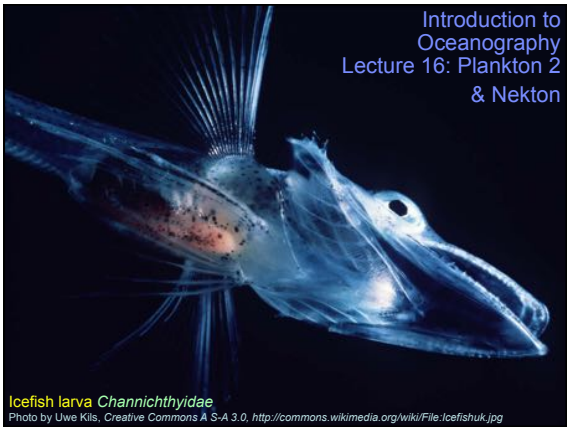
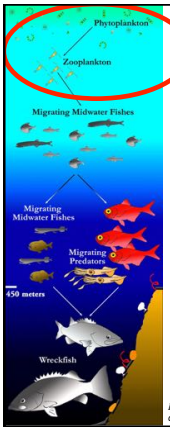



Icefish larva *Channichthyidae*

Photo by Uwe Kils, *Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Icefishuk.jpg*




# PLANKTON

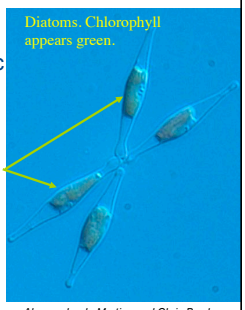
Open ocean (and many coastal) food webs start with plankton

*Food web of Charleston Bump, NOAA/Weaver and Sedberry, 2001, Public Domain(?), http://oceanexplorer.noaa.gov/explorations/03bump/background/lifeonbump/media/foodweb.html*

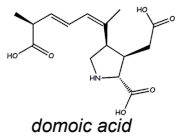
# Diatoms

Extremely efficient photosyntheic conversion of sunlight to chemical energy

- Chloroplasts within frustule
  - Fixes Carbon, releases Oxygen
- Tiny holes in frustule allow gas/water exchange with ocean
- Frustule surface may also increase $CO_2$ availability
- *Skeletons used to make filters*
  - *"cold filtered, never pasteurized"*




*Alessandra de Martino and Chris Bowler, PLoS, Creative Commons A 2.5, http://commons.wikimedia.org/wiki/File:Phaeodactylum_tricornutum.png*



*domoic acid*

Toxins can be fatal to animals near the top of the food chain (fish, sea birds, humans, etc.)

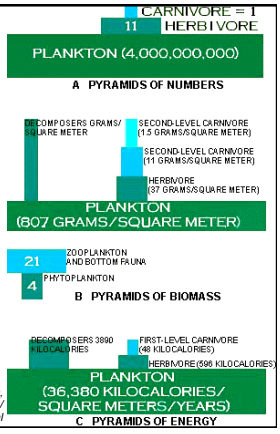



*Figure from U. Michigan Global Change Program, http://www.globalchange.umich.edu/globalchange1/current/lectures/kling/energyflow/energyflow.html*

# DINOFLAGELLATES

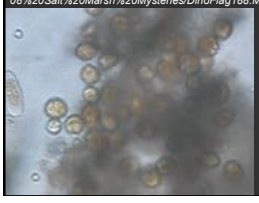
- 2nd most abundant plankton group
- Unicellular algae
  - – exist singly, cellulose (organic) cell walls rather than mineral skeleton.


*Ceratium longipies, Photo by Mitchell Sogin, UNH Marine Biological Lab, http://www.eos.unh.edu/newsl_0708/dinoflagellate.shtml*

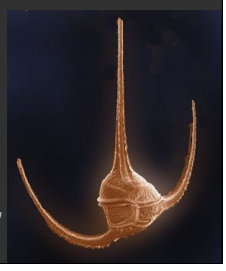
# Dinoflagellates

- Possess two flagella: **motile**
  - – 1 flagellum for translation, other for rotation
- Transverse groove: **girdle**, separates anterior & posterior halves

*Movie by Wayne Lanier, http://www.hikingwithafieldmicroscope.com/00%20CONTENTS/08%20Salt%20Marsh%20Mysteries/DinoFlag188.MOV*



