I. Development
II. Age
III. Growth

I. Development

A. Types
B. Stages
C. Metamorphosis

<u>2 Types of Development in fishes:</u>

Direct - no larval phase

Indirect - larval phase present

<u>Direct development:</u>

- all elasmobranchs
- most livebearing bony fishes
- most fishes with large eggs

<u>Indirect development:</u>

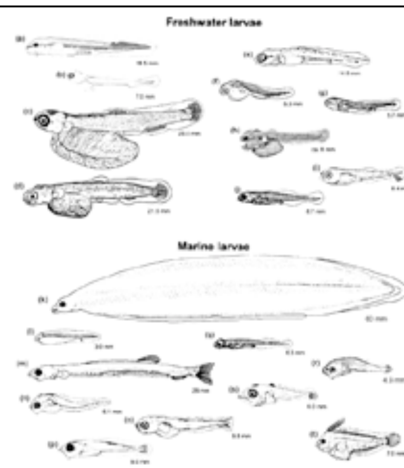
- most bony fishes

goosefish larva

goosefish adult

Larvae:

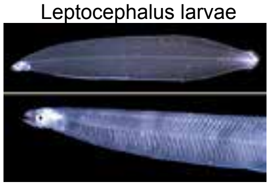
diverse shapes & forms

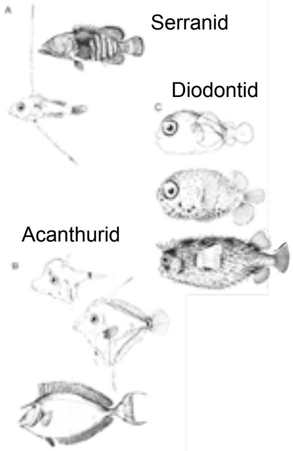


more larval forms

flatfish larva

Leptocephalus larvae





Larval Adaptations

A) Myctophid sp 1: *stalked eyes and trailing gut*

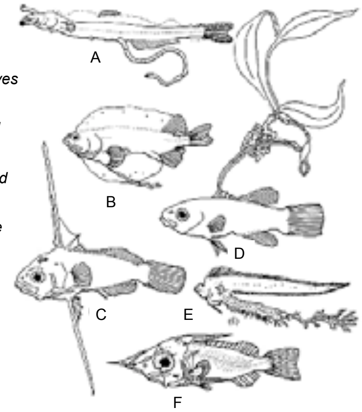
B) Myctophid sp 2: *elongated pectoral ray*

C) Serranidae sp 1: *pelvic and dorsal spines*

D) Serranidae sp 2: *elaborate dorsal fin*

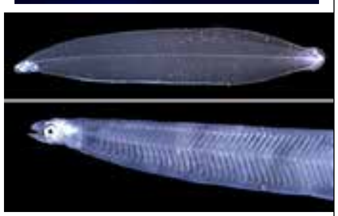
E) Ophidiidae, **cavernous assfish** (*Porogadus gracilis*): *trailing gut*

F) Holocentridae: *head and snout spines*



Leptocephalus larvae

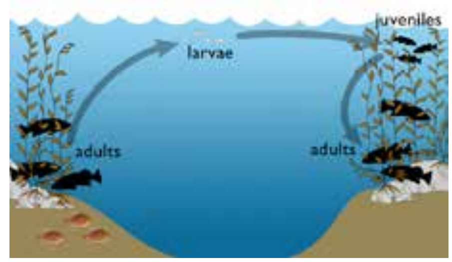
- found in 3 orders:
  - Elopiformes (tarpon)
  - Albuliformes (bonefish)
  - Angulliformes (true eels)
- long larval phase
  (>6 months – 3 yrs)
- body morphology probably assists with the absorption of dissolved organic nutrients through their body wall



Indirect Development usually leads to…

Bipartite Life Cycle

- larval stage lasts from 1 week to > 6 months
- average pelagic larval duration (PLD) is about 30 d



