Freshwater Fishes

I. Evolution
II. Types of FW fishes
III. Ecology

Freshwater fishes: high biodiversity and density

Habitat	% of total species	# individuals/species	% of water volume
Marine	58	10^{10}	97
Freshwater	41	10^{8}	0.01
Diadromous	1	?	

- 7500x more species per unit volume in FW than SW!
  (1 sp. per 15 km^3 vs. 1 per 113,000 km^3)
- 75x higher density (fish/area) in FW than SW

Why are there so many FW fish species?

- **productivity**: freshwater habitats are generally more productive than marine environments
  - shallower ⇒ more sunlight ⇒ more photosynthesis
  - more terrestrial input of nutrients

- **isolation**: FW habitats tend to be isolated by:
  drainages, drought, landslides, waterfalls, plate tectonics, etc.
  ⇒ impedes gene flow
  ⇒ can lead to explosive speciation when new habitats are invaded

- in contrast, marine habitats are more connected, separated mainly by continents)

Cause of high rate of speciation in FW: rapid evolution

***Evolution**: a change in gene frequencies between generations*

Causes of **evolution**

1. **Natural selection**: best adapted individuals pass on more genes to the next generation than do less adapted individuals
2. **Genetic drift**: random processes cause certain genes to disappear from or become fixed in a population
3. **Gene flow**: genes enter a population from outside sources
4. **Sexual selection**: selected genes become more common in the next generation when one or both sexes (1) prefer to mate with individuals with certain phenotypes that (2) have a genetic basis

BUT…
- ***speciation*** will only occur if evolving populations become ***reproductively isolated***

Causes of **reproductive isolation**

1. **Physical (geographic)** isolation: populations cannot come into contact due to physical barriers
2. **Environmental** isolation: populations live in different habitats
3. **Behavioral** isolation: mating behaviors of individuals from different populations are too different for successful reproduction
4. **Mechanical** isolation: sex organs are too different for mating to occur
5. **Physiological** isolation: hybrid offspring are not formed or have lower fitness than pure offspring

Case study:

Evolution of African Cichlids
(family Cichlidae)

Evolution of African Cichlids

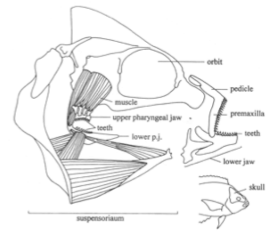
- most rapid and extreme case of speciation in any vertebrate group
- Great Rift Valley of Africa
- ~**1500 species** from a handful of ancestral species
  - Lake Victoria: 450 spp. in < 1 my (possibly 15,000 yr) from 1 ancestor
  - Lake Malawi: 850 spp. in 4-9 my from a few ancestors
  - Lake Tanganyika: 215 spp in 9-12 my from a few ancestors

How can so many species evolved so quickly?!

numbers of species estimated by Kaufman 2007

Causes of massive speciation in African Cichlids:

- extremely adaptable feeding structures
  - highly specialized & variable teeth on premaxilla
  - highly specialized & variable pharyngeal jaws
  - has allowed very specialized feeding:
    - algal turfs
    - invertebrates
    - fishes
    - scales
    - eyeballs
    - broods of young from mother's mouth



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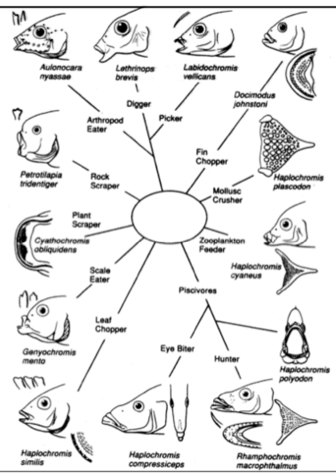
variable tooth shape

variable pharyngeal jaws



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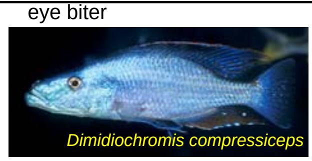
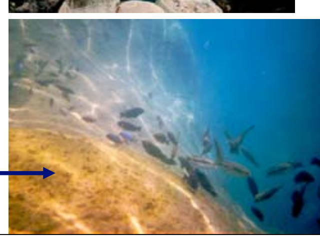
eye biter



