the fact that the first 2 pairs of pereopods are subchelate gnathopods.

Thoracic gills- unique ventral projections of the body wall, ventilated by movements of the pleopods.

Class Malacostraca

Peracarida

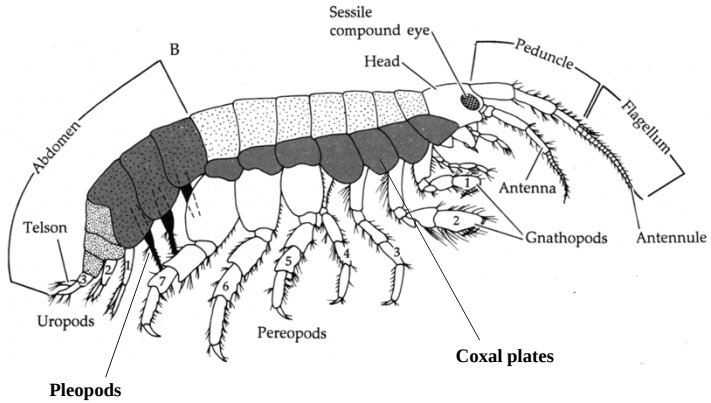
Includes amphipods, isopods, mysids and others

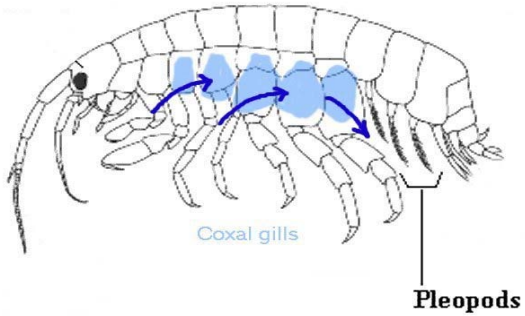
“the marsupial crustaceans”- females have oostegites - medial appendages on the pereopods that form a brood pouch for the eggs and young.

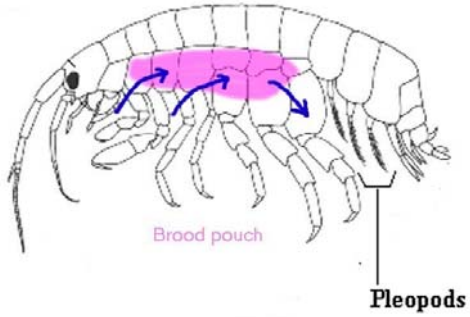
Direct development (no larval stages)

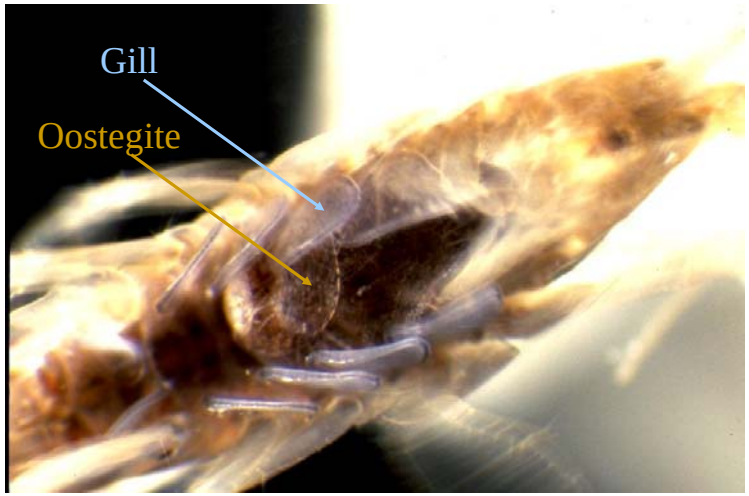
Carapace reduced or absent, most with sessile compound eyes (stalked in mysids).