Typical stages of development in Indirect Developers

ontogentic development in a jack

(*Trachurus symmetricus)*

egg (embryo)

hatching

yolk sac

1st feeding

pre-flexion

flexion

post-flexion

metamorphosis

juvenile

adult

larvae

improving swimming & sensory abilities

Embryonic Period

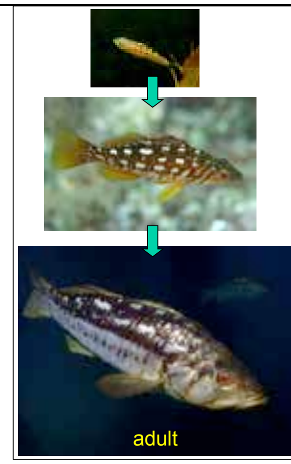
- organism entirely dependent on nutrition provided by the mother (yolk or placental-like nutrition)
- period begins when cells first divide; ends when embryo is free of the egg case but still absorbing nutrients from a yolk

Larval Period

- characterized by the development of axial skeleton, fins, organs, and sensory abilities
- mortality extremely high
- flexion of the notochord – important early transition stage

Juvenile period

- miniature version of adult form (but immature)
- fully formed skeleton, organs, fins, and pigmentation
- larval features and adaptations for pelagic life are lost
- transition from larval to juvenile periods can be quick or slow; and often accompanied by a change in habitat and prey types



Benthic Juvenile vs. Benthic Adult

- metamorphosis occurs during settlement (in demersal species)
- many juveniles are colored differently than adults

beaugregory damselfish

juvenile

adult

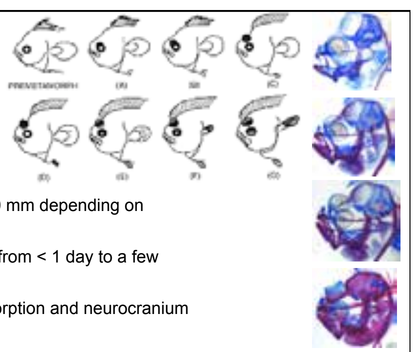
Pelagic Juvenile vs. Benthic Adult

- metamorphosis occurs in the pelagic realm prior to settlement

juvenile gopher rockfish

adult gopher rockfish

Metamorphosis in flatfish: eye migration



- occurs at from 4-120 mm depending on species
- eye migration takes from < 1 day to a few weeks
- occurs via bone resorption and neurocranium reshaping
- other structures change simultaneously (i.e. fin modifications, eye development, etc.)

Metamorphosis in Parrotfish

- adults have teeth fused into a beak
- larvae have sharp canine teeth
- larvae settle after a 25-50 day PLD
- metamorphosis occurs over a three week period
  - jaw transforms into a beak
  - phyrangeal jaw develops
  - gut becomes highly acidic to digest plant and coral material

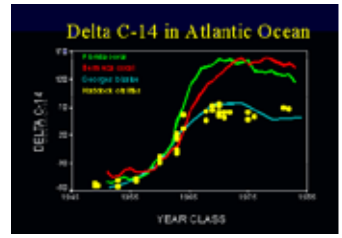
II. Age

A. Techniques
B. Maximum Ages
C. Age at Maturity

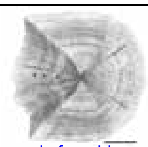
shortraker rockfish, ≈100 years old

Techniques for ageing fishes

- known individuals (e.g., in aquaria or tagged)
- environmental time marker (radiocarbon ^{14}C from nuclear testing in 1950's & 1960's)
- age marks on body parts
  - otoliths
  - scales
  - vertebrae
  - fin spines
  - fin rays
  - opercula
  - cleithrum

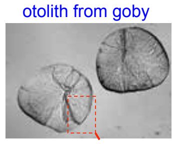


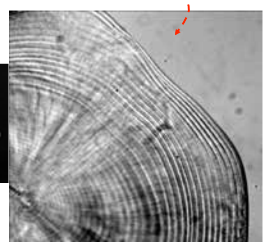
Age studies using body hard parts



scale from Ide

otolith from goby

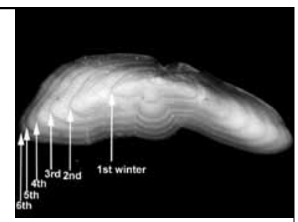




otolith from drum

shark vertebra

Age studies using body hard parts



- can have growth marks (like tree rings) corresponding to a unit of time (day or year)
- determine age from counts of growth increments