algae scraper

arthropod eater

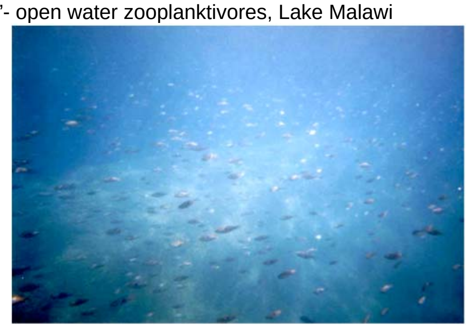
Mbuna: rock dwelling cichlids



"aufwuchs"

(turf aglae & inverts)

"Utaka"- open water zooplanktivores, Lake Malawi

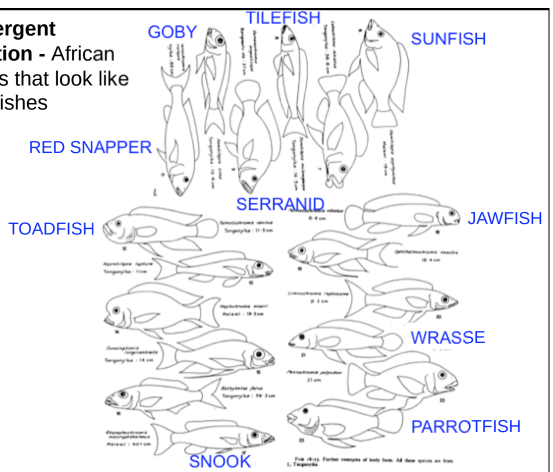


Death feigner, Lake Malawi

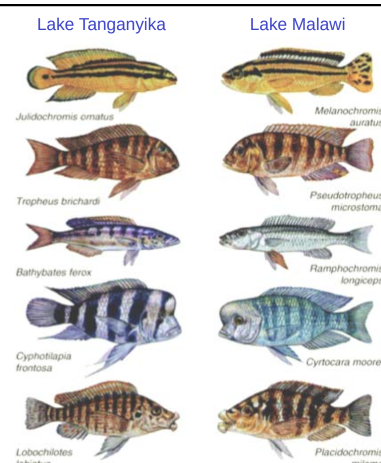
Nimbochromis livingstoni

Surf Zone – Tanganyikan “Goby” Cichlids

Convergent evolution - African cichlids that look like other fishes



Convergent evolution in two of the African Rift Lakes



Causes of massive speciation in African Cichlids:

- extremely adaptable feeding structures
- **specialized life history**
  - mouthbrooders
  - very limited dispersal

Causes of massive speciation in African Cichlids:

- extremely adaptable feeding structures
- specialized life history
- **extremely territorial**
  - also limits dispersal

Causes of massive speciation in African Cichlids:

- extremely adaptable feeding structures
- specialized life history
- extremely territorial
- **geographic isolation**
  - lakes have been subdivided into isolated pools during droughts
  - lakes are huge & habitats are patchy

Causes of massive speciation in African Cichlids:

- extremely adaptable feeding structures
- specialized life history
- extremely territorial
- geographic isolation
- **very small populations**
  - increases genetic drift & founder effects

Causes of massive speciation in African Cichlids:

- extremely adaptable feeding structures
- specialized life history
- extremely territorial
- geographic isolation
- very small populations
- **complex mating systems**
  - complex behaviors
  - elaborate color patterns (strong sexual selection)
  - (but not physiologically isolated — successful hybrids)

Extinction!

