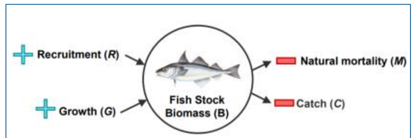
A Taste of Fisheries Science

LECTURE 2: THEORETICAL FOUNDATIONS OF STOCK ASSESSMENT

Quick Recap



$$B_{t+1} = B_t + G + R - M - C$$

Biomass this year = Biomass last year + Growth + Recruitment – Natural Mortality - Catch

Vital Rates and Necessary Parameters

- Individual growth rates of fish
- Longevity and age structure
- Natural mortality rate
- Maturity and reproduction

→ Population growth rate
Carrying capacity

- Timing of events (e.g. reproduction)
- Distribution relative to stock definition

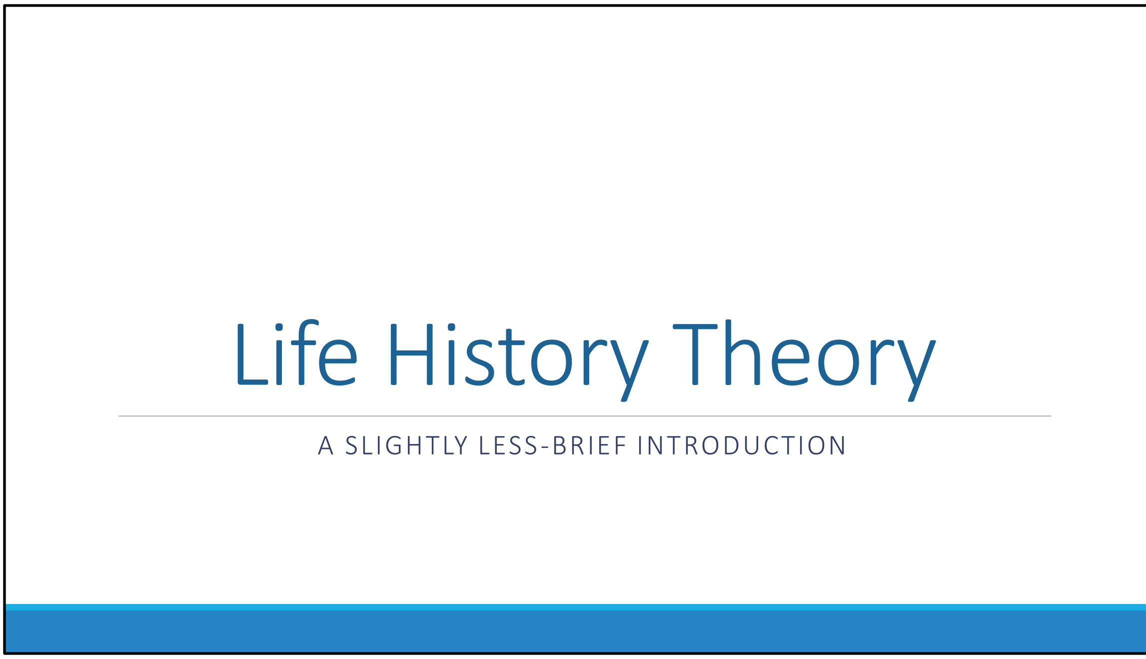
→ Exploitation pattern

- Catchability/vulnerability to gear → Selectivity pattern

Must describe the population
Must describe the fishery

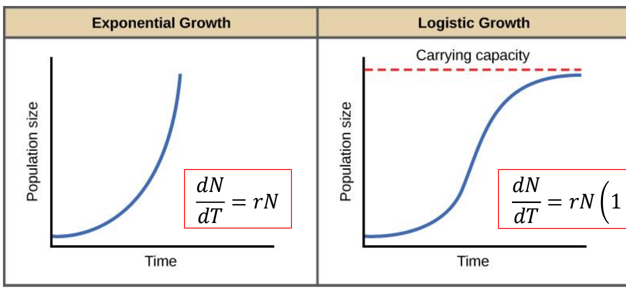
Calculate how much the fishery is affecting the population

Reminder of what parameters we are trying to estimate and whether they link to population dynamics (e.g. population growth rate), or fishery characteristics (e.g. selectivity pattern).



Discussion with the group.

