1st WORKSHOP ON CONNECTING THE IOTC SCIENCE AND MANAGEMENT PROCESSES (SMWS01)

Basic Models

INDIAN OCEAN TUNA COMMISSION
Secretariat

http://www.iotc.org

Basic Understanding from Stock Assessment: How's and Why's - Relating Biology into Math Models

Acknowledgements

- Don Bromhead, SPC for materials
- Ray Hilborn, UW for stock assessment material.

Overview

(i) Fish populations generally

- What is a “population”? What is a “stock”?
- Life cycles and life history strategies
- Basic population dynamic processes
- Movement

(ii) Fished populations in particular

- What is “fishing mortality”?
- Natural variability in populations versus fishing-based impacts
- Some characteristics of the behaviour of exploited populations
- What is “overfishing”?

Fish populations

Two important definitions

What is a "population"? Does it differ from a "stock"?

The definition and use of the terms "population" and "stock" tends to be a bit rubbery. They are often taken to mean the same thing, but are not necessarily the same.

A population is:

"A group of individuals of the same species living in the same area at the same time and sharing a common gene pool, with little or no immigration or emigration."

A stock is:

- "The part of a fish *population* which is under consideration from the point of view of actual or potential utilization." (Ricker 1975)
- "A group of fish of one species which shares common ecological and genetic features. The stocks defined for the purposes of stock assessment and management ***do not necessarily*** coincide with self-contained population units." (Restrepo 1999)

An example of natural variation in populations over time

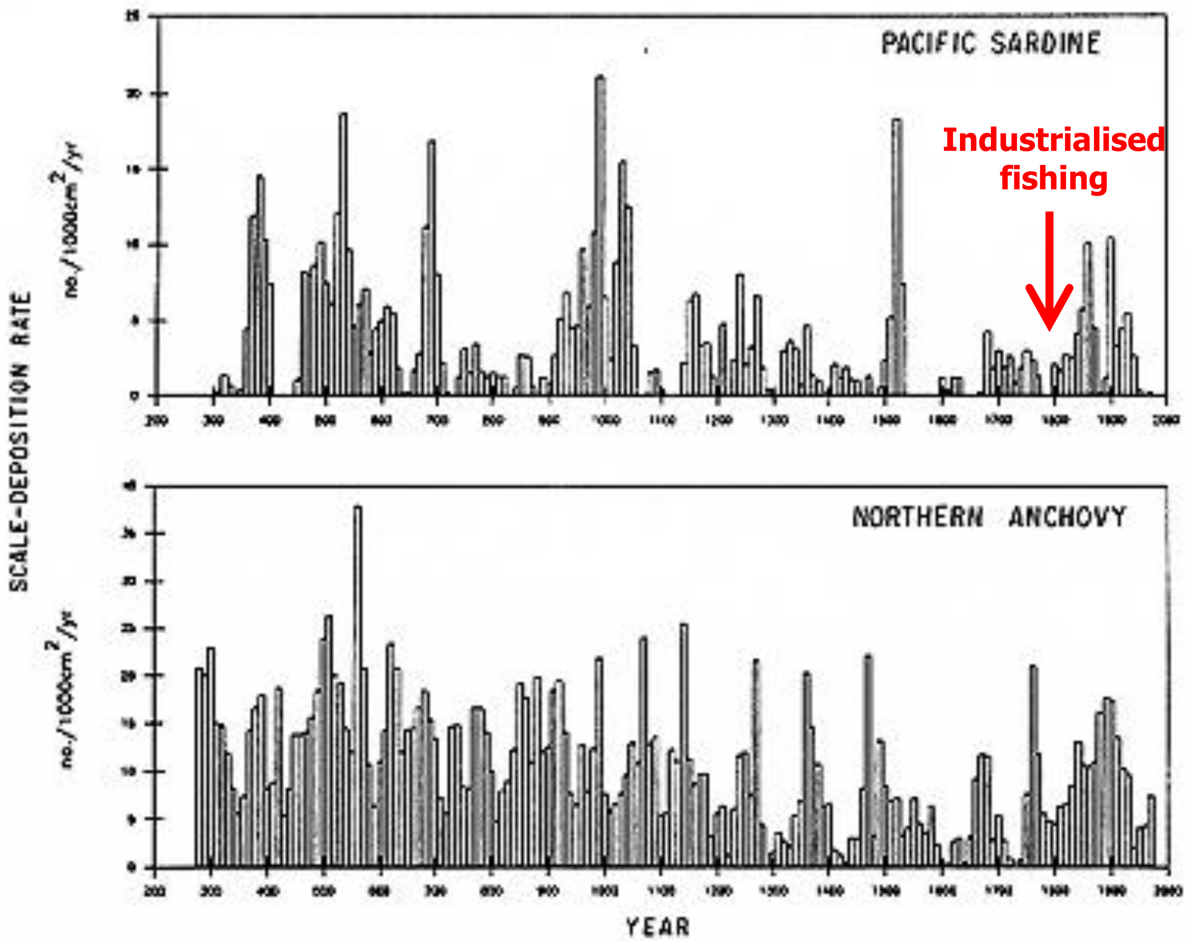
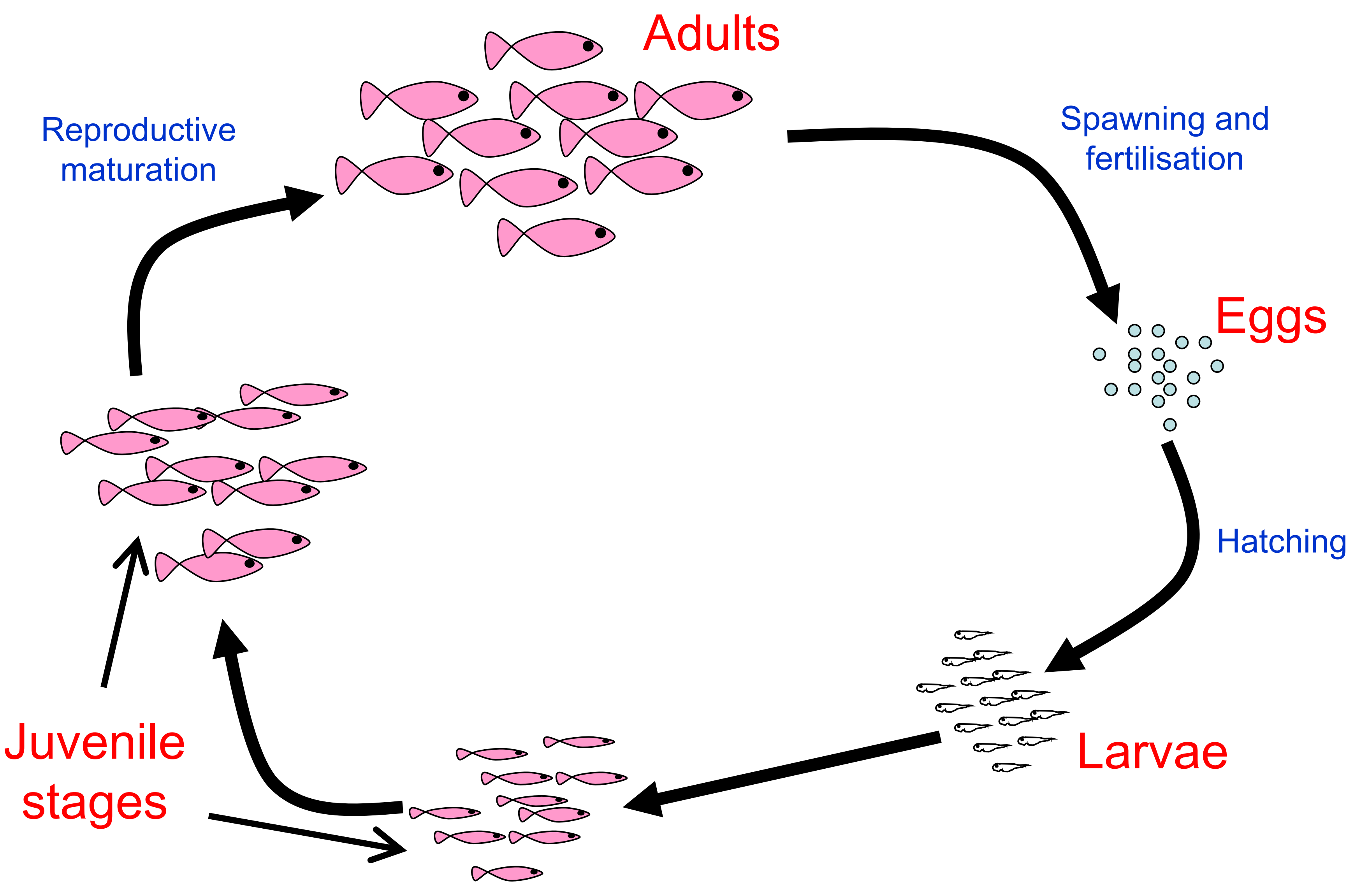