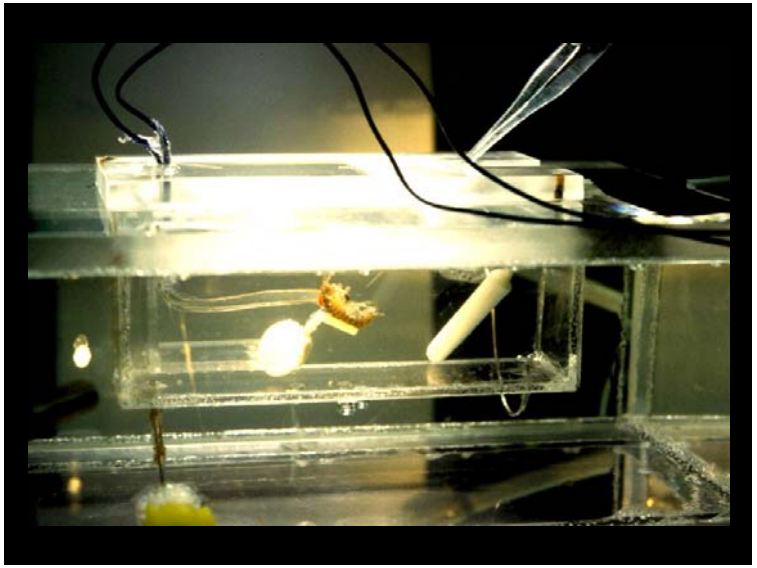
Usually 1 pair of pereopods is modified as maxillipeds- so 7 pairs of thoracic appendages

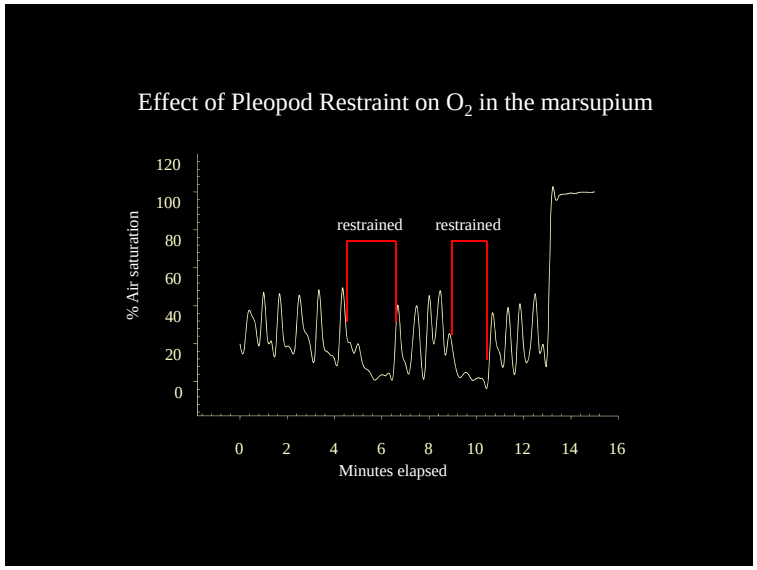



Coxal gills
Pleopods


Brood pouch
Pleopods


Gill
Oostegite

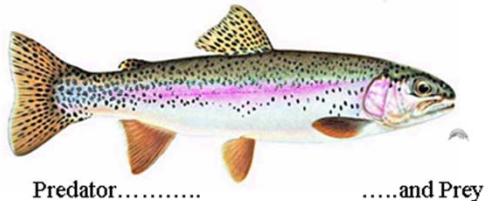




Pouch juveniles from females fed with green (left) and orange (right) flake food

A new species of the amphipod genus *Crangonyx* (ca. 8 mm long) from Mammoth Cave System, Kentucky, USA

