Marine Zooplankton Ecology and Oceanography

Cabell Davis, Biology Department
Woods Hole Oceanographic Institution

• Brief History of Woods Hole and WHOI
• Plankton – Key facts
• Zooplankton – Background: the players…
• Plankton Research – Some History
Woods Hole History

Woods Hole, Massachusetts, 1840
U. S. President Ulysses Grant appointed Spencer Baird head of US Bureau of Fisheries to determine causes of fish stock fluctuations.

Woods Hole fisheries laboratory established. Many prominent scientists like L. Agassiz (Harvard) visit the laboratory.
“Study nature not books” - L. Agassiz

MBL: Biology of marine organisms, Biomedicine, Ecosystems

55 Nobel Scientists -
- Vitamin C - Myosin/Actin (Albert Szent-Györgyi)
- Neurobiology (Hodgkin-Huxley: squid voltage clamp), Embryology
Oceanographic Research – NAS, Rockefeller Foundation Grant

Discoveries: Project “Famous” - Plate Tectonics - Hydrothermal Vents, Redfield Ratio, Stommel model, Gulf Stream Rings, Picoplankton, Titanic, …
WHOI Underwater Vehicles

HOV Alvin

ROV Jason

HROV Nereus

AUV Remus
Ships

R/V Atlantis (84m)  R/V Tioga (18m)  R/V Neil Armstrong (73m)
Woods Hole Oceanographic Institution (WHOI)

- World’s largest private ocean research institution
- 780 employees, 135 scientific staff
- Biology, Chemistry, Geology, Physics, Engineering
- Scientists’ grants = 85% WHOI operating costs
The Water Planet

- The ocean covers 71% of the Earth's surface
- It contains 97% of Earth's water.
- Earth’s life support system
- Plankton throughout ocean
- 99% of Earth’s living space
- <1% Explored
- The Ocean is dying
Plankton definition: from Greek word Planktos = “Drifters”

Vast majority of ocean species are plankton

**Holoplankton:**
- Copepod
- Pteropod
- Amphipod

**Larvae:**
- Fish
- Shrimp
- Snail
- Crab
- Starfish

Most numerous animals on earth: $10^{18}$
Fastest animals on earth for their size.
Cheetah (20 BL/s) vs Copepod (500 BL/s)

Cheetah 100 km/h

Copepod 3000 km/h
Fish is juvenile mullet (*Mugil cephalus*). Copepod is *Anomalocera ornata*
Clownfish preying on copepod (Bestiolina)
Cyclopoid copepod *Oithona davisae*

Ambush Feeding  (slow motion: 270x slower than real time)

(Kiørboe, Jiang, et al, 2014 PNAS)
Copepod *Acartia tonsa*
Feeding

*(Kiørboe, Jiang, et al, 2014 PNAS)*
Copepod *Acartia tonsa*

Nauplius swimming

(Kiørboe, Jiang, et al, 2014 PNAS)
Copepod *Acartia tonsa*: Escape
Copepod *Acartia tonsa*

Repositioning

(Kiørboe, Jiang, et al, 2014 PNAS)
Zooplankton Footprints found using Schlieren Optics:

Cladocera *Daphnia lumholtzi*
Hydrodynamic footprints

Copepod *Cyclops scutifer*
Hop-and-sink swimming pattern

(Strickler and Balázsi, Phil. Trans. R. Soc. B 2007)
Cyclopoid copepod *Cyclops scutifer*

escaping from an artificial hydrodynamic disturbance

(Strickler and Balázsi, Phil. Trans. R. Soc. B 2007)
Importance of swimming behavior: Interaction with microscale patchiness

\[
\frac{\partial}{\partial t} B = gB + \frac{\partial^2}{\partial x^2} (\kappa B)
\]

(Davis, Flierl, et al. 1991)
Phytoplankton: primary producers; 50% of oxygen in air

> 5000 known species
Plankton Key Facts

- Plankton form base of ocean food web

**Microbial loop**

- **Phytoplankton**
  - Nutrients
  - Detritus
  - Bacteria

- **μ-Zooplankton**

**NPZD**

- **Copepods**
  - Fish, corals, whales and many others
• Plankton regulate ocean chemistry

Redfield Ratio C:N:P = 106:16:1


Redfield AC (1958) The biological control of chemical factors in the environment. In: American Scientist. p 205–221
Plankton Key Facts

- Plankton remove CO$_2$
  “The Biological Pump”