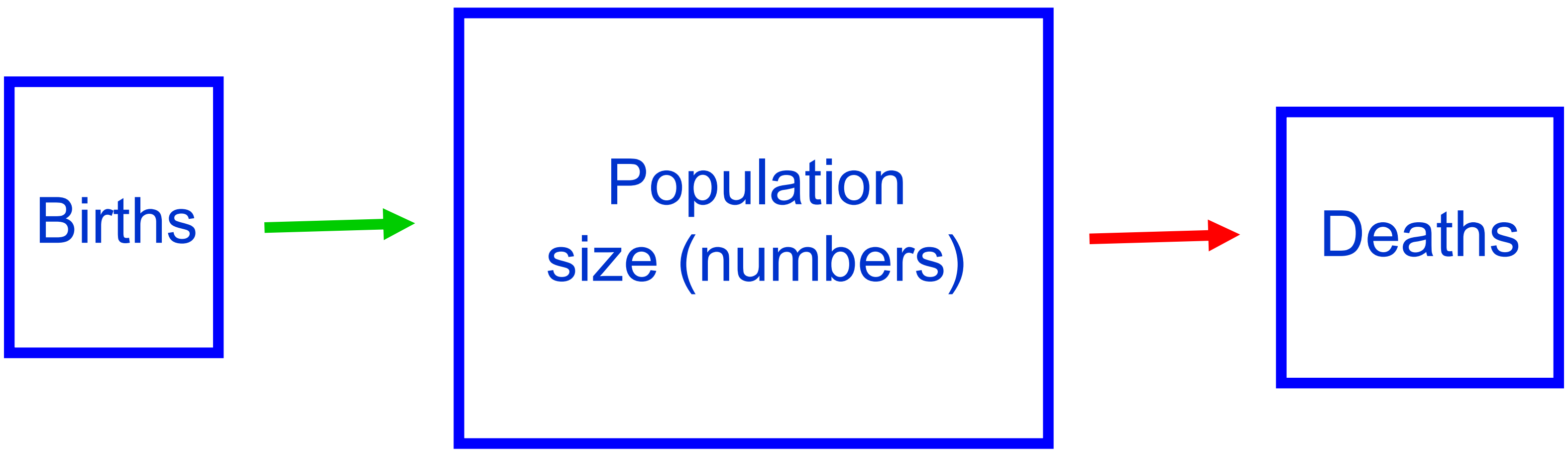
Figure 11. Time series of sardine and anchovy scale deposition rates. (from Baumgartner et al. 1992)

A generalised fish life cycle



Basic population dynamics

What are the processes that drive population fluctuations? In a closed animal population, that is, one with no immigration or emmigration:



$$N_{t+1} = N_t + B - M$$

N_t+1 = Number of animals in the next year

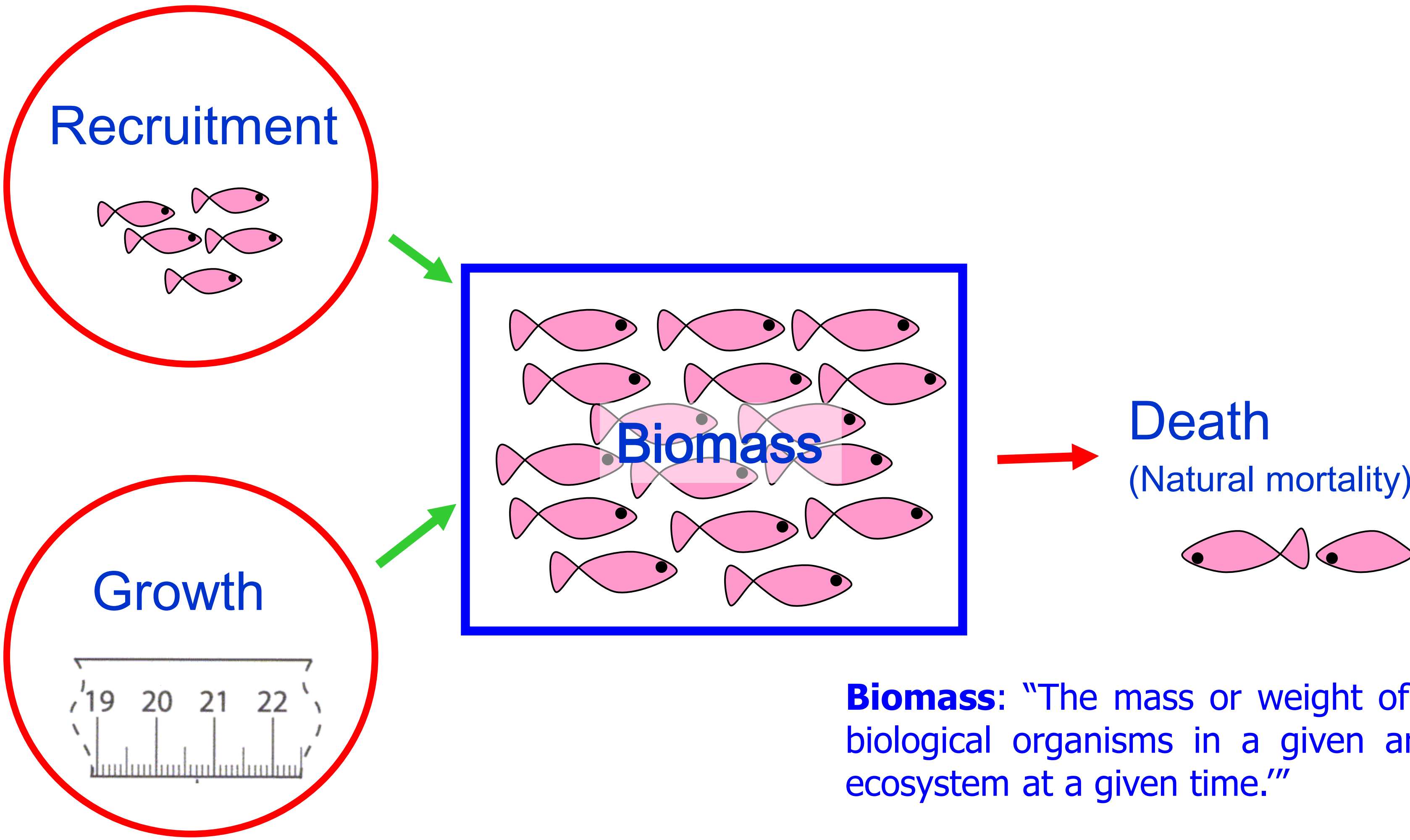
N_t = Number of animals in the current year

B = "Births" after one year

M = Natural deaths after one year.

Basic population dynamics

A biomass version of the previous model: conceptual



Biomass: "The mass or weight of living biological organisms in a given area or ecosystem at a given time.'"

Basic population dynamics

A biomass version of the previous model: mathematical

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

B_t+1 = Biomass of fish next year

B_t = Current biomass

R= Biomass of current new recruits

G= Additional biomass due to growth of current fish

M = Biomass of fish from current population that died.

NB: each of the processes of **recruitment**, **growth** and **mortality**, are affected by numerous other factors, both **endogenous** (relating to the fish's genetics, physiology and behaviour) and **exogenous** (determined by the fish's environment and external influencing factors).

Biomass: "The mass or weight of fish in a given area or ecosystem at a given time.'"

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

Recruitment (R)

What is recruitment?

Recruitment is another rubbery concept. **Recruitment simply refers to the appearance of new, young organisms in a population following a previous reproductive event**. However, when fish are considered to be recruited is often defined to be when new individuals can be detected (i.e., counted or estimated).

Four alternative recruitment definitions:

1. In demography, recruitment usually refers to the maturing of individuals into the adult age classes.
2. In fisheries science, recruitment is usually defined as the appearance of a new cohort in the catch due to it becoming big or old enough to be vulnerable to the fishery.
3. Particular fisheries definition 1: "The population still alive at any specified time after the egg stage." (Haddon, 1997)
4. Particular fisheries definition 2: "The number of fish [of a cohort] alive in a population at any arbitrarily defined point in time after the subsidence of initial high mortality." (Rothschild, 1987)

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

Recruitment (R)

What are the processes that affect recruitment in the sea?

Firstly, we need to remind ourselves of the life-history stages from when an adult population spawns to when individuals produced by that spawning event enter (recruit to) the adult population.

Having sorted that out, we may ask what factors influence the production of eggs and the probability a given egg moving through each of the subsequent stages?