How Do Populations Change in Size?



$$\frac{dN}{dT} = rN$$

$$\frac{dN}{dT} = rN\left(1 - \frac{N}{K}\right)$$

$$N_{t+1} = r_{max}N_t$$

$$N_{t+1} = r_{max}N_t\left(1 - \frac{N_t}{K}\right)$$

- Populations do not grow without bound.
- Density dependence
- How fast a population grows is related to how close it is to its ‘maximum’ size

The concept of density dependence puts an upper limit on population growth. In essence, population growth rates slow down as abundance approaches carrying capacity.
Note population growth can be described relative to an instantaneous rate (r) or an annual rate (rmax).
1/N/K is essentially a penalty term that describes how close abundance is to the maximum.

Carrying Capacity

- In theory: An equilibrium between the availability of habitat and the number of animals of a given species the habitat can support over time
- In practice: It determines the largest stock size that could be expected for a specific fish species
- Rate of population growth is related to carrying capacity (r).
  - As abundance increases, *r* decreases
- KEY IDEA: when populations are small they grow more quickly than when populations are big

When F is high and abundance is reduced, stock is expected to grow more quickly

Carrying capacity is a key idea in stock assessment because its magnitude controls maximum stock size. AND how far we are away from carrying capacity determines population growth rates.

How Does Fishing Come In?

$$N_{t+1} = N_t \frac{\left(1 - e^{-(M+F)}\right)}{(M+F)}$$

$$C_t = N_t e^{-(M+F)} \frac{F}{(M+F)}$$

Baranov Catch Equation (1918)

Exploitation Rate $U = e^{-F}$

$Z = M + F$

- KEY IDEA: fishing mortality is proportional to abundance
- In practice: if there are a lot of fish, we expect that we will catch a lot.

$$CPUE = qN_t$$

Changes in abundance from year to year is also influenced by catches. Baranov's catch equation relates catches to survival and fishing mortality. This depends on the proportionality assumption (catch for a given unit of effort (q) is proportional to abundance).

$$C_t = N_t e^{-(M+F)} \frac{F}{(M+F)}$$

Violations to proportionality assumption

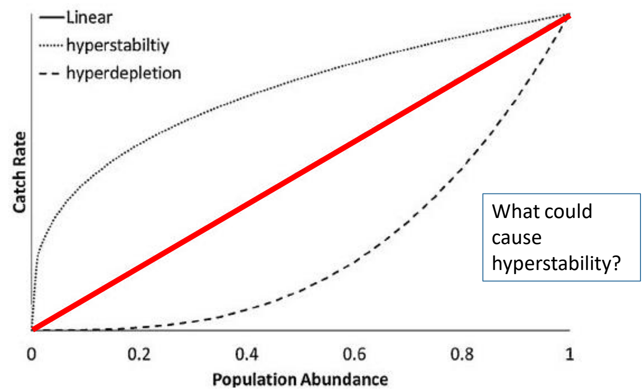
REMEMBER: we are using catches compared to an abundance index to understand mortality rates

If catch rates (CPUE) are proportional to abundance, the relationship is linear

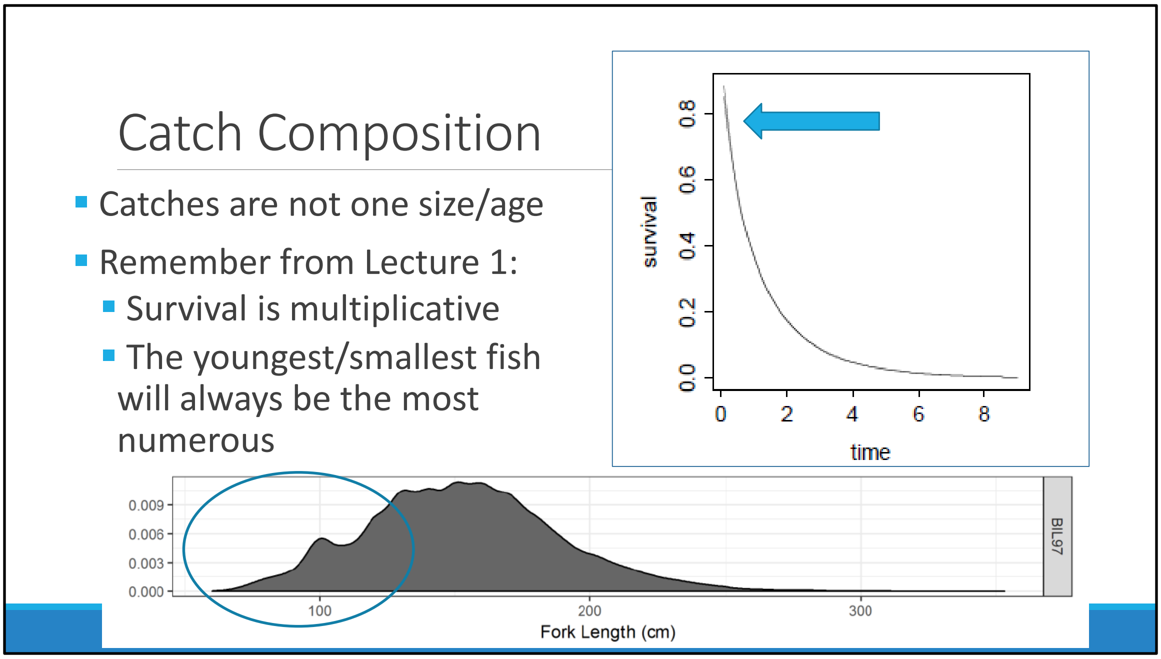
Hyperstability: when catch rates remain high even as abundance plummets