*Ceratium longipies, Photo by Mitchell Sogin, UNH Marine Biological Lab, http://www.eos.unh.edu/newsl_0708/dinoflagellate.shtml*



## Dinoflagellates

- Variety of feeding strategies:
  - Some are autotrophic (photosynthesis)
  - Some are heterotrophs without chloroplasts
  - Some are **mixotrophs**
    - Can photosynthesize but also feed on other plankton

*Ceratium longipies, Photo by Mitchell Sogin, UNH Marine Biological Lab, http://www.eos.unh.edu/news/_0708/dinoflagellate.shtml*

## Dinoflagellates

- Rapid reproduction in warm, nutrient rich waters
  - Can result in blooms: **Red Tides**
- Can produce a range of chemicals
  - **Bioluminescence** and neurotoxins
  - As with domoic acid & mercury, organisms that eat dinoflagellates concentrate toxins

*Noctiluca scintillans, photo by Maria Antónia Sampayo, Instituto de Oceanografia, Universidade de Lisboa, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Noctiluca_scintillans_unica.jpg*

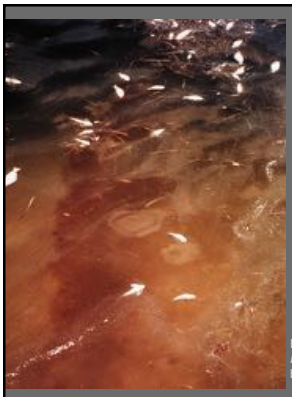
*Photo by catalano82, Flickr, Creative Commons A 2.0, http://commons.wikimedia.org/wiki/File:Dinoflagellate_luminescence.jpg*

## Dinoflagellates

Red Tides

*Red tide near La Jolla, CA, P. Alejandro Diaz and Ginny Velasquez, Public Domain, http://commons.wikimedia.org/wiki/File:La-Jolla-Red-Tide.780.jpg*

## Dinoflagellates



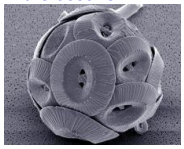
- Post-Bloom:
  - After nutrients are exhausted:
    - Bloom ceases
    - Bacterial decomposition (ie, bacterial respiration) of deceased bloomers removes oxygen from water column
  - Anoxic conditions: **Post bloom fish kills**

Fish kill during *Karenia brevis* bloom, Florida

*Woods Hole Oceanographic Institute Photo, http://www.cop.noaa.gov/stressors/extremeevents/hab/features/florida_0406.html*

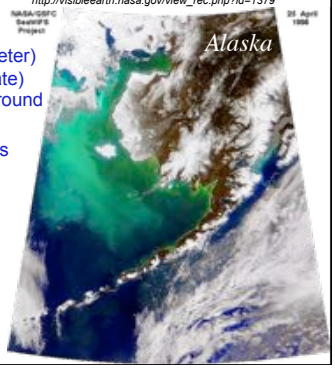
## COCCOLITHOPHORES

- Abundant single-celled autotrophic plankton
- Tiny (3 - 50 micron diameter) $CaCO_3$ (calcium carbonate) shells, about 30 shells around each individual
- Leading calcite producers in the oceans



*Richard Lampitt, Jeremy Young, The Natural History Museum, London, Creative Commons A 2.5*

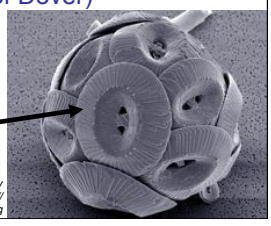
*SeaWiFS/NASA, Public Domain, http://visibleearth.nasa.gov/view_rec.php?id=1379*




## Coccolithophores

- External shell of many calcareous plates called coccoliths
- Chalk is an uplifted ocean sediment composed dominantly of coccolith shells (ie, the White Cliffs of Dover)

Coccoliths



*Richard Lampitt, Jeremy Young, The Natural History Museum, London, Creative Commons A 2.5, http://commons.wikimedia.org/wiki/File:Coccolithus_pelagicus.jpg*

# Questions

*Paraeuchaeta norvegica, a copepod, photo Hege Vestheim, University of Oslo, http://oceanworld.tamu.edu/resources/oceanography-book/marinefoodwebs.htm*

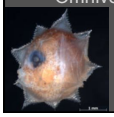
# Zooplankton

- Definition: Animals (heterotrophs) may be capable of movement but still controlled by surrounding currents