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

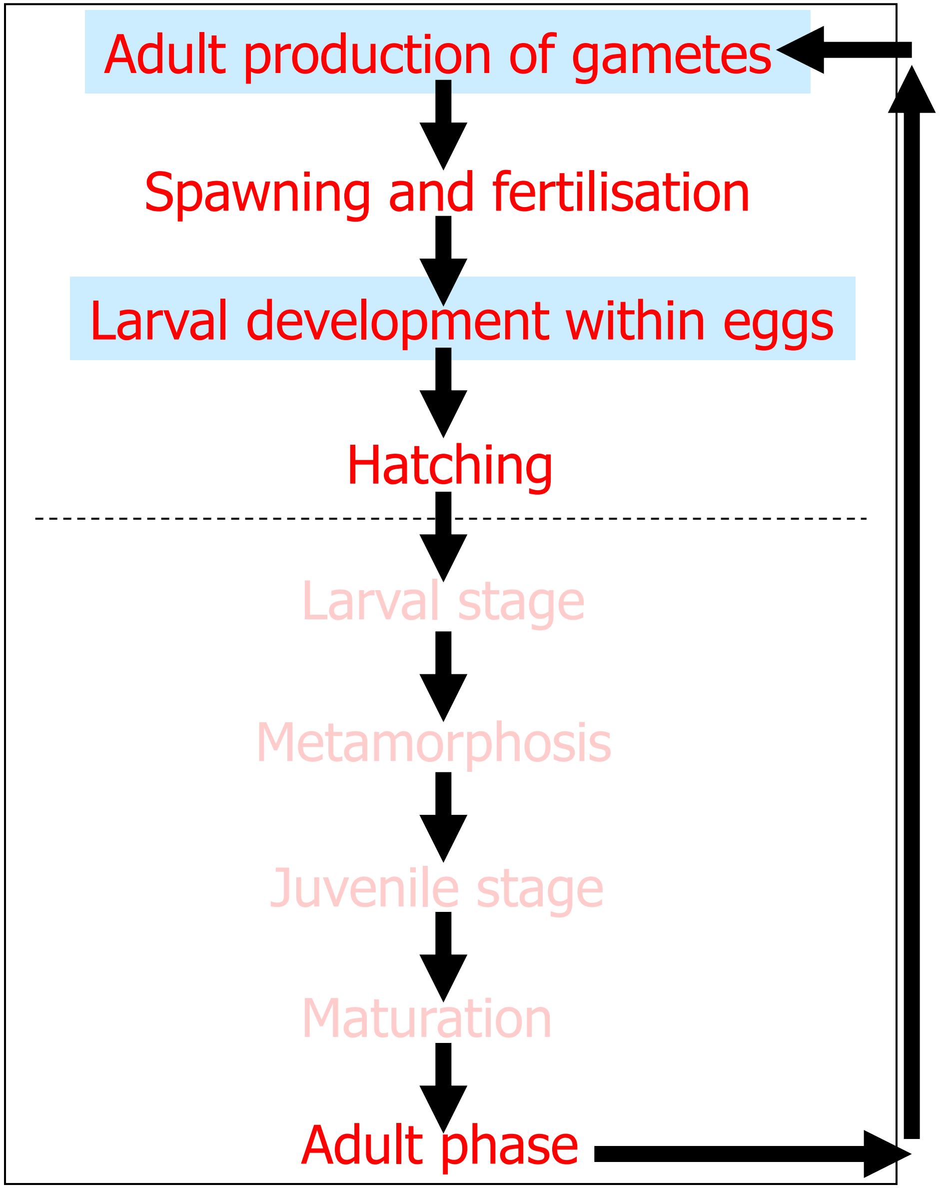
Recruitment (R)

Some processes that may affect egg production, egg condition, and larval survival

Fecundity ("quantity")

Adult condition ("quality")

Environment ("good fortune")



Recruitment (R)

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

Some processes that affect larval and juvenile survival

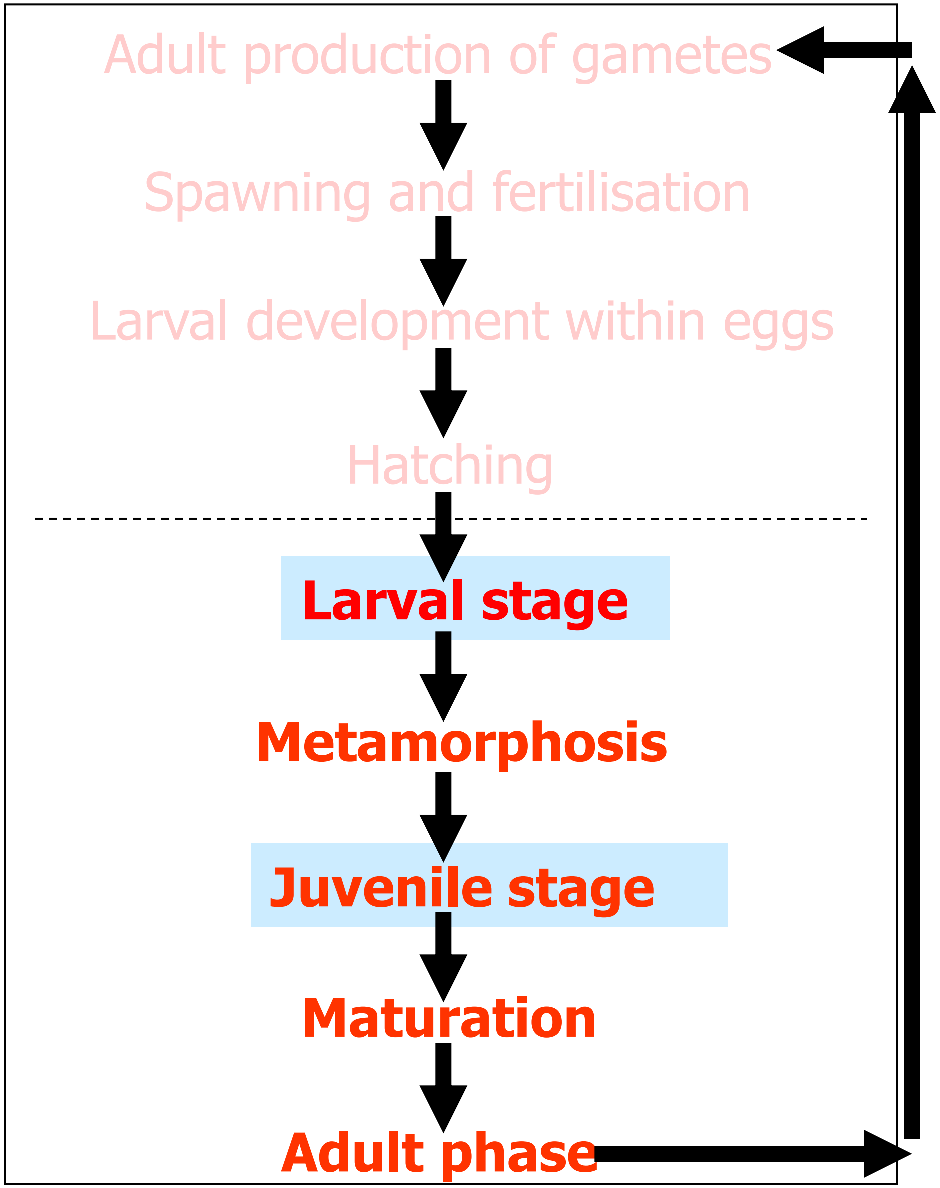
Biotic factors:

Starvation/Competition
Predation/Cannabalism
Disease

Abiotic factors:

Temperature
Salinity
Oxygen

Apparently small variations in relative or proportional survival at these stages can lead to big variations in subsequent recruitment



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

Recruitment (R)

In summary

Many different factors can impact the survival of marine fish at any of the different stages in the recruitment process

So, how do we measure recruitment?

Three possible strategies include:

a) Sampling regimes targeted at juveniles

b) Size specific indices of abundance from catch-effort data

c) Assume a relationship with adult stock size

Where information on (a) and (b) above are not available, scientists require a predictive relationship that is based on other available data. The most commonly used, and debated, of these in fisheries science is the **stock-recruitment relationship.**

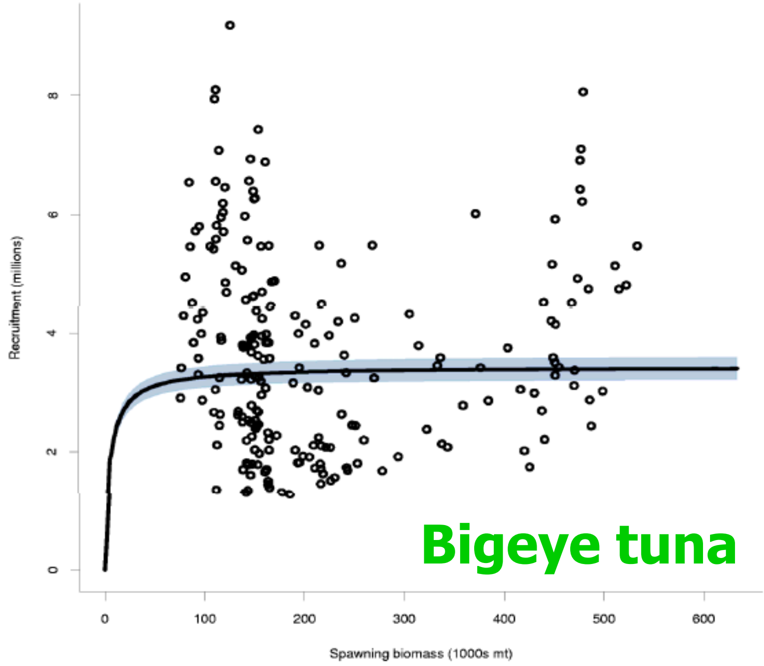
Recruitment (R)

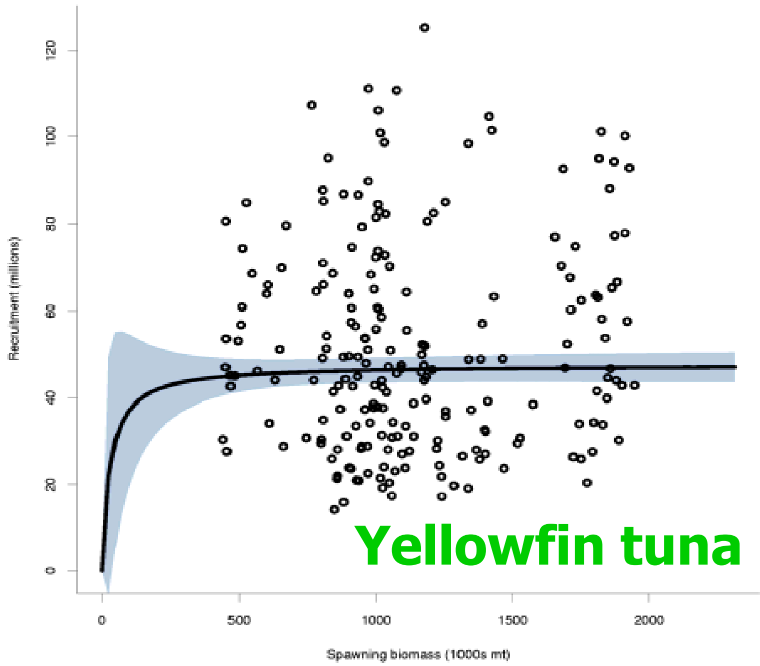
The stock-recruitment relationship

Two general theories:

1. Recruitment is **density-dependant**
2. Recruitment is **density-independent**

The latter theory was once very popular due to a lack of obvious correlations in many plotted spawner-recruit datasets (i.e., recruitment plotted as a function of spawning biomass)

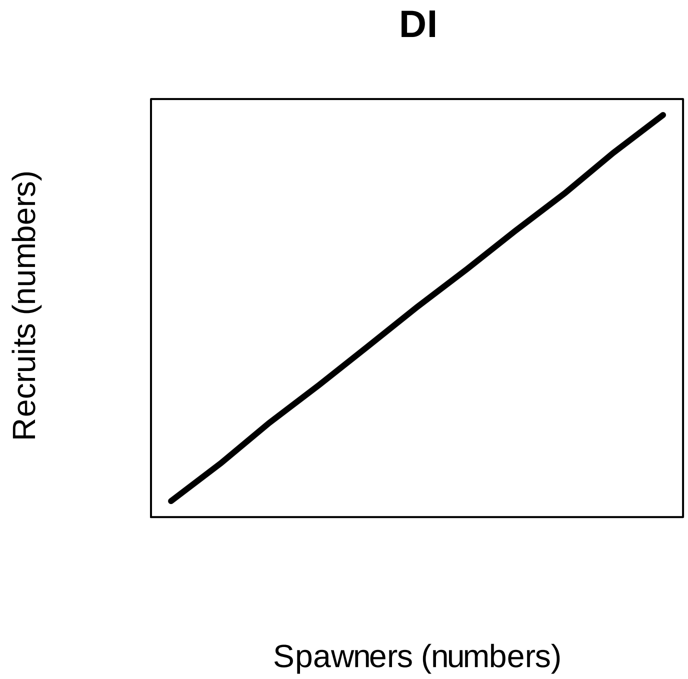


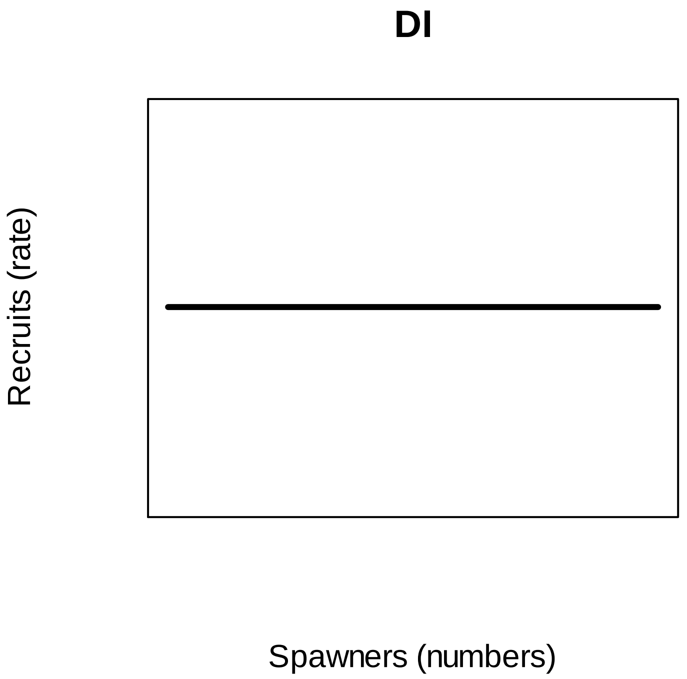


Recruitment (R)

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

The stock-recruitment relationship

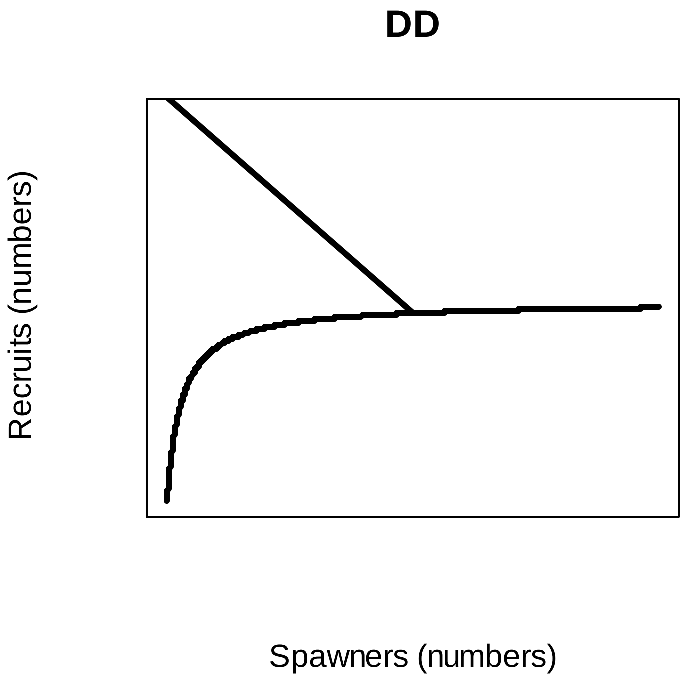


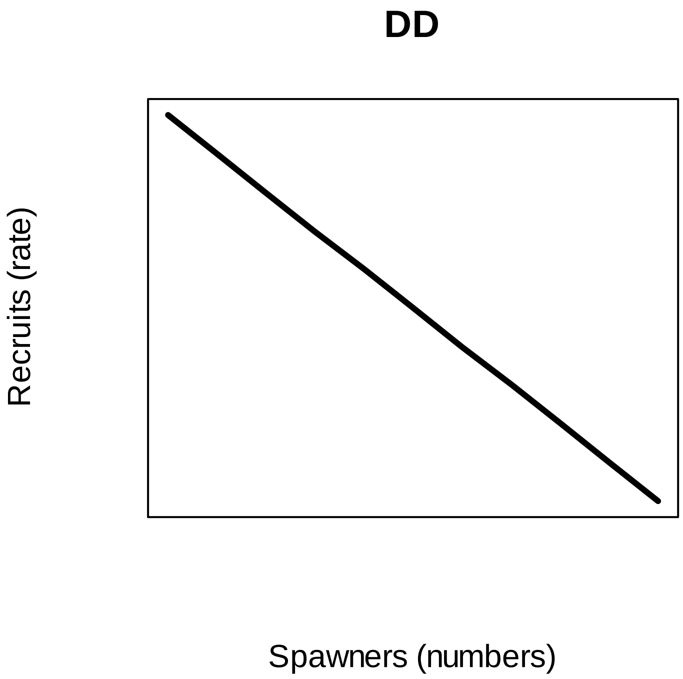


$B_{t+1}=B_t+R+G-M$

Recruitment (R)

The stock-recruitment relationship





NB: density-dependent recruitment ("DD") provides a mechanism for natural regulation of population numbers around a natural maximum population size. However, we now think that populations, especially populations in the sea, are not thought to be in a natural equilibrium. More on this later.

Natural mortality (M)

What is natural mortality?

It is the process of mortality or **death** of fish in a population due to natural causes such as predation and disease. Think of it as the removal of fish from the population.

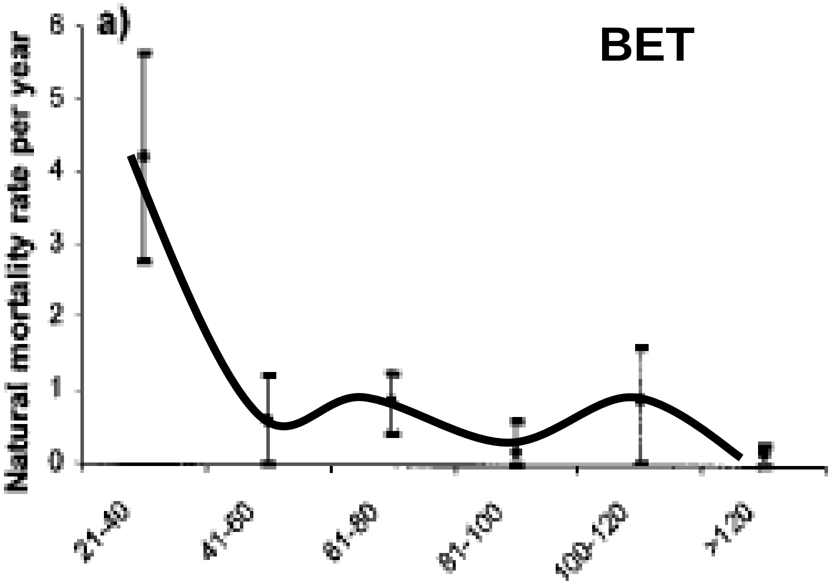
Note also that by “natural mortality” we typically refer to mortality **post-recruitment** as mortality during pre-recruitment life-history stages is usually dealt with during consideration of the recruitment relationship.