Maximum ages in fishes

highly variable among species…

short lifespans: annuals
- *Rivulus* species, some gobies

annual killifish

long lifespans:
- rockfishes (*Sebastes*) -- several over 100 years, one species over 200 years
- many sharks live several decades

rougheye rockfish: up to 205 years

Age at maturity

- related to lifespan (e.g., short lifespan, early maturity)
- often differs between sexes (w/ males maturing first usually)
- maturity typically reached in first 1/4th of maximum lifespan
- extremes:
  - male dwarf surfperch are born mature
  - spiny dogfish don't mature until about 30 years old
- reproduction doesn't typically stop in old fishes (i.e., no reproductive senescence)

III. Growth

A. The importance of growth

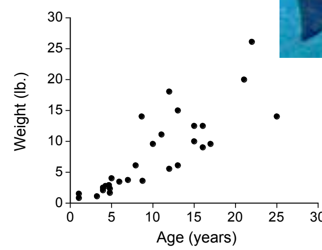
B. Growth patterns in fishes

C. Factors that influence growth

D. Measuring growth

Growth is very important in fish because...

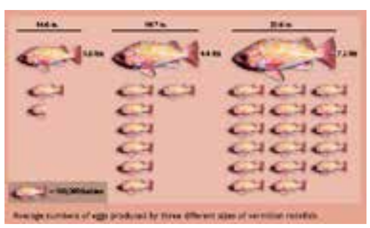
- fish never stop growing...



Growth is very important in fish because…

- fish never stop growing
- maturity is a function of size
- size has a huge influence on reproductive output
- size may influence susceptibility to predators

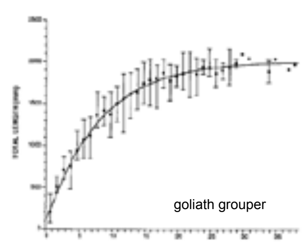
(also need to know growth rate to parameterize some fisheries models)

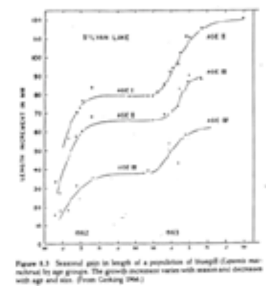


Growth Patterns

Indeterminate growth

1. **continued growth after maturation**
2. **slow approach to asymptote, rarely achieved**
3. **stanzas: growth may vary in different stages**

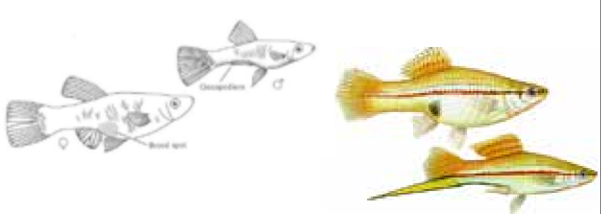




Age, sex, & maturity affect growth

1. growth slows with age, why?
   - **- increasing allocation to reproduction**

2. growth often differs between sexes, why?
   - **- different age of maturity**
   - **- differential allocation to reproduction**



Growth Patterns cont.

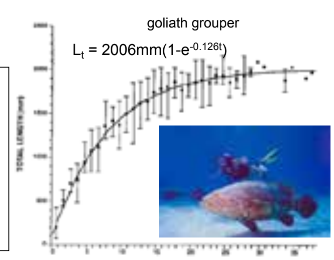
Mathematical Model of Fish Growth

- von Bertalanffy growth equation
- models asymptotic growth (doesn't fit all species)

$$L_t = L_\infty(1-e^{-Kt})$$

where:

- L_t is length at age t
- L_∞ is the theoretical max. length
- t is age ("time")
- e is base of natural log
- K is the Brody growth coefficient



Bullock *et al.* 1992

Growth can only occur if there is surplus energy...