Hyperia macrocephala- Antarctic ice-feeding amphipod



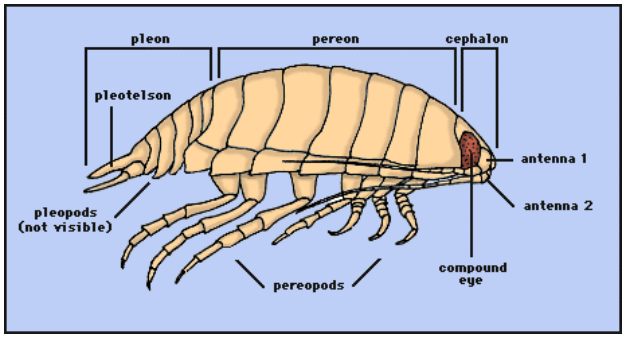
Predator…….. …..and Prey

Model…….. …..and Mimic

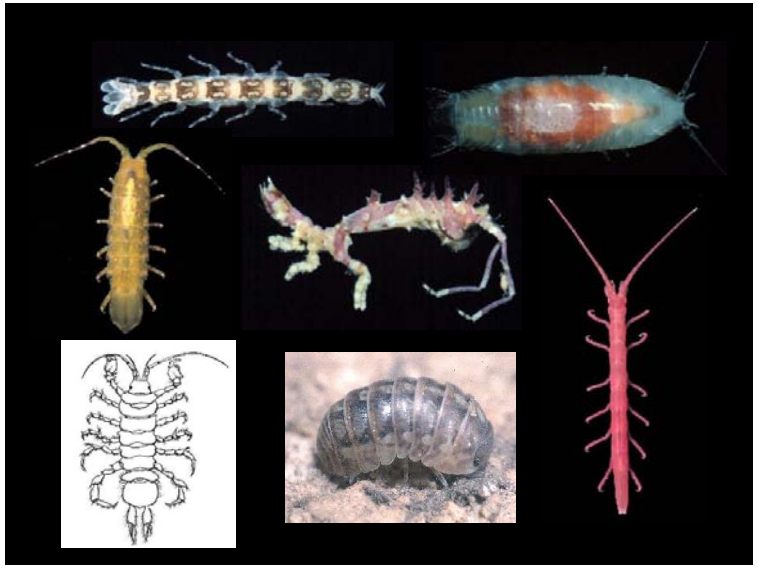
Peracarida

Order Isopoda

- Even more diverse than amphipods-10,000 species: 5000 land, 4500 marine, 500 FW,
- Dorsoventrally flattened – freshwater and land forms can only walk, but some marine forms can swim with pleopods
- The pleopods are gills (no thoracic gills). In land forms there are branched invaginations in the pleopods for gas exchange

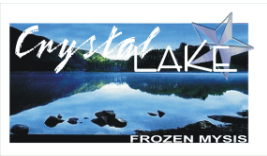


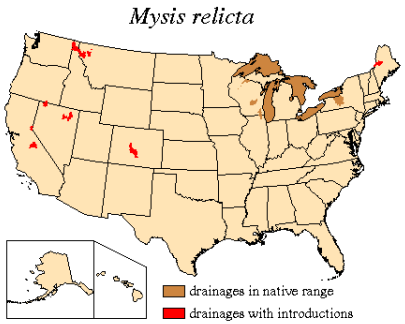

M. C. Barnhart



Peracarida

Order Mysidacea- opossum "shrimps"
Mysis relicta from Great Lakes was introduced into western lakes in as forage for trout





Yet another introduced species problem…

- *Mysis* is good food for lake trout and lake whitefish in the Great Lakes
- It was introduced into several big lakes in Montana as food for kokanee salmon
- But it feeds on large zooplankton during the night and then goes deep during the day- kokanee do not go deep during the day.
- *Mysis* has caused collapse of kokanee in Flathead Lake and elsewhere. Also the native bull trout, *Salvelinus confluentus*, which is now endangered.

Crustacean taxa you should know

Class Remipedia

Class Branchiopoda

- **Notostraca** –tadpole shrimp
- **Anostraca**-fairy shrimp
- **Cladocera**- water fleas
- **Conchostraca**- clam shrimp

Class Maxillopoda

- **Ostracoda**- ostracods
- **Copepoda**- copepods
- **Branchiura**- fish lice
- **Cirripedia**- barnacles

Class Malacostraca

"Peracarida"-marsupial crustacea

- **Isopoda**- isopods
- **Amphipoda**- amphipods
- **Mysidacea**- mysids

"Eucarida"

- **Euphausiacea**- krill
- **Decapoda**- decapods- ten leggers
  - **Penaeoidea**- penaeid shrimp
  - **Caridea**- carid shrimp
  - **Astacidea**- crayfish & lobsters
  - **Brachyura**- true crabs
  - **Anomura**- false crabs

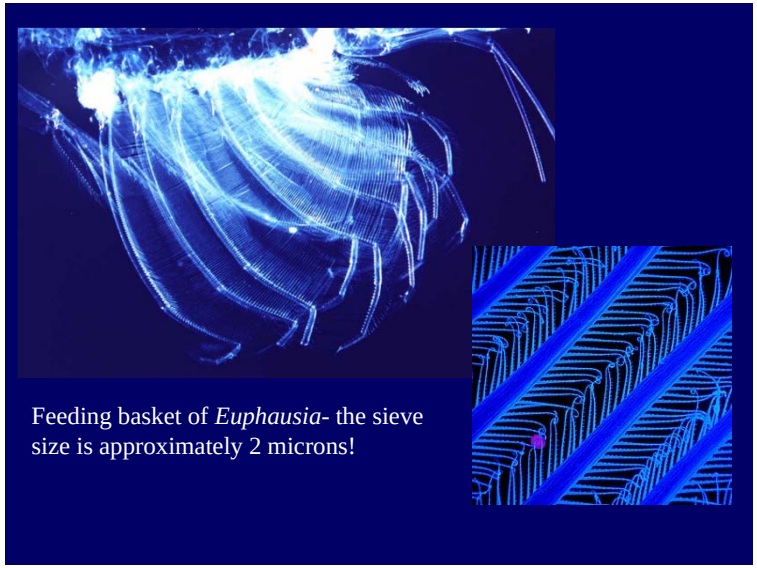
"Stomatopoda"– mantis shrimps

Eucarida

- 0, 1, or 3 pairs of maxillipeds
- Carapace present covering and fused dorsally with head and entire thorax to form cepahlothorax.
- Includes most of the larger and commercially important crustaceans