How do we express natural mortality?

Natural mortality is usually expressed as an **instantaneous rate**. This is a relative change in the proportions of the size or age classes that suffer natural mortality during each time period.

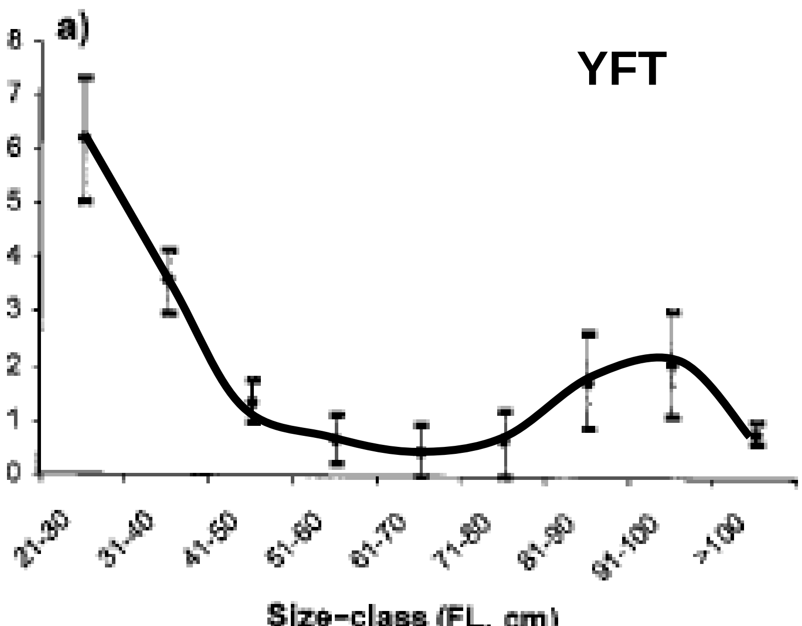
Natural mortality rates are critical in understanding of the relative impacts of fishing. In a stock assessment, we often compare natural and fishing mortality rates. Natural mortality also permits some understanding of the **“resilience”** of a stock to fishing.

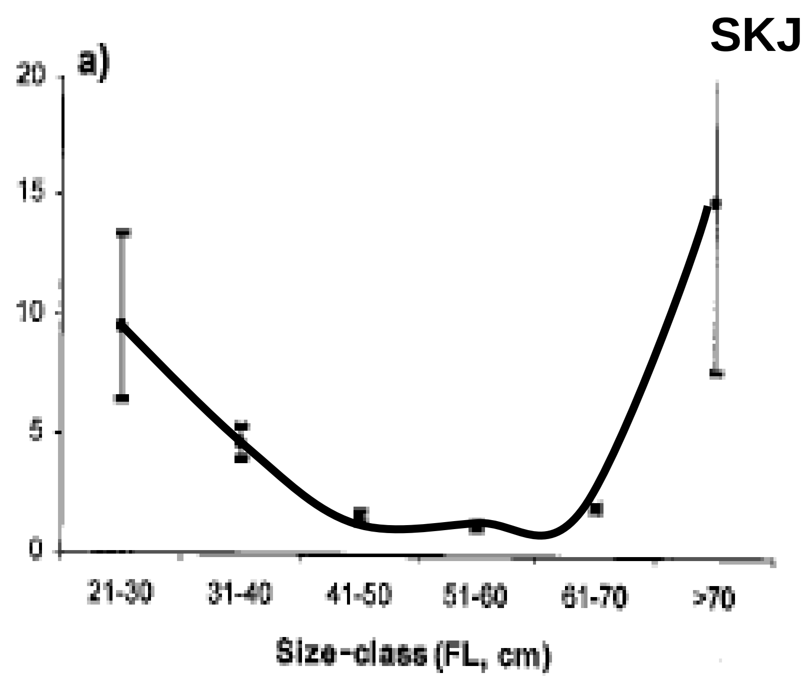
Natural mortality (M)



Fluctuations in M with age

M tends to decrease with age as fish "out-grow" predators, but it may increase again in older fish due to the stress associated with reproduction





Natural mortality (M)

Why does natural mortality fluctuate over a fish's life?

Some reasons include:

- **Reduced vulnerability to predation with increased age or size**
  Fish may "out-grow" predators as they age and increase in size

- **Senescence**
  Fish may "wear out" as they age and approach the end of their life cycle; their fitness may decline with age and accumulated reproductive and other stresses

- **Movement**
  Fish may move away from areas of high mortality as they grow

- **Behavioural changes**
  Formation of schools or other social structures

- **Changes in ecosystem status**
  Changes in prey or habitat availability due to other factors may trigger a change in natural mortality

- **Changes in population abundance**
  Density-dependant effects such as intra-specific competition or cannibalism

Growth (G)

What is growth?

All fish "grow". Growth is usually considered to mean a change in fish size (usually some form of length) or weight with age. Growth is an important process to understand as among other things it:

- **Influences a range of related population processes**
  E.g., natural mortality and reproductive maturity rates.

- **Influences the rate at which a cohort gains biomass**
  Growth is the process by which a size or age group moving through the population (a "cohort") increases in size and thus in weight and hence in "biomass".

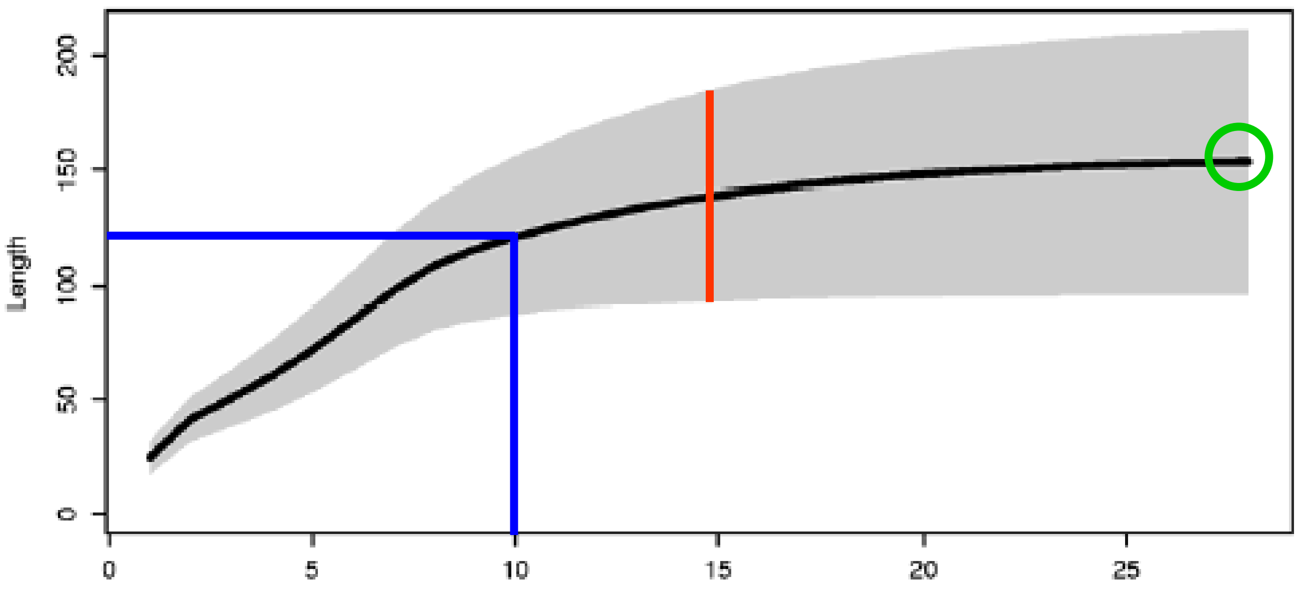
- **Influences fish vulnerability to the fishing gear**
  The vulnerability of individual fish to fishing gear often changes as fish change in size or age. Note that we refer to the different vulnerability of fish of different size or age classes in the population to the fishing gear as **"selectivity".**

Growth (G)

Describing growth

Typically, fish grow **asymptotically**, where the rate at which fish size or weight increases with age slows down as the fish ages, approaching a species-specific maximum size or weight. Note that there is no guarantee that an individual fish from a particular species or stock will follow the average growth trend for that species or stock.