Surplus energy =

energy from food – metabolic costs – energy excreted

body maintenance & repair, digestion, movement

feces, ammonia, urea, mucus

Other than growth, what can surplus energy be used for?

Growth rate is set by…

- physiology
- environment

Physiology:

- growth is controlled by hormones secreted by the **pituitary** and the **gonads**

(stress produces hormones that reduce growth)

II. Factors that affect growth:

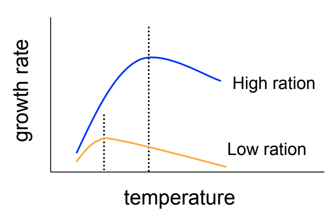
1. Food
2. Temperature
3. O_2
4. Ammonia
5. Salinity
6. Exercise
7. Age & Maturity
8. Competition
9. Predators

Food

- quantity and quality matter
- seasonal variations in growth rate partially driven by abundance of food
- food is usually limited for fishes (e.g., Geoff Jones & Graham Forrester: damselfishes on the GBR)

Temperature

- growth increases with temperature
  - **- chemical reactions and tissue synthesis faster**
  - **- but metabolic costs increase too**
  - **- on reduced ration, fastest growth at lower temperatures**
  - **- fish prefer optimal temperature for growth**



Oxygen

- more dissolved O_2 ➔ more growth
  - **- higher efficiency at converting food to tissue**

Ammonia

- more ammonia ➔ less growth
- un-ionized form (NH_3) more toxic than ionized form (NH_4^+)

Salinity

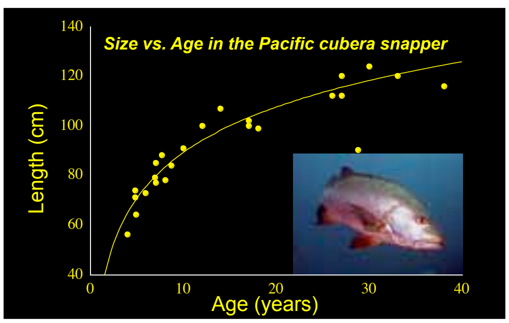
- each species has an optimal salinity for growth
- at sub-optimal salinities, growth declines because the cost of osmoregulation increases

Exercise

- increases growth rate
  - **- Why?**
  - **- Should increase metabolism and reduce growth, but...**
    - – increases growth hormone levels
    - – decreases aggressive interactions (which use energy and cause injury and stress)

Age & Maturity

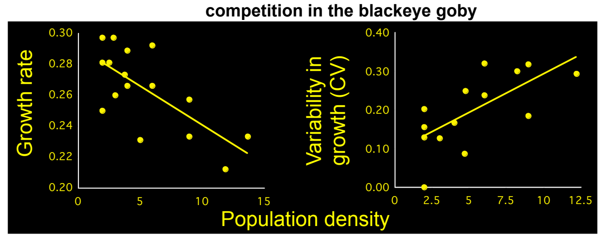
- fastest growth when young (as a fraction of body mass)
- mature fish invest energy into gonads and reproductive behavior



Competition

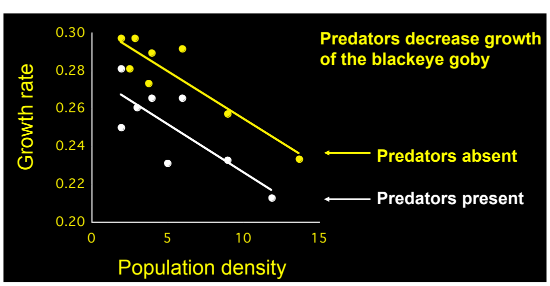
- decreases growth rate
- can increase variability in growth rate (through social interactions) (known as "growth depensation")
  - **- limits food**
  - **- increases stress**

competition in the blackeye goby



Predators

- can increase or decrease growth
  - – increase growth by thinning prey population
  - – decrease growth by causing prey to forage less or on lower quality food