Antarctic krill- *Euphausia superba*

- Largest biomass of any macroscopic organism on earth
- Key predator/prey organism in the Antarctic ecosystem. Form dense schools in summer (up to 20,000 individuals per m^3).
- Filter-feed on plankton ($\geq$ 2 micron) with setal basket. Also harvest algae from under ice
- Primary food for many Antarctic birds & mammals, including whales and penguins.
- Increasing commercial harvest- for human consumption, salmon aquaculture, pet food
- Population crash due to global warming/overharvest?



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"Stomatopoda"– mantis shrimps

Superorder Eucarida

Order Decapoda

- The most conspicuous crustaceans- often large body size, good to eat. Includes crabs, crayfish, true shrimp
- 3 pairs of maxillipeds (i.e. 3 segments fused to primitive head) leaving just 5 "thorax" segments- therefore, 10 legs (decapod)
- Extensive carapace covering pereon, forming lateral branchial chambers.
- Water is circulated (back to front) through the branchial chambers by scaphognathites (gill-bailers)
- The gills are outgrowths of the pereopods (thoracic legs)

Just what is a "shrimp"?

The word has little taxonomic significance (rather like "fish").
Any elongate, laterally compressed crustacean is likely to be called a shrimp.

The shrimps that we eat are from a couple of different decapod groups:

Class Malacostraca

Superorder Eucarida

Order Decapoda

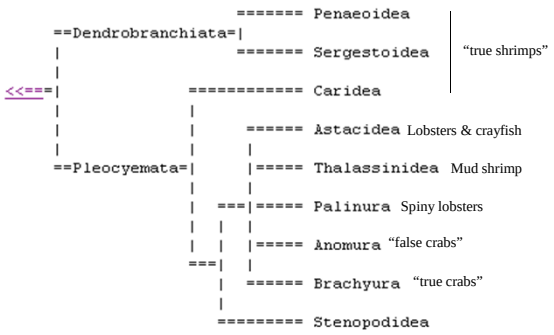
Penaeid shrimps including *Penaeus* and *Litopenaeus* are farmed or harvested commercially for human consumption. Do not brood eggs.

Caridean shrimps including *Pandalus*, *Macrobrachium*, *Palaemonetes.* Brood eggs on pleopods. Enlarged 2nd pleural lobe.

Class Malacostraca

Superorder Eucarida

Order Decapoda

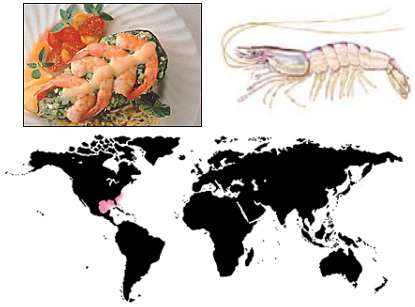


Penaeus monodon, the giant tiger prawn, accounts for more that 60% of all farmed shrimp worldwide, especially in Asia

Black Tiger Shrimp

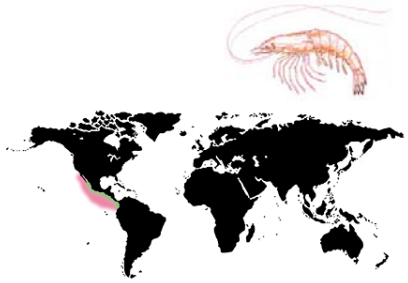
Penaeus monodon
(Black tiger, giant tiger, jumbo tiger shrimp, tiger prawn)

Gulf Shrimp
pink *(Penaeus duorarum)*, brown *(P. aztecus)*, white *(P. setiferus)*,



Pacific Shrimp
white: *Penaeus vannamei;* blue: *P. stylirostris*

Pond aquaculture of these two species in the Americas



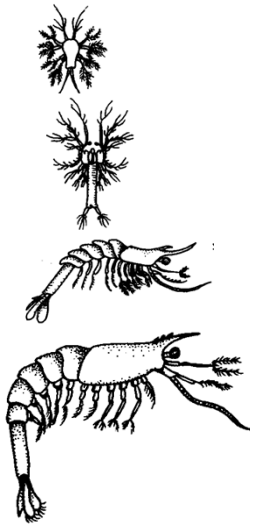
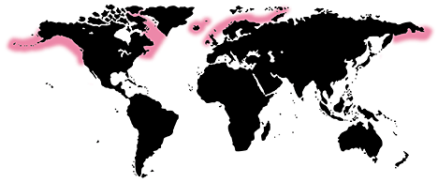


Table 1. Types of feed required for shrimp larvae at various developmental stages.