- about 250 of 450 species extinct in Lake Victoria
- causes:
  - introduced predator: Nile perch
  - increased turbidity (loss of planktivores & eutrophication)
  - pollution (pesticides & others)

II. Types of Fishes in Freshwater

- **Primary FW fishes**: families strictly confined to FW, cannot tolerate SW; have a long evolutionary history in FW
  - e.g., characins, minnows, catfishes, sunfishes
- **Secondary FW fishes**: families generally restricted to FW but may occasionally tolerate SW; originally of marine origin
  - e.g., cichlids, poecilids
- **Freshwater representatives of marine families ("peripheral")**
  - e.g., sculpins, puffers, gobies, stingrays
- **Diadromous fishes ("peripheral")**: migrate from SW to FW or vice versa at different stages in their life cycles
  - e.g. salmon, smelt, eels
- **Euryhaline marine visitors**
  - e.g., sharks, snappers

Primary FW fishes (~85 families)

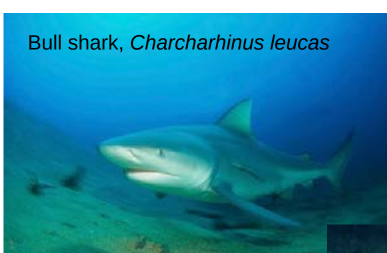
- Characidae
- Cyprinidae
- Siluriformes
- Centrarchidae

Secondary FW fishes (11 families)

Freshwater representatives of marine families

Diadromous fishes

Euryhaline marine visitors

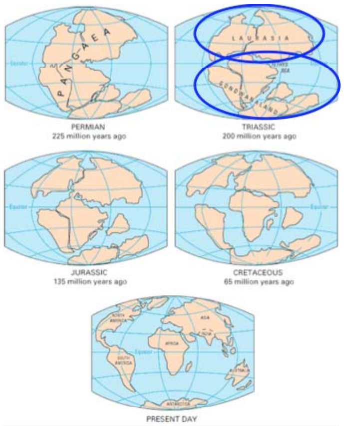


III. Ecology of Freshwater Fishes

Factors that affect the abundance and distribution of FW fishes:

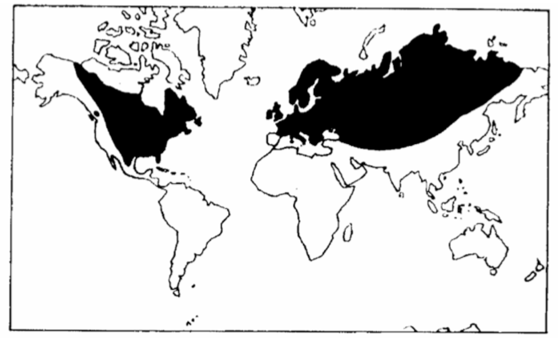
- zoogeography (e.g., continental drift)
- physical factors (e.g., water flow)
- chemical factors (e.g., pH)
- biological factors (e.g., competition, predation)
- introductions (e.g., rainbow trout & largemouth bass)

Zoogeography: Continental drift



Percidae (perches & darters)

- Laurasian distribution



Osteoglossidae (bonytongues)

- Gondwana distribution

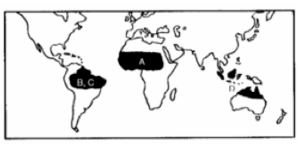
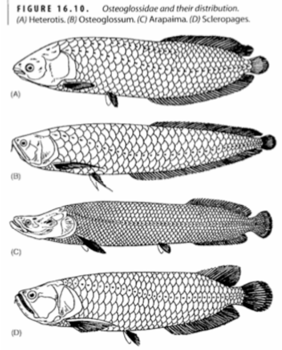
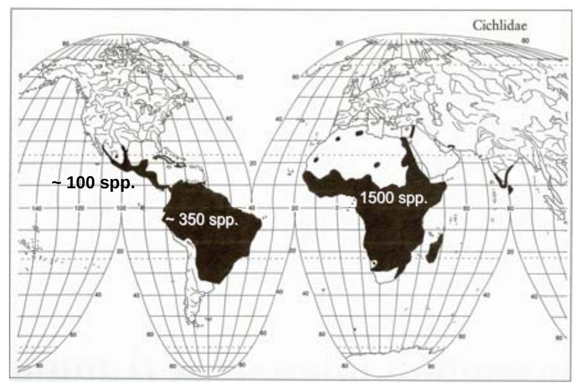


FIGURE 16.10. Osteoglossidae and their distribution. (A) Heterotis. (B) Osteoglossum. (C) Arapaima. (D) Scleropages.