(modified from Herndl & Reinthaler, Nature, 2013)
Plankton Key Facts: Summary

- Regulate ocean chemistry
- Produce 50% of oxygen in air
- Remove CO$_2$: “The Biological Pump”
- Base of ocean food web
- Vast majority of ocean species are plankton
- Zooplankton are key link in food web
Marine Zooplankton: Who are they?
¾ of known animal species are insects, only \textit{Halobates} (sea skaters) are oceanic.
Key Fact
The vast majority of the ~400,000 non-insect animal species on earth are members of the marine zooplankton — all major phyla

Plankton Classification*

<table>
<thead>
<tr>
<th>Archaea</th>
<th>Bacteria</th>
<th>Protists</th>
<th>Plantae</th>
<th>Animalia (metazoa)</th>
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<tbody>
<tr>
<td></td>
<td>Cyanobacteria</td>
<td>Diatoms (Sargassum)</td>
<td>Zoospores</td>
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<td>Coccolithophores</td>
<td>Ciliates</td>
<td>Cnidaria</td>
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<td>Dinoflagellates</td>
<td>Radiolaria</td>
<td>Anthozoa (anemones, corals)</td>
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<td>Other Flagellates</td>
<td>Foraminifera</td>
<td>Hydrozoa (hydroids, siphonophores)</td>
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<td>Scyphozoa (true jellyfish)</td>
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<td>Cubozoa (box jellyfish)</td>
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<td>Ctenophora (comb jellies)</td>
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<td>Porifera (sponge larvae)</td>
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<td>Rotifera (rotifers)</td>
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<td>Echinodermata (larval starfish etc)</td>
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<td>Chaetognatha (arrow worms)</td>
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<td>Annelida (Tomopterids, larvae)</td>
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<td>Mollusca (veligers, pteropods, etc)</td>
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<td>Arthropoda (crustacea, chelicerata)</td>
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<td>Chordata (salps, larvacea, fish larvae)</td>
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</tbody>
</table>

microzooplankton
zooplankton
Major Groups of Zooplankton: Microzooplankton (20-200 μm)

- Heterotrophic dinoflagellates
- Heterotrophic flagellates
- Heterotrophic ciliates
Major Groups of Zooplankton: Protozoa

- Radiolaria
  - Acantharia

- Foraminifera
Major Groups of Zooplankton: Cnidaria

Anthozoa (anemones, corals)

Hydrozoa: Siponophores

Hydrozoa: Hydroidolina

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**Clarke, UAF**
Major Groups of Zooplankton: Cnidaria

Cnidoblast

- Cnidocil
- Hinged operculum
- Barbs
- Threads
- Tentacle
- Capsule

Images of cnidoblasts and their effects on skin.
Major Groups of Zooplankton: Cnidaria (cont)

**Cubozoa (box jellyfish)**
- Carukia barnesi
- Malo kingi

**Scyphozoa (true jellyfish)**

**Trachelina (Trachymedusae)**
Scyphozoa (true jellyfish)
Life Cycle

Planula larva → Scyphistoma polyp → Ephyra → Medusa
Cloning
Major Groups of Zooplankton: Ctenophora

- Cydippida
- Lobata
- Cestida
- Beroida
Major Groups of Zooplankton: Ctenophora

Lobata:
New species: *Bolinopsis nigerii*

Celebes Sea, 2500m
September 2007

15 cm diameter
Major Groups of Zooplankton: Echinodermata

Holothurian: Sea Cumber

Ophiuroid: Brittle Star

Asteroid: Starfish

Echinoida: Sea urchin

Echinoida: Sand dollar

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Major Groups of Zooplankton: Echinodermata

Holothurian: Sea Cumber
Major Groups of Zooplankton: Echinodermata

Holothurian: Sea Cumber

(Oceaneering, Indian Ocean)
Major Groups of Zooplankton: Chaetognatha

“Arrow worms”
Major Groups of Zooplankton: Annelida

Meroplankton Larvae

Holoplankton: Tomopteris and Swima

*Copyright 2006 Peter Parks/imagequestmarine.com*
Major Groups of Zooplankton: Annelida

Osbourne et al 2009
Science
Major Groups of Zooplankton: Annelida
Major Groups of Zooplankton: Mollusca

**Thecosomata: Shelled Pteropods**

**Gymnosomata: Naked Pteropods**

**Heteropods (Carinarioidea)**

**Meroplanktonic Larvae**

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Major Groups of Zooplankton: Mollusca