*Mastigias papua, video by Gh5046, public domain, http://commons.wikimedia.org/wiki/File:Mastigias_papua-Spotted_jellyfish.ogg*

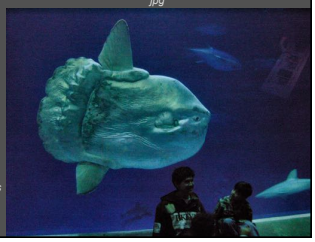
# Zooplankton

- Types:
  - **Holoplankton**: permanently planktonic
  - **Meroplankton**: temporarily planktonic (ie, fish larvae, lobster larvae, etc.)
- Feeding Styles
  - Herbivores: eat plants
  - Carnivores: eat other animals
  - Detritivores: eat dead organic material
  - Omnivores: mixed diets



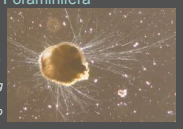
*Planktonic sunfish larva (Mola mola), G. David Johnson, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Molalavdj.jpg*

*Nektonic adult sunfish (Mola mola), Fred Hsu, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Mola_mola_ocean_sunfish_Monterey_Bay_Aquarium_2.jpg*



# Zooplankton

- Major Zooplankton:
  - Foraminifera



*Scott Fay, UC Berkeley, Creative Commons A S-A 2.5, http://en.wikipedia.org/wiki/File:Live_Ammonia_tepida.jpg*

  - Radiolaria

*Living Classrooms Foundation's Weinberg Education Center, http://www.livingclassrooms.org/lbo/biofilm/creature.html*

  - Ostracod

*Anna Syme, Creative Commons A S-A 3.0, http://en.wikipedia.org/wiki/File:Ostracod.JPG*

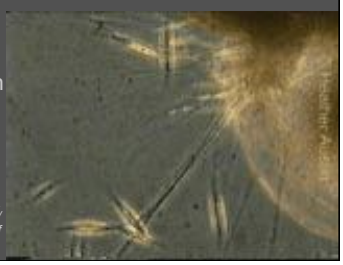
  - Copepod

*Hege Vestheim, University of Oslo, http://oceanworld.tamu.edu/resources/oceanography-book/marinefoodwebs.htm*

(Also dinoflagellates)

# Foraminifera

- Heterotrophic , single-celled plankton
- Calcium carbonate shells (test) & spines
  - Testate amoeba
- Pseudopodia used to capture prey
- Prey includes bacteria, phytoplankton or small zooplankton



*Movie by Heather Austin, U. St. Andrews, http://www.eforams.icsr.agh.edu.pl/index.php/Image:ApertureB1e.gif*

# Foraminifera


*Photo by Howard Spero, UCSC, http://earthguide.ucsd.edu/earthguide/imagelibrary/orbulinauniversa.html*

## Radiolaria

Single-celled plankton

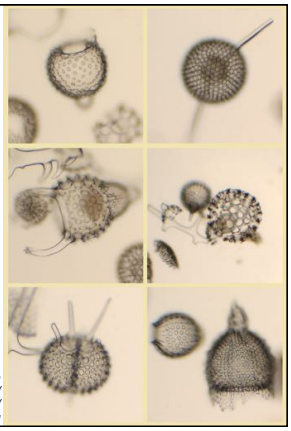
Silica tests (shells)
~ average $5 \times 10^{-5}$ m

Branched pseudopodia for food capture

Carnivorous/Omnivorous

- Food: zoo- & phytoplankton (diatoms), detritus

Sometimes possess symbiotes such as dinoflagellates



*Luis Fernández García, Creative Commons A S-A 2.5, http://commons.wikimedia.org/wiki/File:Radiolaria_varios.jpg*

## Ostracods

- Two clam-like shells
- Crustaceans: 0.5mm - 25 mm
  - 2mm is typical
- Originated around 550 Mya!
- Some are bioluminescent
- Consume plankton, many are also bottom-dwelling scavengers.