Cichlidae (3rd largest family of fishes)

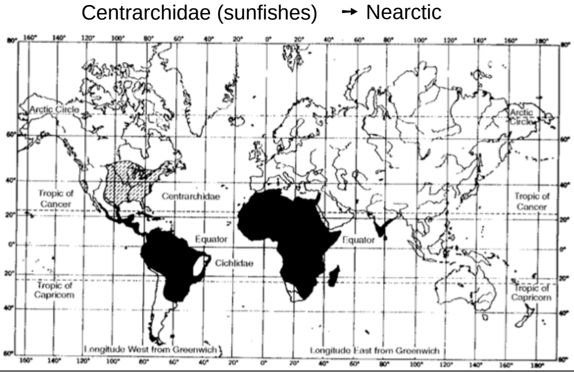
- Gondwana distribution (w/ invasion of Mesoamerica)

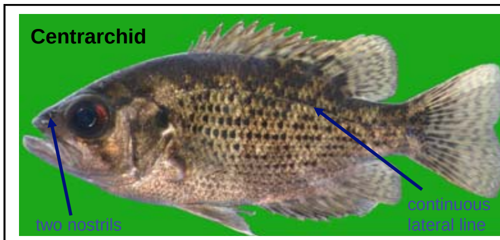


Non-overlapping distributions in ecological equivalents:
-- caused by biological interactions?

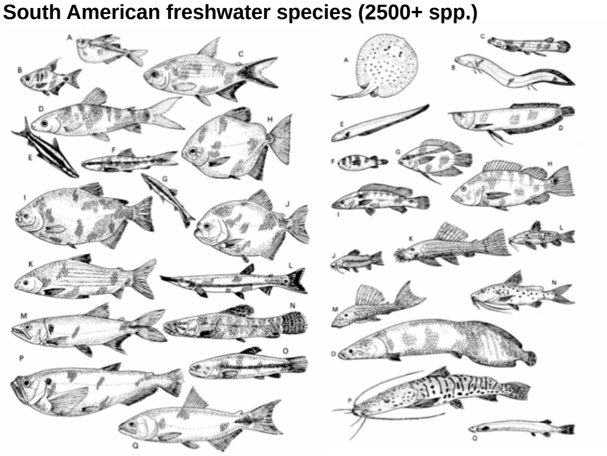
Cichlidae (cichlids) → Gondwana

Centrarchidae (sunfishes) → Nearctic

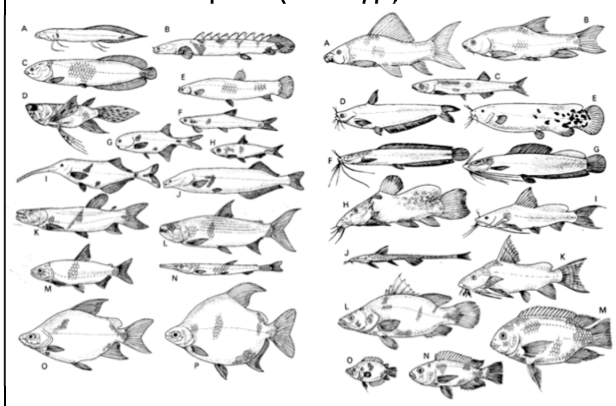




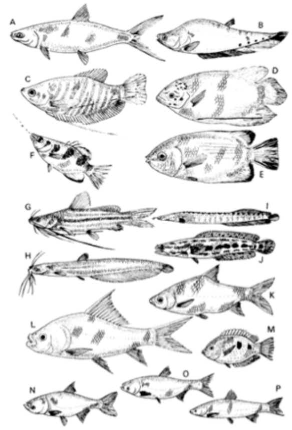
South American freshwater species (2500+ spp.)