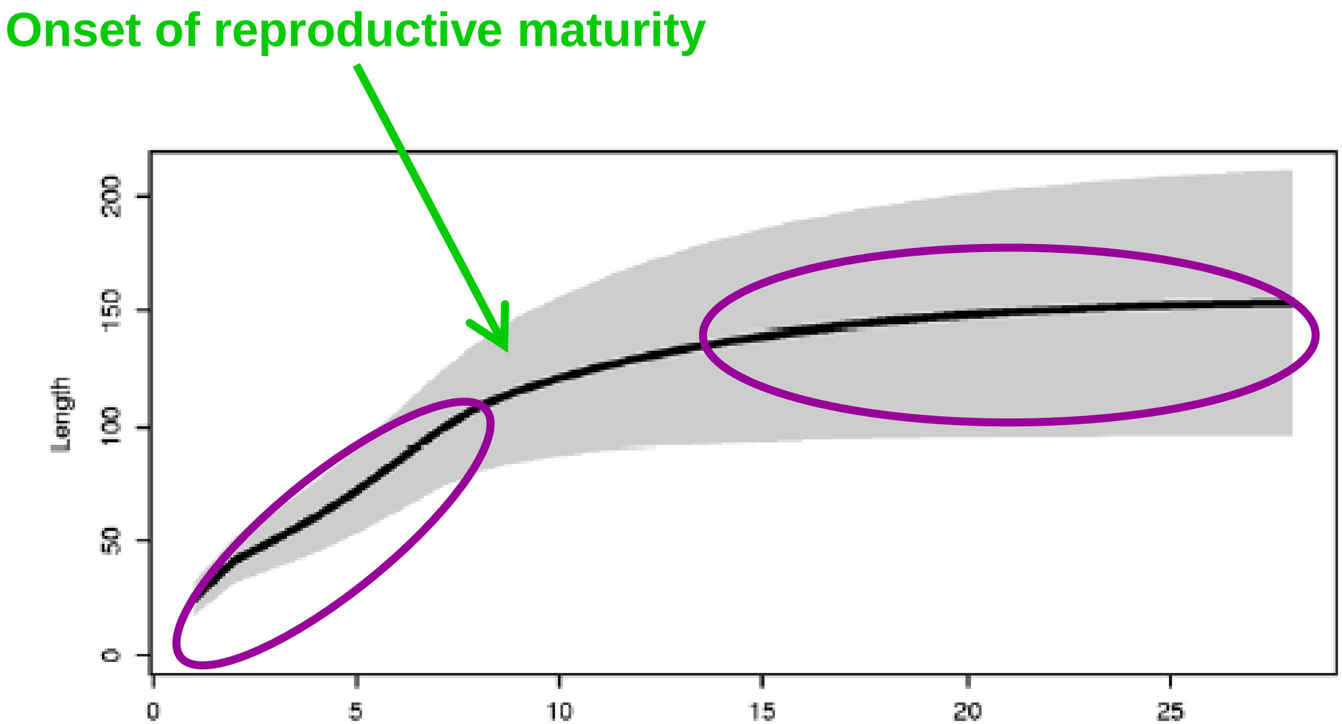
There are three main factors to consider when thinking about growth: (i) the maximum average size or weight that a species can obtain; (ii) the average rate at which fish size or weight changes with age; and (iii) how big or heavy it is when it begins to grow.



Growth (G)

Describing growth

In the tropical tunas (albacore, bigeye, skipjack, and yellowfin) several distinct growth phases can often be recognised. This is often **not** the case with less mobile, demersal and benthic temperate water fishes.



Other factors to consider in fish population dynamics

Why do fish move?

Fish move for reasons that make sense to them! Their movements are usually determined by their physiology and their interactions with their environment. Some possible reasons include:

1. **Biology**

   Maintain their preferred habitat, oxygen flow, to follow prey, to counter negative buoyancy, etc.

2. **Ecology**

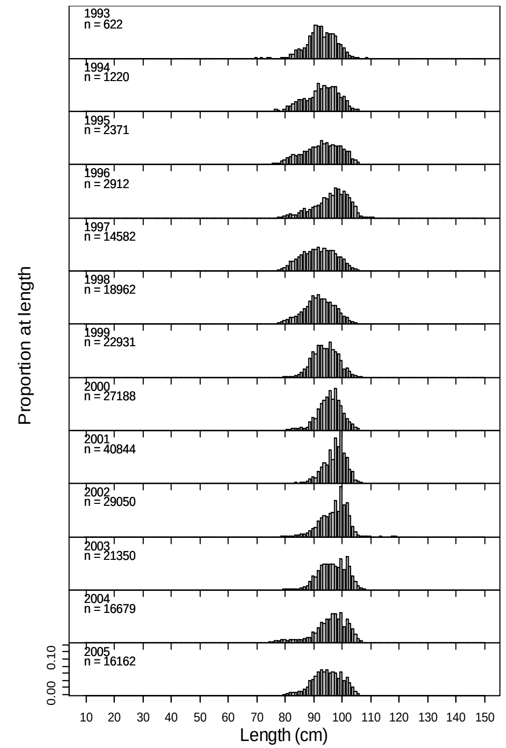
   Migrate to spawning areas (e.g. SBT), an apparent ontogenetic change in preferred habitat (e.g. albacore), a response to seasonal (e.g. albacore) or long term changes (e.g. skipjack) in prevailing environmental or oceanographic conditions, etc.

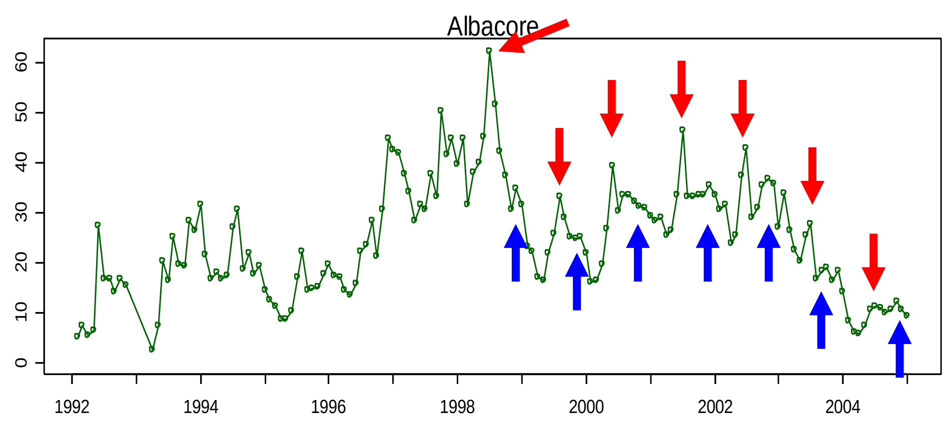
How is movement monitored?