III. Measuring Growth

- can be measured in the lab or field

lab

- strength: tight control over environmental variables
- weakness: lack of realism

field

- strength: realistic
- weakness: little control over environmental variables

Measures of growth can be of:

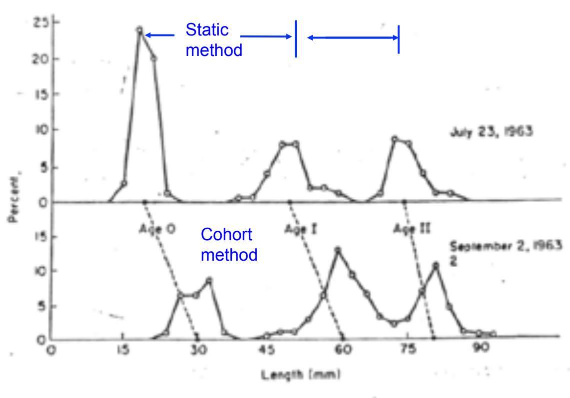
- **Individuals** - provides more information
- **Groups** - easier to obtain

and for each of these can be:

- **Direct** - more reliable
- **Indirect** - easier to obtain

<u>**Direct** measures of growth</u>

- measure–re-measure **known individuals**
  - **advantages**: most accurate; allows measurement of individual variation
  - **disadvantages**: labor intensive
- measure–re-measure a **cohort**
  - **advantages**: less time consuming; don't need to recover tagged fish
  - **disadvantages**: only gives average growth; may be biased
- measure several **cohorts** (static method)
  - **advantages**: least time consuming; don't need to recover tagged fish & only sample one
  - **disadvantages**: only gives average growth; most likely to be biased



Mark–recapture

<u>**marks**:</u>

- clipped fins
- "cold brands"
- coded wire tags
- sonic tags
- genetic tags
- GPS position/data transmitting tags
- external tags (disks, streamers, beads)
- passive integrated transponders (PIT)
- injected paint, dye, or elastomer
- injected visual implant tags with codes
- chemically stained otoliths or bones

<u>**Indirect** methods of measuring fish growth</u>

1. Radiocarbon uptake
2. RNA/DNA ratio
3. Marks on bony structures

<u>Radiocarbon uptake</u>

- measure uptake of radio-labeled amino acids by live epidermis on scales
  - **get "instant" data on current growth rate**
  - **but, only get a relative estimate of growth rate**

<u>RNA/DNA ratio</u>

- high ratio = high current growth rate
  - **same advantages & disadvantages as for radiocarbon uptake**

Marks on bony structures

- one mark = one unit of time alive (e.g., one year, one day)

advantage:

– provides a real estimate of growth (e.g., mm per day, or kg per year)

– only need to collect fish once & entire growth history is recorded

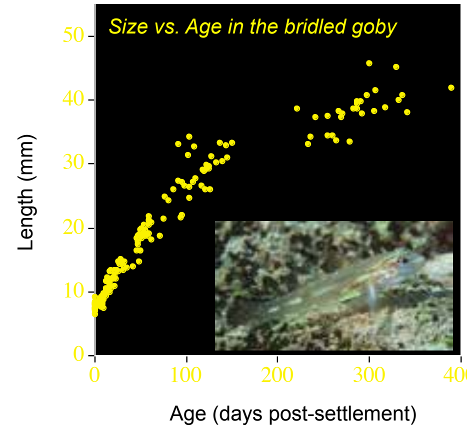
disadvantages:

– can be labor intensive

– marks may not represent the time intervals believed

– for many structures, must kill the fish to age it

– sample may be biased — only contains survivors (e.g., survivors may be fastest growers)



Potential problems:

- increments may be formed at some interval other than what you think (e.g., may be sub-daily or sub-annual)
  – need to validate the periodicity of increment formation

- increments can be lost
  – scales, bones, and vertebrae can be re-mineralized and partially resorbed