Hyperdepletion: when catch rates remain low even as abundance increases

$$CPUE = qN_t$$



Is it good to assume that catches are proportional to abundance? Not necessarily. Causes of hyperstability: fish schooling behaviour, technological advances (e.g. vessel power/speed), gear changes. Gives the appearance that fishing is not affecting abundance very much.



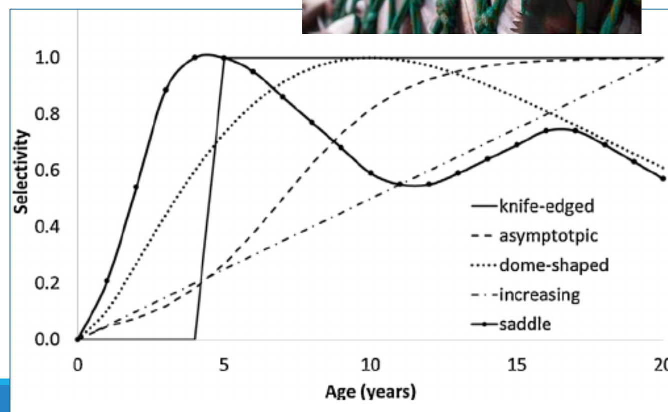
Why do we care how CPUE (or other indices) relate to abundance? Key part of understanding the catch composition.
Example distribution of catch at length for shortfin mako sharks.

Why don't we catch the most of the smallest size fish if they are the most numerous?

Catchability continued……

- Catches of each size of fish is a function of the fishing gear
- Catch and effort data are related to abundance

$$\boxed{CPUE_{age1} = q_{age1} N_{t,age1}}$$



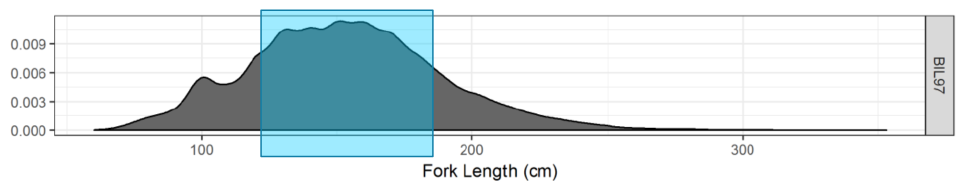
Quick example, If q is 100%, N is essentially the same as catch – meaning, if adults are there, then all of them are susceptible to capture and you can catch all adults that are there. If catchability is lower, you will only catch a proportion of what is there. q is 10% for mature ages, if CPUE is 100, predicted N is 1000.
This is the basis for our comment in lecture 1 that selectivity assumptions really matter in stock assessment.

Why else might our assumptions around selectivity have huge impact on our ability to undertake stock assessment?

Understanding Recruitment

- Our first good look at cohort abundance is when animals recruit to the fishery
  - q=1
- Year-class strength is uncertain
  - Don't know how many animals were born in a specific year
- Survival in these early years links to M

	2001	2002	2003	2004	2005	2006
Age0	100	150				
Age1		82	123			
Age2			67	101		
Age3				55	83	
Age4					45	68
Age5						37

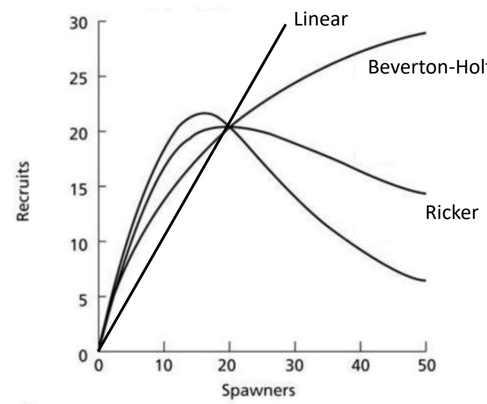


Selectivity affects our understanding of recruitment. Even though the smallest ages/sizes are the most numerous, we don't catch them for several years – see table example assuming age 3 recruits to the fishery.