*Danielopolina mexicana – actually a cave-dweller http://www.tamug.edu/cavebiology/fauna/PhotoGallery/Yucatan/Yucatan-sm-crustaceans-1.html*

## Copepod

- Crustacean: average sizes 0.5 - 15 mm
  - Max size ~ 25 mm
  - ~ 9000 known species
- Voracious feeder/filterer
- Forms key food for many other larger plankton and nekton

*Photo Alfred Wegener Institute, http://www.awi.de/fileadmin/user_upload/News/Press_Releases/2006/3_Quarter/Plankton3_p.jpg*

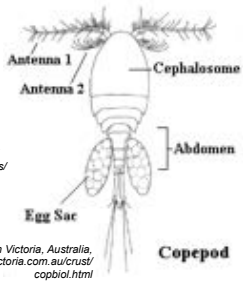
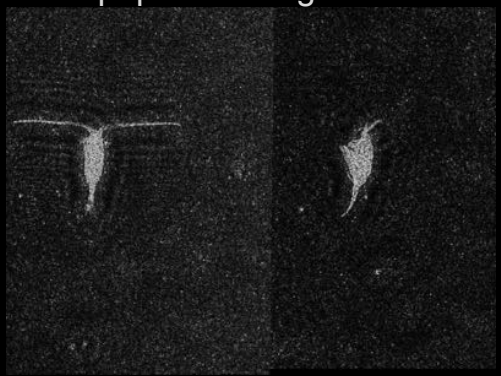


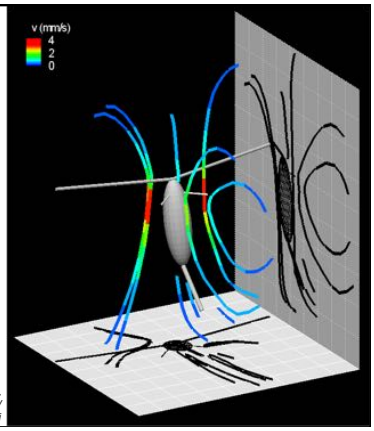

*Image from Museum Victoria, Australia, http://museumvictoria.com.au/crust/copbiol.html*

## Copepod feeding motion



*Malkiel et al., 2003, J. Exp. Biology, 206:3657, http://jeb.biologists.org/cgi/content/full/206/20/3657/DC1*

## Reconstructed feeding currents




*Malkiel et al., 2003, J. Exp. Biology, 206:3657, http://www.me.jhu.edu/lefd/shc/sinking%20particle%20tracks.avi*

## Questions

*Breaching Mobula ray, photo by Nick Bonzey, Flickr, Creative Commons A S-A 2.0, http://www.flickr.com/photos/99584876@N00/2306666364*

## Diurnal Migrating Plankton

- Upwards vertical migration by night
- Downward vertical migration by day
- Occurs in some species of every major group of zooplankton
  - Some nekton & possibly phytoplankton as well

## Polar Seasonal Vertical Migration

- North Atlantic copepods & Antarctic krill undergo seasonal vertical migrations
  - Feed during spring/summer
  - Dive to ~ 500-2000 m during winter
    - **Diapause**: slow metabolism, no feeding
    - Lay eggs at depth that slowly float upwards
  - Return to surface in spring

## Planktonic Patchiness

- Plankton are often found in patches
- Physically due to:
  - Gyre circulations, water mass boundaries, turbulence & mixing, wind-induced mixing, wave action
- Biologically due to:

  Ecosystem scale (water masses), spring blooms, different growth rates of different species, reproductive cycles, grazing/ predation, diurnal migration

*NASA/MODIS, Public Domain, http://veimages.gsfc.nasa.gov/5608/ NovaScotia.A2003183.1720.500m.jpg*

## Questions

*Anchovies, NOAA image, Public Domain, http://www.photolib.noaa.gov/htmls/nur00009.htm*

## Multicellular life

*Sardines, by James Kilfiger, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Sardines.ogg*

## Origin of Animals

Rise of oxygen: ~2,500 million - 400 million years ago

- Photosynthetic autotrophs pump out $O_2$
- Atmosphere goes from <<1% to 20% $O_2$

  Allows respiration to occur

  Evolution of multicellular heterotrophic animals.