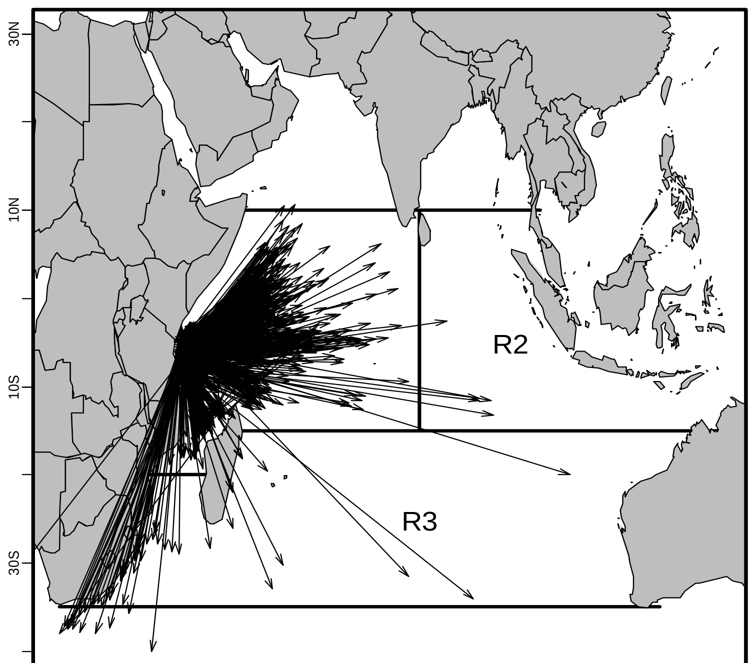
1. Size –frequency analyses

2. CPUE analyses

3. Tagging analyses



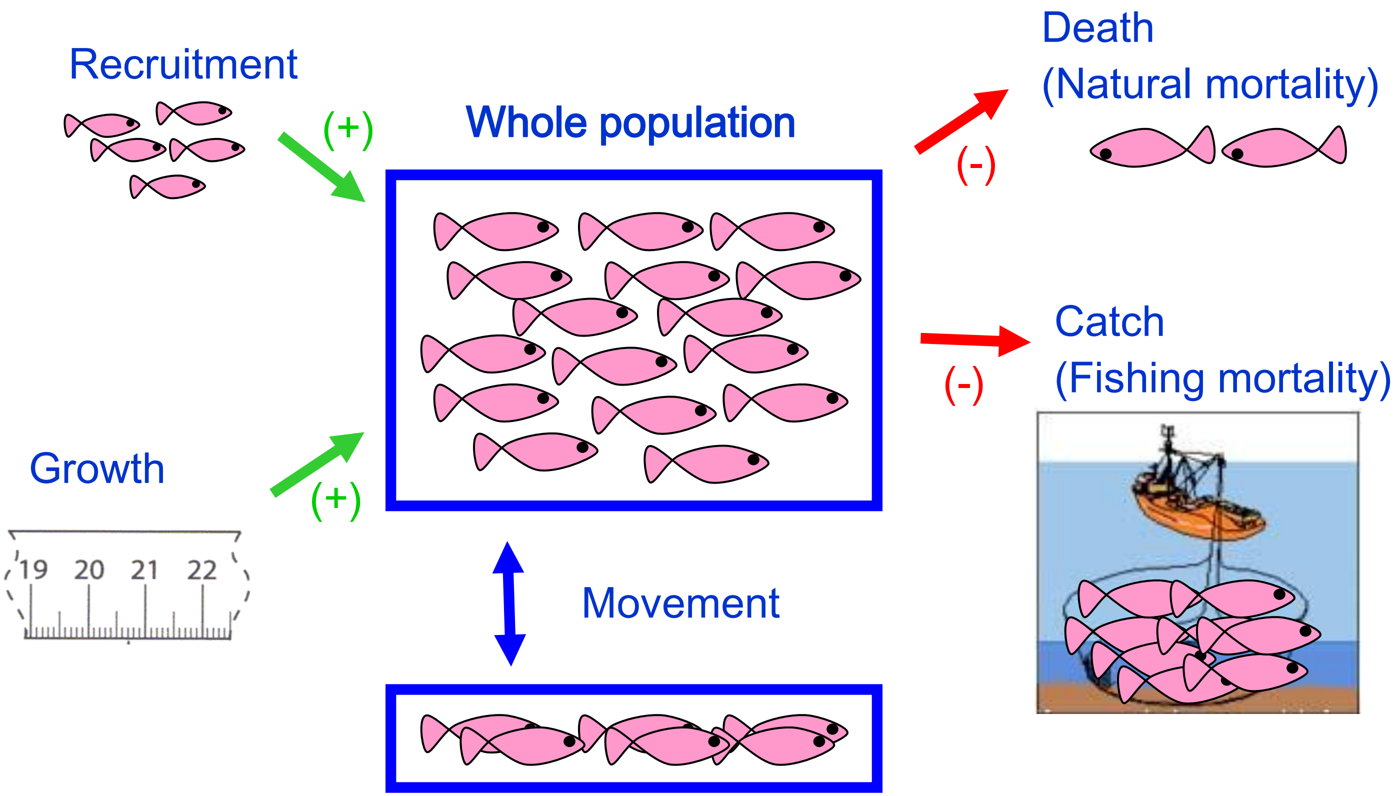




Fished Populations

Our conceptual model of a fish population

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



Fishing and the "balance of nature" myth

Sardine and anchovy population natural fluctuations from the study of scale deposition in marine sediments

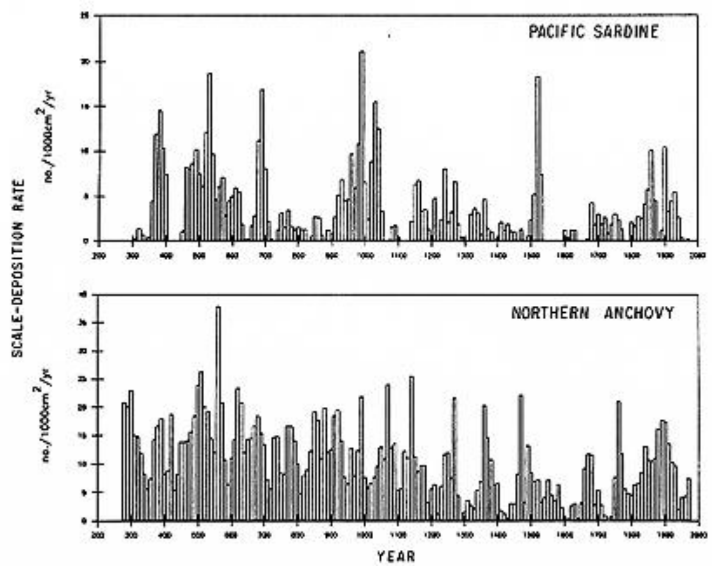
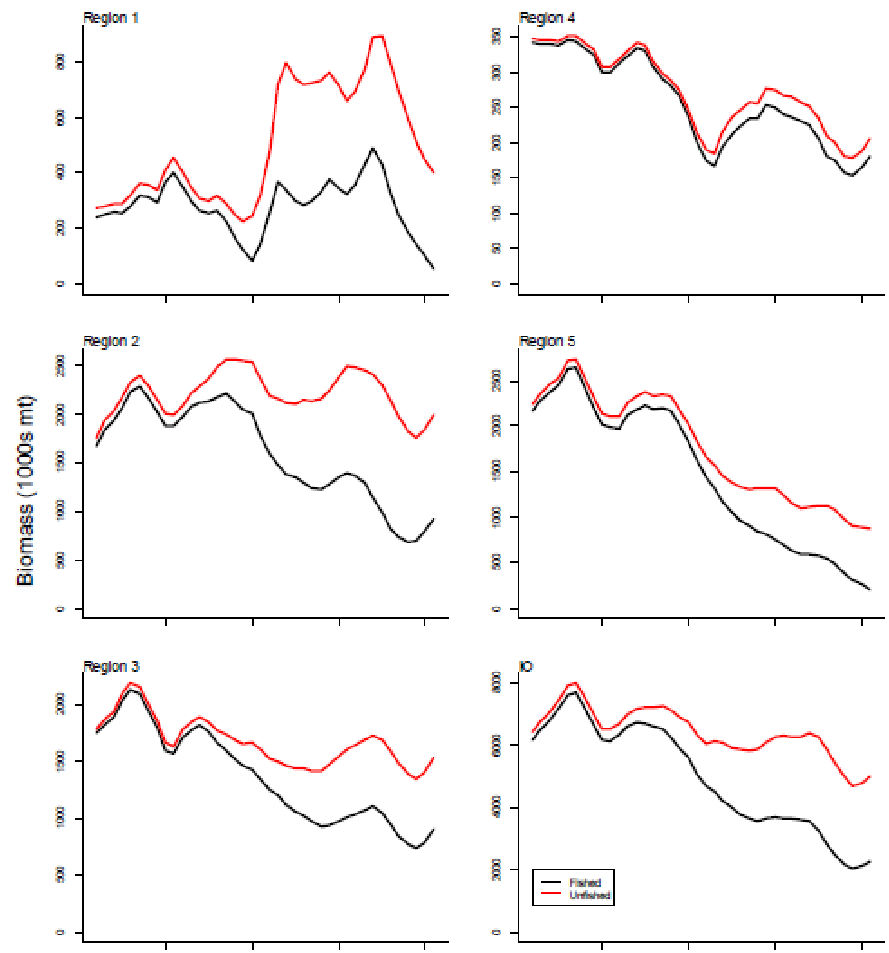
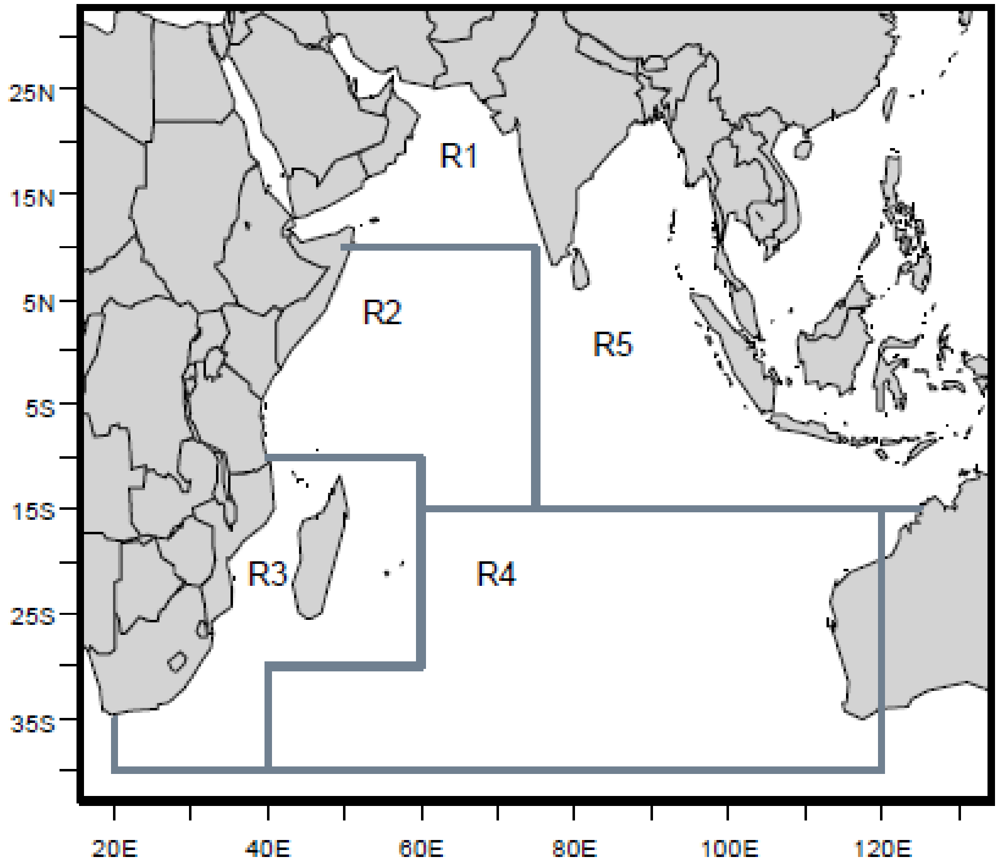


Figure 11. Time series of sardine and anchovy scale deposition rates. (from Baumgartner et al. 1992)

Yellowfin tuna – fishery impacts analyses of estimated biomass with and without the impacts of fishing (WPTT Langley 2012)