If we have a good estimate of recruitment, we can get meaningful information on M and annual survival rates.
How do we estimate age0 if we have no data on it because we can't catch fish that size??

Stock-Recruitment Relationships

- Number of offspring is related to the number of parents
- Required to describe reproductive output of a year-class
  - Expectation is that young fish experience density-dependent mortality
  - Year class strength (recruitment) scales relative abundance and is critical for reference points



We assume a S-R relationship, where the abundance of spawners gives an expected number of recruits.

Simple as 1, 2, 3…

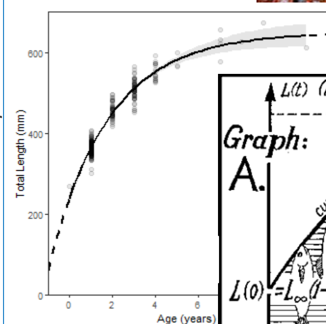
- Stock Assessment
  - Take information about the animal’s life history and build a model to describe it
  - Link the sources of data that you have (e.g. catch at age) and use the model to estimate rates (e.g. survival, reproductive output)
  - Estimate total mortality from these rates and account for the proportion that comes from fishing!
  - HOW can this possibly go wrong???

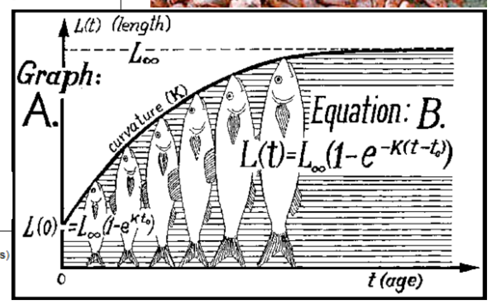
Now we have all of the components we need!

Challenge 1: Individual vs. Biomass

- Canadian catch monitoring (dockside, at-sea observer) records weights
- Not possible to count most species
- The same number of animals increase in biomass during the year
- Example: Von Bertalanffy Function
- Growth curve to relate changes in length to age
- Depends on length at birth (L0), maximum length (Linf) and a growth coefficient (k)

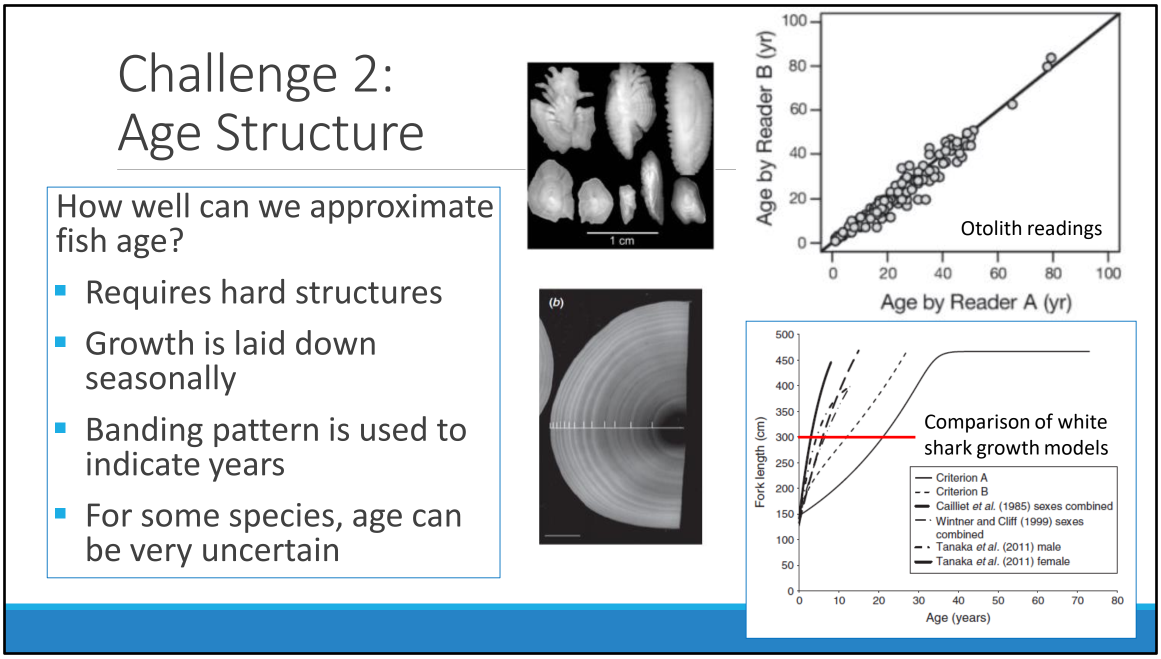
$$L_a = L_{inf}\left(1 - e^{-k(a-t_0)}\right)$$





Accounting for growth is very important in stock assessment when catches are understood as weight.
Key point is that animals of the same age can be different lengths and/or weights.