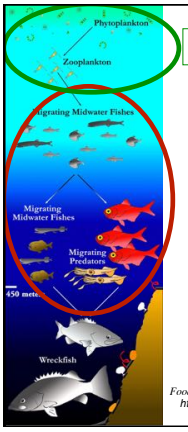
*Dickinsonia, Verisimilus, Creative Commons A S-A 2.5, http://en.wikipedia.org/wiki/File:DickinsoniaCostata.jpg*

*Cyclomedusa, Verisimilus, Creative Commons A S-A 2.5, http://en.wikipedia.org/wiki/File:Cyclomedusa_cropped.jpg*

*Anomalocaris, Photnart, Public Domain, http://commons.wikimedia.org/wiki/File:AnomalocarisDinoMcanb.jpg*

## What kinds of Animals exist?

- Invertebrates
  - No internal skeletons
  - Includes simplest animals, evolved first
- Vertebrates
  - Internal backbone
  - Evolved from invertebrates



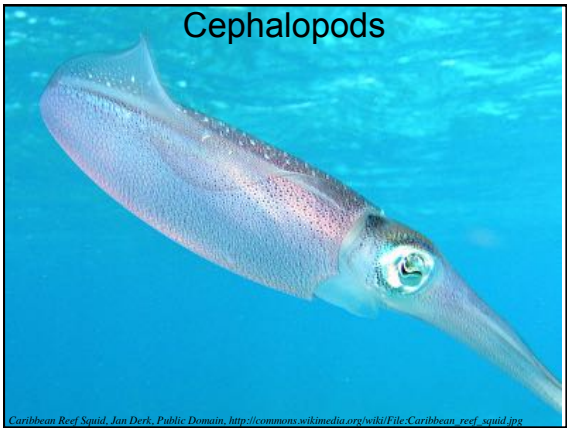

**Plankton**

## NEKTON

Lifestyle classification: organisms that swim strongly in the water column (able to overcome currents). Must be big enough to swim "fast" & far.

*Food web of Charleston Bump, NOAA/Weaver and Sedberry, 2001, Public Domain, http://oceanexplorer.noaa.gov/explorations/03bump/background/lifeonbump/media/foodweb.html*

## Cephalopods



*Caribbean Reef Squid, Jan Derk, Public Domain, http://commons.wikimedia.org/wiki/File:Caribbean_reef_squid.jpg*

## Cephalopods

Invertebrates - no internal skeleton
-- some species have firm "cuttlebone" support structures

Subdivision of Molluscs

- Cephalopods ("head-foot")
  - Most complex and intelligent molluscs
  - Mostly nektonic or nektobenthic lifestyle
    Swim along the bottom

*Nautilus, video by Shizhao, Creative commonsC A S-A 3.0, http://commons.wikimedia.org/wiki/File:Nautilus.ogg*

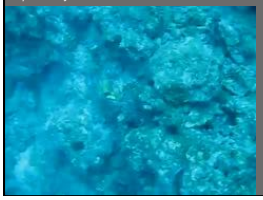
*Mastigoteuthis_flammea, Carl Chun, Public Domain, http://commons.wikimedia.org/wiki/File:Mastigoteuthis_flammea.jpg*

## Cephalopods

Include squid, octopus, cuttlefish, nautilus
Have three hearts, blue blood
copper based; blue when its oxygenated
ours is iron based; red when oxygenated
650 living species, around at least
~ 500 Mya

Many change color rapidly

*Reef octopus, Okinawa, video by goebelte,, http://www.youtube.com/watch?v=TcGwtExuenY*



Ordovician nautiloid (490-440 Ma), China

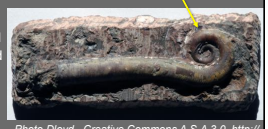
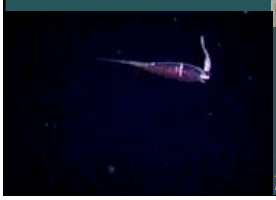


*Photo Dloyd,, Creative Commons A S-A 3.0, http://en.wikipedia.org/wiki/File:Nautiloid_trilacinoceras.jpg*

*Video by Joel Ang, http://www.tonmo.com/images/vids/CFvsFish.MPG*

## Cephalopods

- Motion
  - Some swim by moving tentacles/fins



*Video by Vecchione and Young, Smithsonian Museum of Natural History (1997) Vie et Milieu, 47:101-110. http://www.mnh.si.edu/cephs/vy97/grimpo1.mpg*

Jet propulsion by forcing water through siphon

*Video by Vecchione and Roper, Smithsonian Museum of Natural History (1991) Bulletin of Marine Science, 49(1-2):433-445. http://www.mnh.si.edu/cephs/vr91/tpavo1.mpg*

## Cephalopods

Giant squid
- up to 18 m long
- Deep Water
- ~ 2000 m

Feed on what?