Stages	Time & substages	Food types
Nauplius	6 substages 36-51 h	Body yolk
Zoea	3 substages 120 h (28°C)	Phytoplankton Artificial feeds Artemia nauplii (Zoea III)
Mysis	3 substages 72 h (28°C)	Artemia nauplii Phytoplankton Artificial feeds
Postlarvae (PL)	PL 1-10	Artemia Artificial feeds

Pink Shrimp: *Pandalus borealis*
(a caridean shrimp)

Common names: *Northern shrimp, pink shrimp, coldwater shrimp, salad shrimp*



Caridean freshwater shrimps in Missouri

Glass shrimp- *Palaemonetes kadiakensis*
In Missouri, found in the SE lowlands- possibly also in oxbow lakes and wetland areas of the Osage drainage.

Ohio shrimp, ***Macrobrachium ohione***
Up to 4 in long- formerly common in Mississippi & Ohio Rivers- declined in the 1930s and 1940s- none collected in Missouri or Illinois from 1962-1997. Rediscovered in 1997 by MDC. (Conaway, L. K., and R.A. Hrabik. 1997)

Order Astacidea- crayfishes and lobsters

Orconectes longidigitus
White River of MO and AR

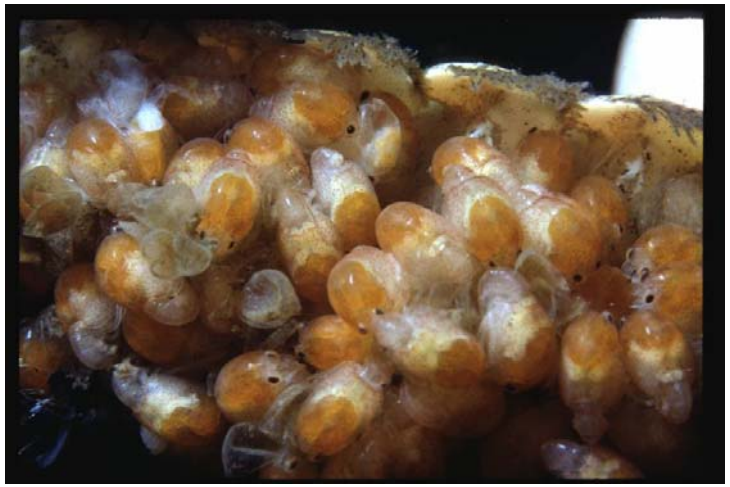
Cambarus maculatus – found only in the Meramec River system

Astacideans in Missouri- crayfish

- There 32 crayfish species found in Missouri
- Most of these are in three genera:
  Orconectes (19), *Cambarus* (5), and *Procambarus* (4)
- Most species found in the Ozarks are endemic
  (i.e native only in the Ozarks).
- MDC crayfish information

Bristly cave crayfish- *Cambarus setosus*
caves of the Springfield Plateau

Brood of a prairie crayfish from western Missouri



Prairie crayfish (*Procambarus gracilis*) with brood …from western Missouri

Order Anomura

- "false crabs" including hermit crabs, box crabs, porcelain crabs, king crab, snow crab, and others
- Mainly marine- some hermit crabs are terrestrial (all decapods have marine larvae)
- The fifth pair of legs (these are decapods) are reduced and hidden under the carapace- used for grooming the gills and branchial chambers

A Philippine porcelain “crab” *Neopetrolisthes oshimani*

The giant anomuran
Birgus latro

also called coconut or robber “crab”

Up to 4 kg, 30 years of age

Distribution on South Pacific islands coincides with coconut palms-larvae possibly dispersed by rafting on floating coconuts

Tuna crabs *Pleuroncodes planipes* - whale food
Stranded on Palos Verdes peninsula, Los Angeles CA during El Nino

A Philippine hermit “crab”- *Dardanus pedunculatus*

More anomuran diversity…..

Lopholithodes foraminatus

Box “crab” – west coast of North America

Class Malacostraca

Superorder Peracarida

Isopods, amphipods, mysids

Superorder Eucarida

Ephausiids, Decapods

Superorder Hoplocarida

Order Stomatopoda: Mantis “shrimp”