African freshwater species (2000+ spp.)



Asian freshwater species (28 families)



Physical factors that set FW fish distributions:

- temperature
- light (turbidity)
- gradient (steepness)
- substrate
- flow regime
- size of water body

Chemical factors that set FW fish distributions:

- pH
- dissolved oxygen
- salinity
- dissolved ions
- anthropogenic pollutants

Biological factors that set FW fish distributions:

- predator-prey interactions
- competitive interactions
- symbiotic interactions

Freshwater Habitats:

- streams
- rivers
- puddles
- ponds
- lakes
- hot (& cold) springs
- caves

Temperate streams as an example

- **biological interactions** are typically flexible because of strong influences of physical & chemical factors

→ **results in many different combinations of species**

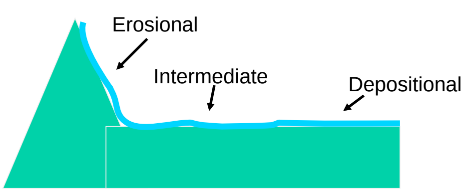
Physical and chemical factors that cause…

Zonation of Temperate Streams

<u>Zones</u>

- **erosional**
- **intermediate**
- **depositional**

→ fishes tend to occur in areas with particular physical and chemical characteristics



1. Erosional zone

- **physical characteristics**: high gradient, rocky bottom, swift current, cold water; long riffles and small pools are main habitat
- **typical fishes**: streamlined, active swimmers (i.e., trout), small bottom-dwellers (sculpins and dace)

Cyprinidae (longnose dace)

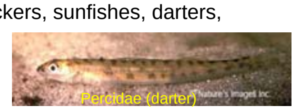
Salmonidae (brook trout)

Cottidae (sculpin)

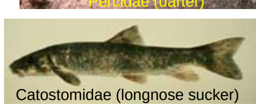
2. Intermediate zone

- **physical characteristics**: moderate gradients, warm water, intermediate current; main habitats are shallow riffles and deep pools with rocky bottoms or mud bottoms, and runs with undercut banks
- **typical fishes**: minnows, suckers, sunfishes, darters, catfishes

Cyprinidae (minnow)



Percidae (darter)



Catostomidae (longnose sucker)

Centrarchidae (sunfish)

Ictaluridae (catfish)

3. Depositional zones

- **physical characteristics**: lower reaches of rivers, where waters are warm, turbid, and slow flowing and stream bottom is generally muddy; aquatic plants can be common
- **typical fishes**: deep-bodied forms that are bottom feeders (carp, suckers), planktivores (shads), invertivores (sunfish), or predators (centrarchid basses). (Same as those found in nearby lakes)

Catostomidae (suckers)

Centrarchidae (large mouth bass)

Cyprinidae (carp)

Tropical streams and **lakes**:

- biological factors are usually more important than physical/ chemical factors in determining fish distributions and abundances. Why?
  - climate is more stable/constant (temp. is always warm and food is always abundant)
  - geological stability - tropics are old
  - more different types of food (detritus, plant material, fruits, etc.)

  - **Freshwater fishes show an amazing array of morphological adaptations for feeding, predator defense, habitat use, prey capture, etc.**

Deserts & other seasonally dry habitats


Protopteridae

Challenges:

- **drying** (desiccation, concentration of solutes & waste products, lack of aqueous O_2)
- **heat**

Devil's hole pupfish (Cyprinodontidae)

Adaptations:

- **diapause** (dormant eggs)
- **accessory respiratory structures**
- **estivation**
- **altered physiology** (e.g., fat metabolism)
- **eurythermal**
- **"euryhaline"**


African rivuline (Nothobranchiidae)

Caves

blind cave catfish (Ictaluridae)

Challenges:

- **lack of light**
- **lack of food**

Adaptations:

- **loss/reduction of eyes**
- **"hypertrophy" of other senses**
- **anguilliform shape**
- **loss of scales**
- **low reproductive output but large offspring**

cavefish (Amblyopsidae)


blind cavefish (Characidae)


cave catfish (Clariidae)