Hunted by sperm whales

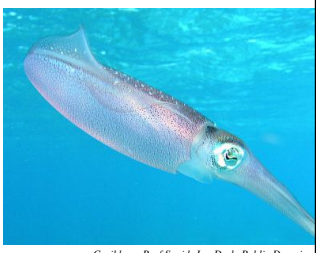
*National Institute of Water and Atmospheric Research - NIWA Greta Point, Wellington, New Zealand, Public Domain(?), http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/SQUID/clyde_squid_table.jpg*

## Cephalopods

- *Cuttlefish, squid, & octopi:*

Color change ability
Intelligence
Short-range jet propulsion
Advanced nervous systems
Acute eyesight
Other special adaptations?

***Why such unique adaptations?***



*Caribbean Reef Squid, Jan Derk, Public Domain, http://commons.wikimedia.org/wiki/File:Caribbean_reef_squid.jpg*

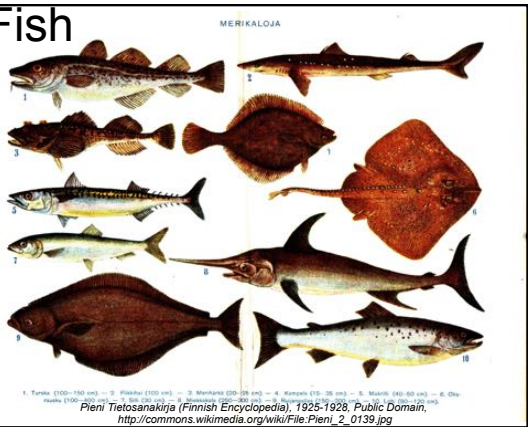
## Questions

*Octopus vulgaris, photo by Gronk. Wikimedia Commons, Creative Commons A S-A 3.0, http://species.wikimedia.org/wiki/File:Octopusy.JPG*

## Fish

*Amberjack, Public Domain, http://commons.wikimedia.org/wiki/File:Seriola_dumerili.jpg*

## Fish




*Pieni Tietosanakirja (Finnish Encyclopedia), 1925-1928, Public Domain, http://commons.wikimedia.org/wiki/File:Pieni_2_0139.jpg*

## Jawless Fish (Class Agnatha)

- Jawless fish, flexible snake-like bodies, no paired appendages for movement
- Earliest related fossils ~ 500 Mya
- Survive by sucking on wounds of other fish, eating out interiors
- Include hagfish (right) and lampreys (below)

Self-camming flesh pullers

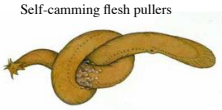


*Image Patricia J. Wynne, 2004, Natural History Magazine/American Museum of Natural History, http://biomechanics.bio.uci.edu/_html/nh_biomech/slime/slime.htm*

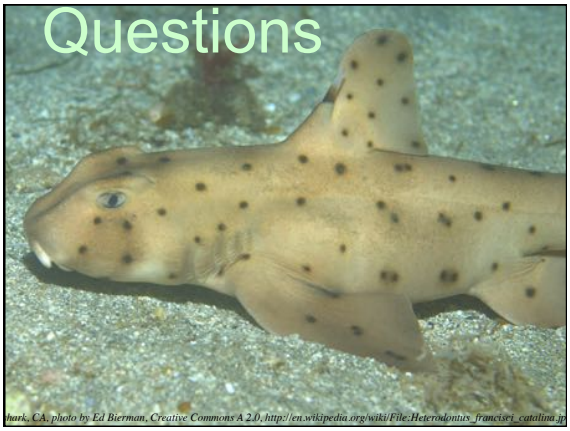
**Becomes slimy when provoked!**

*Photo by Drow male, Wikimedia Commons, Creative Commons A S-A 3.0, http://upload.wikimedia.org/wikipedia/commons/6/6f/Diversas_lampreas.1_-_Aquarium_Finisterrae.JPG*

Hagfish face a similar problem to cephalopods – they're soft!
Their defense? Slime predators when provoked!

*Video by Nimrod Levy (U. British Columbia), YouTube, http://www.youtube.com/watch?v=Bb2EOP3ohnE*

# Questions



*hark, CA, photo by Ed Bierman, Creative Commons A 2.0, http://en.wikipedia.org/wiki/File:Heterodontus_francisci_catalina.jp*

# Bony Fish

30,000 living species: Most diverse of all vertebrate groups

90 million tons removed by humans each year

- Equivalent to ~15 kg per person per year
- US residents ate about 7 kg/person per year in 2003, more goes to fertilizer and animal feed products.