Thecosomata: Shelled Pteropods
Major Groups of Zooplankton: Mollusca

Gymnosomata: Naked Pteropods
Major Groups of Zooplankton: Crustacea, Copepoda
Major Groups of Zooplankton: Crustacea, Copepoda

*Calanus hyperboreus*
Major Groups of Zooplankton: Crustacea, Copepoda

Candacia
Major Groups of Zooplankton: Crustacea, Copepoda

*Euchaeta barbata*

*Valdiviella insignis*
Major Groups of Zooplankton: Crustacea, Copepoda
Major Groups of Zooplankton: Crustacea, Copepoda
Major Groups of Zooplankton: Crustacea, Hyperiid Amphipods
Amphipod: *Phronemia*
Major Groups of Zooplankton:  Crustacea, Decapoda

Dendrobranchiata:  

Penaeoidea:  larvae

Sergestoidea

Caridea:  true shrimp

Pleocyemata:

Anomura:  zoea

Brachyura:  zoea

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Major Groups of Zooplankton: Crustacea

- Euphausiids
- Mysid
- Cladocera
- Ostracod

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Major Groups of Zooplankton: Chordata, Urochordates

Tunicates

Pyrosomes

Thaliacea
Salps

Doliolids

Appendicularia (Larvacea)

Sea squirt larva
Major Groups of Zooplankton: Chordata, Urochordata
Tunicates
Pyrosome

(www.eaglehawkdive.com.au)
Other Groups of Zooplankton

- **Sponge Larvae**
- **Limulus Larva**
- **Rotifers**
- **Fish Larvae**
Zooplankton Ecology: History

1674: Antony van Leeuwenhoek describes the alga *Spirogyra*

1702: Leeuwenhoek describes several protists including *Vorticella*

1722: Leeuwenhoek describes oyster veligers

1778: Martinus Slabber publishes plates of invertebrate larvae and copepods (available at MBL on-line)

1816 J. V. Thompson uses muslin tow net near Mauritius/Madagascar to study bioluminescence

Mid 1800s: Thompson and Johannes Muller use plankton net and Muller begins systematic collections of plankton in Baltic Sea. Establishes the field of plankton research.

Muller on the plankton net: “I have used this method for many years with the best results...It is quite indespensible...”
Zooplankton Ecology: History

Later 1800s: Ernst Haeckel used the plankton net and illustrated many species of plankton.
Zooplankton Ecology: History

1865-1871: President Ulysses Grant appoints Spencer Baird head of US Bureau of Fisheries to determine causes of fish stock fluctuations. Woods Hole fisheries laboratory established. Many prominent scientists like L. Agassiz visit the laboratory. Leads to establishment of the Marine Biological Laboratory in 1888.

1887: Victor Henson at the University of Kiel coined “Plankton” from the Greek word “planktos”, meaning “drifter” or “wanderer”. He also set up the basic constructs for biological oceanography by reasoning that fish production can be predicted from nutrients and the available biomass of plankton.

1893: Haeckel first use the terms holoplankton and meroplankton.
Zooplankton Ecology: History

1873-1876: Wyville Thompson and John Murray lead the British Challenger Expedition, conducting deep plankton tows (>3,000 m). Surprisingly find life there.
Zooplankton Ecology: History

1907-1930: Henry Bryant Bigelow conducts ground breaking cruises in Gulf of Maine (with Alexander Agassiz), describing the plankton, fish, and physics. He is instrumental in establishing WHOI in 1930 and was our first director.

1925-1927: Sir Alistair Hardy invents the Continuous Plankton Recorder (CPR) and uses it on the Discovery expedition to the southern ocean. The Sir Alistair Hardy Foundation for Ocean Science (SAFOS) is established. The CPR becomes routinely used in the North Sea and North Atlantic beginning in 1932.

1931-1932: The Sir Alistair Hardy Foundation for Ocean Science (SAFOS) is established. The CPR becomes routinely used in the North Sea and North Atlantic.
Major Research areas in Marine Zooplankton Ecology:

Distribution and abundance measurements
- Regional
- Basin and global scales

Biological/Physical processes controlling observed patterns

Pure exploration

Food web interactions

Fisheries ecology

Diel vertical migration

Population dynamics analysis
- Empirical analyses
- Modeling

Organismal level analyses
- Vital rates: Feeding, Respiration, Excretion, Growth, Fertility, as functions of temperature and food
- Behavioral Studies, predator-prey interactions, swimming and feeding cues and responses, neurobiology

Trophodynamics: Biogeochemical cycling

Molecular genetics, systematics, transcriptomics, proteomics