Again, we are assuming a constant relationship (e.g. Von B function) to approximate how old a fish is at a given weight/length.

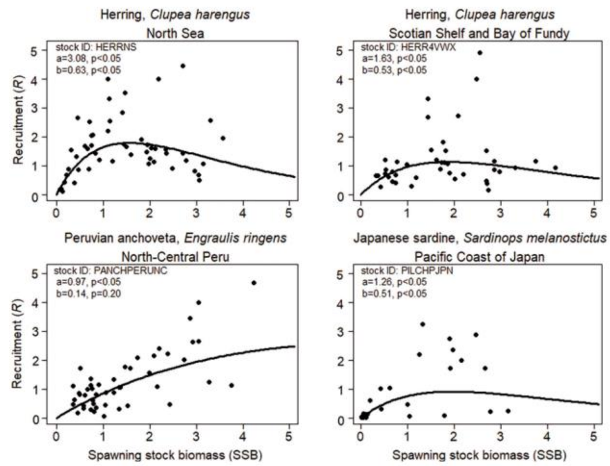


How accurately can we age animals?
Otoliths – fish ear bones – top graph compares ages estimated by two individual readers. Fairly good agreement, but not perfect.
Another point is that even though the readers are consistent, there is no guarantee that the ages are right.

Second example, shark vertebrae – as methods for aging changed, our understanding of white shark age SIGNIFICANTLY changed. Compare how old a 300 cm animal was expected to be from each of the different methods (~4 vs. ~24).

Challenge 3: Estimating S-R

- Can't have recruitment without spawners (intercept has to be zero)
- Very hard to determine slope at the origin, shape and the asymptote
- Examples: Ricker model to herring
- Note the level of variability in R for a specific value for SSB
- Equilibrium is typically assumed
  - Data is a value from a single year
  - See different stock sizes
  - Different recruitment at same stock size
  - Assuming the function is the same to fit the line



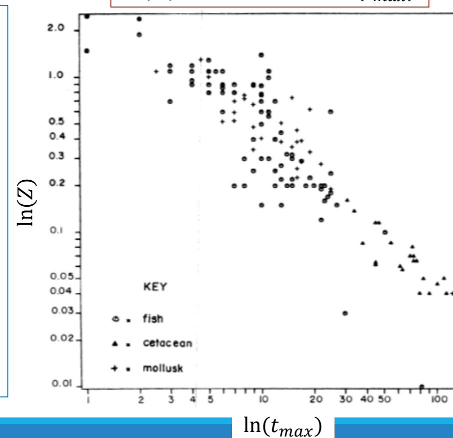
S-R relationships are notoriously uncertain. We are also not sure what function shape (Ricker, Beverton-holt, hockey-stick, threshold etc.) is biologically reasonable.

Challenge 4: Natural Mortality

M = 0.2

$\ln(M) = 0.941 - 0.873\ln(t_{max})$

- Data gives you information on total mortality
- Need to partition it into M and F components
- How do you determine M?
  - Estimate it on the basis of longevity?
  - Set the value at a constant?
  - Try to model different rates among ages?
  - Assume that M is tied to environmental conditions?



Natural mortality – this is the key parameter that we need to understand fishing mortality. Z=F+M. Our stock assessment gives information on Z.
Here is an example of M estimates based on longevity (maximum age). A common assumption was M=0.2 for groundfish.
What if M isn't constant – as we know it isn't because of environmental variability.

Note that all mortality that isn't fishing is considered M. Thus, non-constant M could happen because of something like ocean acidification reducing habitat quality and thus reducing survival.

Recap

Fish stocks are assumed to grow to a theoretical limit called **carrying capacity**

The speed at which they get there depends on **abundance** and **fishing pressure**

We assume that **fishing pressure** relates to **abundance** (proportionality assumption)

We assume that what we **catch** (at particular sizes) relates to **abundance** (catchability)

We use a **stock-recruit relationship** to try to understand abundance of **young fish** to calculate survival

Our ability to estimate mortality rates and population size depends on how well we can describe key life history characteristics:

Growth, Age, S-R relationships and natural mortality (equilibrium assumption)

Discussion Forum

QUESTIONS OF CLARIFICATION; PHILOSOPHICAL QUESTIONS