- Buoyancy
  - Many have swim bladders (gas filled sac)
    - Allows fish to maintain position in water column
    - Some swallow air at surface, release at depth
    - Some have gas gland that transfers gas from blood
    - Swim bladders are a hindrance to bottom dwellers and fast swimmers (tuna)

# Shape of Fast-swimming Fish

Fineness = diameter/length ≈ 0.25 in tuna
Minimal drag at high speed
(large Reynolds number)

Aspect ratio of tail = span/chord
most efficient for generating lift

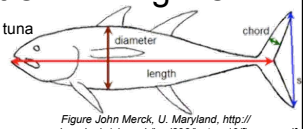



*Figure John Merck, U. Maryland, http://www.geol.umd.edu/~jmerck/bsci392/lecture10/fineness.gif*

Teardrop shape minimizes frictional drag
Thrust by waves of body motion and fins
Fins
- Pelvic and pectoral: turning, braking, balance, little thrust
- Dorsal & anal: stability and steering
- ***Caudal (tail):*** Most thrust

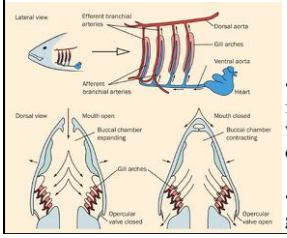
*Video by onitube, YouTube, http://www.youtube.com/watch?v=6lv51E-q1xU*

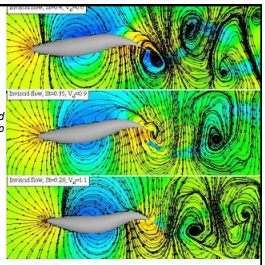
# Bony Fish

•A fish's hinged tail generates efficient forward motion

*U. Minnesota Computational hydrodynamics and biofluids laboratory, http://cfdlab.safl.umn.edu/fmlao.php*

*U. Michigan Museum of Zoology, http://animaldiversity.ummz.umich.edu/site/resources/Grzimek_fish/structure_function/v04_id131_con_gillfun.jpg*

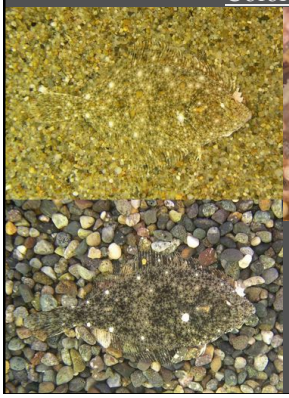


• **GILLS**: extract dissolved oxygen from sea water. Oxygen-rich sea water **diffusively** exchanges with oxygen-poor blood in gills

•Faster swimming fish have bigger gills (and higher body temperatures)

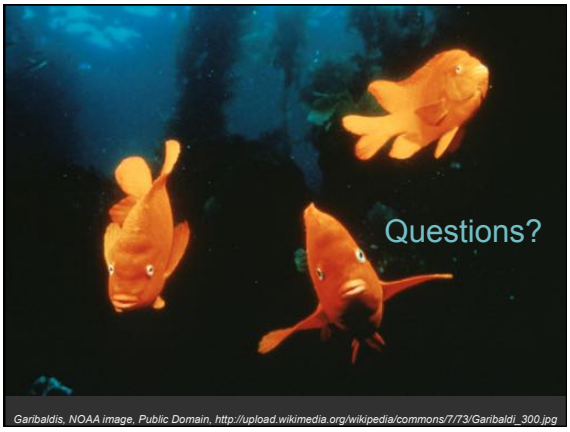
# Coloration



*Sargassum fish, photo by Art Howard/Ross et al, NOAA-OE, HBOI, Public Domain, http://oceanexplorer.noaa.gov/explorations/05coralbanks/logs/oct31/media/fig1.html*

*Stone flounders, photo by Takahashi, Wikimedia Commons, Public Domain, http://commons.wikimedia.org/wiki/File:Kareius_bicoloratus_Camouflage.JPG*


*Great white shark, photo by Sharkdiver68, Wikimedia Commons, Public Domain, http://commons.wikimedia.org/wiki/File:Carcharodon_carcharias.jpg*




*Garibaldis, NOAA image, Public Domain, http://upload.wikimedia.org/wikipedia/commons/7/73/Garibaldi_300.jpg*