- increments can be difficult to discern or interpret

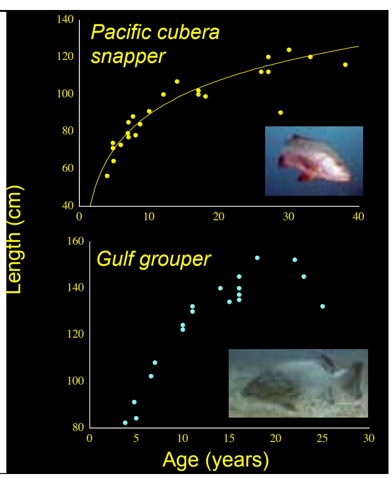
Types of hard part studies of growth

- Population growth rate/age structure
- Individual growth rates

Population growth rate/age structure

Information provided:

- average growth rate
- variation in growth rate
- age-related changes in growth rate
- maximum age
- age structure of population

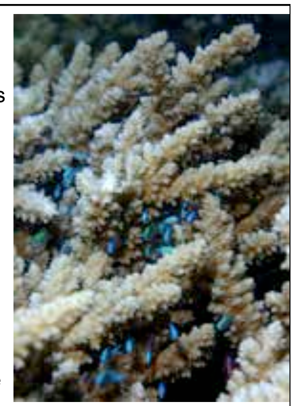


Individual growth rates

- relative growth rates or
- estimate absolute growth rates by "**back calculation**"

—allows comparison of growth rates of individuals over specific portions of life

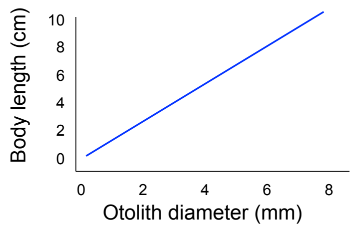
-- e.g., how fast does *Chromis viridis* grow in first month of life after settlement in dense populations vs. sparse populations?



Back calculation

Steps:

1. Determine mathematical relationship between body size and hardpart (usually otolith or scale) diameter (or radius)



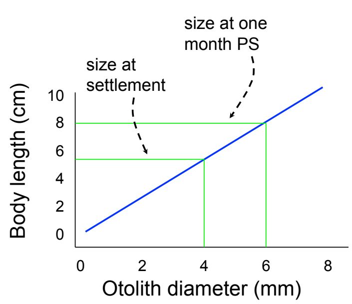
Back calculation

Steps:

1. Determine mathematical relationship between body size and hardpart (usually otolith or scale) diameter (or radius)
2. Measure the diameter of the hard part of the individual at the appropriate ages
3. Estimate the size of that individual at those ages by using the relationship between body size and hard part diameter
4. Subtract the smaller estimate of size from the larger one to get growth of the individual (divide by # of days, months, or years to get a growth rate)

Back calculation

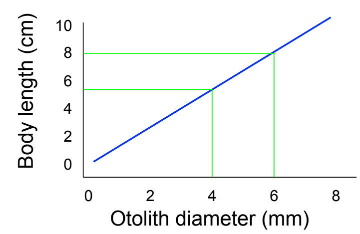
Example: What is the rate of somatic growth over the 1st month of life after settling to the reef?



Back calculation

Example: What is the rate of somatic growth over the 1st month of life after settling to the reef?

- at settlement (30 days old), otolith diameter is 4 mm
- one month later (60 days old) otolith diameter is 6 mm
- estimated growth = about 2.5 cm/month



Back calculation

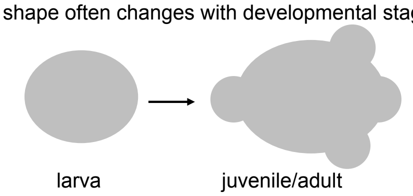
Assumptions:

1. Hard-part growth is proportional to somatic growth
2. There is no variation in the relationship between body size and hard part diameter

Other types of otolith studies

Developmental stage

- shape often changes with developmental stage



Chemical concentrations as markers of past environments

- trace elements
- strontium/calcium ratio
- O^{18}/O^{16} ratio