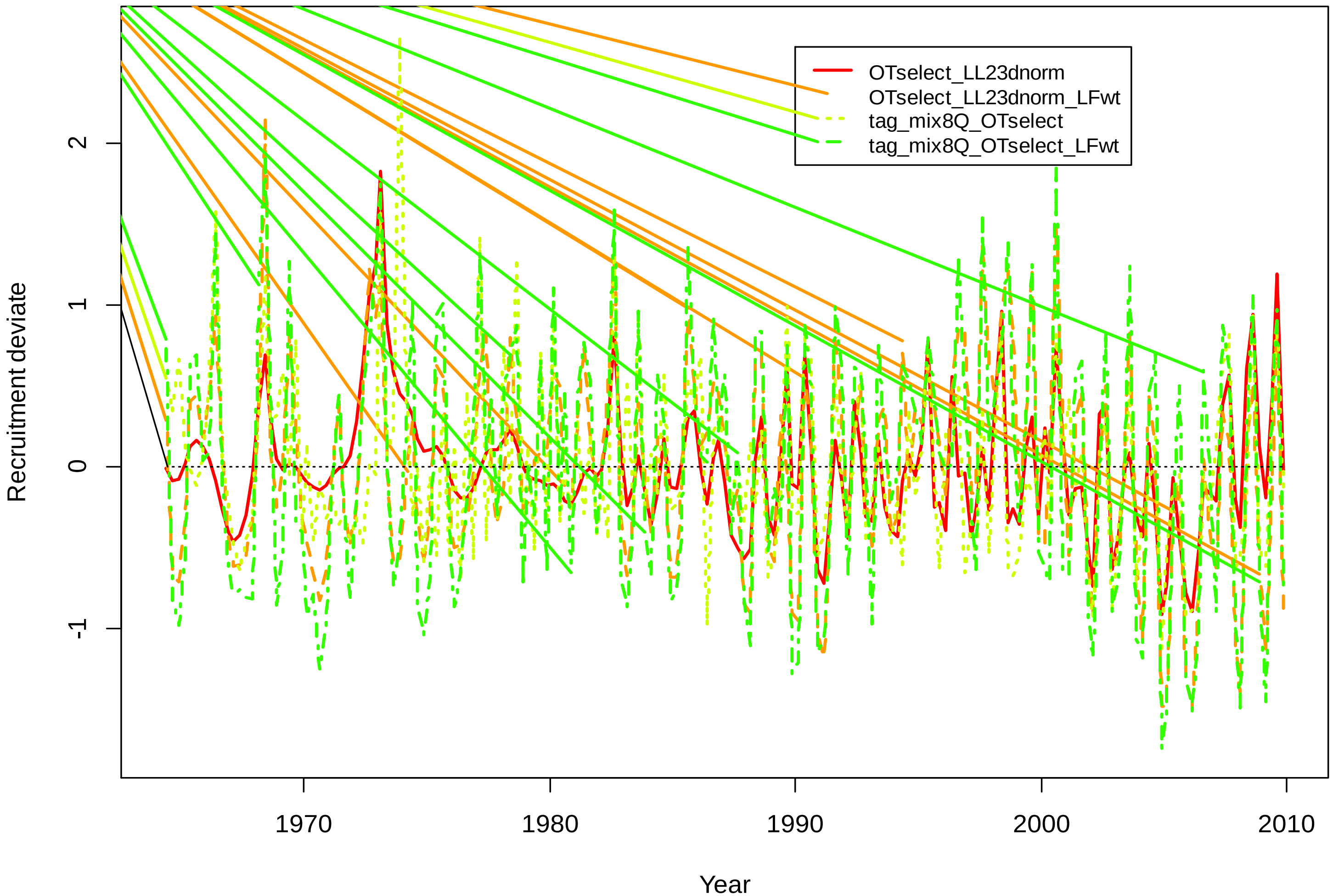


NB: environmental impacts on recruitment tend to be significant drivers of population variability for pelagic species such as tunas



Langley 2012 _ MFCL
YFT Assessment

Recruitment series for Bigeye Tuna in the Indian Ocean



Fishing impacts: nature vrs man

So, which is more important, natural factors or fishing?

The relative impacts of natural factors versus fishing on fish stocks has been debated for many decades. However, there are four key points we would like you to consider.

Four key points

1. **Observed change may not be due to fishing**

   It is dangerous to automatically ascribe changes in the size of a fished stock to fishing itself. There are many factors that can influence either stock size, or the indicators used to track stock size, that are not directly related to fishing.

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

Fishing impacts: nature vrs man

2. **Observed change may not be due to natural causes**

   It is equally dangerous to assume that natural variability is the key factor. One might then miss an opportunity to implement changes to the fishery that might ensure sustainability of catches and stock recovery

3. **Observed change is more than likely to be due to some combination of natural and fishing effects**

   Changes in fished populations over time are likely to be influence by both fishing and by environmental or other factors (e.g., eastern pacific sardine and anchovy)

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

Fishing impacts: nature vrs man

4. **However, fishing can affect natural dynamics**

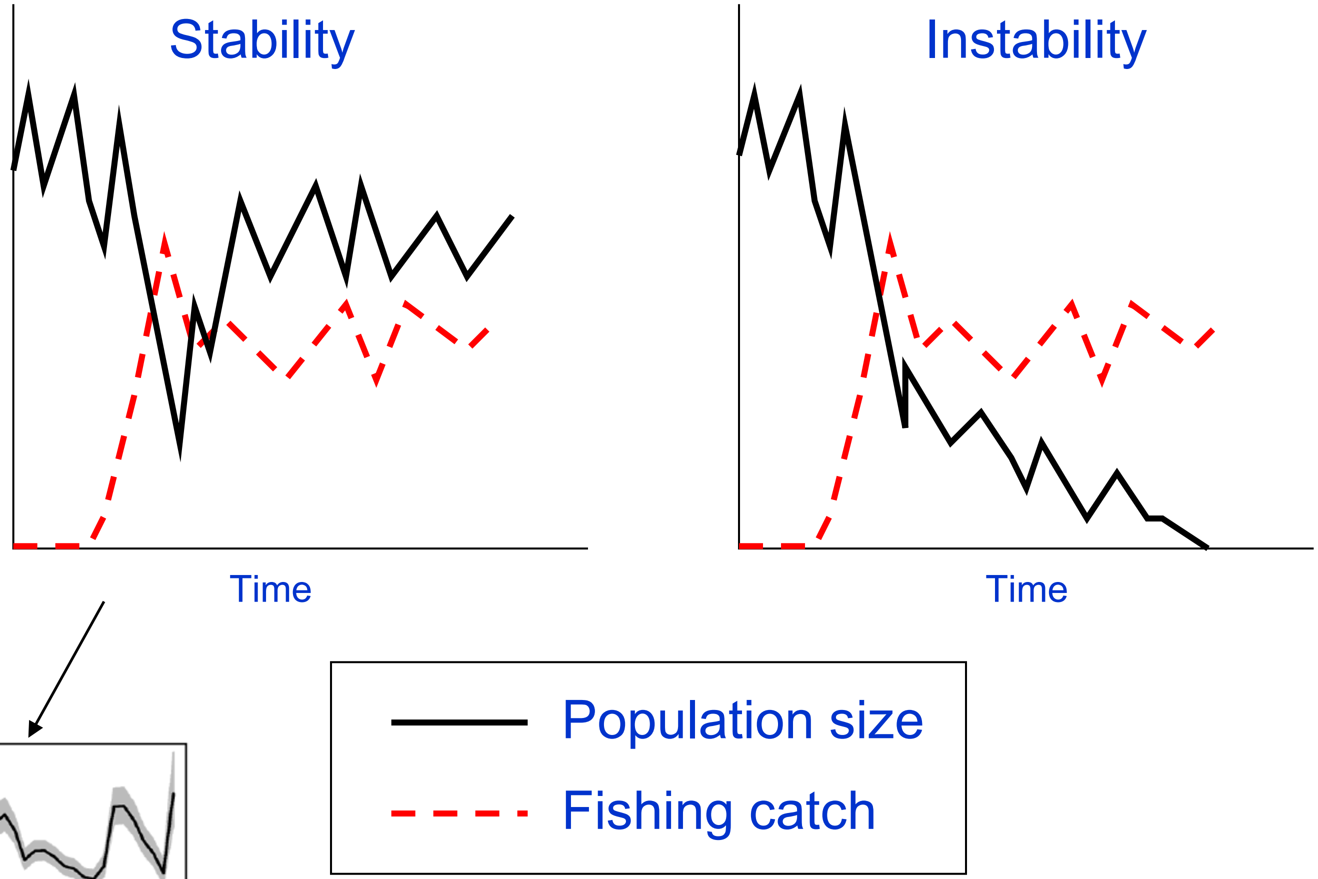
   A population's response to its environment may in fact be changed by the impacts of fishing so the two processes are interrelated (e.g., increased growth and reproduction from reduced competition for resources)

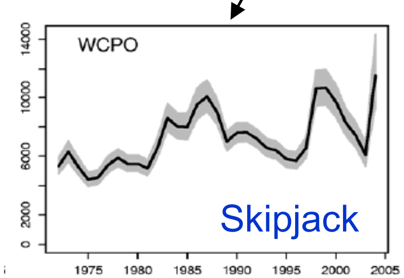
It's complicated!

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

Population states

Stability versus instability of fished populations





Population states

Resilience

"Natural systems are not stable but do exhibit changes within certain bounds or regions of stability. A system with a large region of desirable behaviour is called resilient"
(Hilborn and Walters 1992)

If a population has shown a capacity to regularly recover from low population levels then it can be thought of as **resilient**.

If a population naturally varies within a fairly narrow population range then reducing the population below its lower "boundary" (e.g. by introducing fishing) carries high risk. Introducing fishing may take the population into a state where we have no idea how it might react or whether it can recover.

Resilience in a fishing context is thus the capacity of a population to sustain itself in the long term despite the added impact of fishing at some given level.

Population states

How can we work out how resilient a population is

How do we know how stable or resilient a population might be without fishing it? Unfortunately, we don’t.

We cannot determine where or if a boundary state exists until we have pushed past it. However, we can, if we’re clever, learn from history!

We can also learn from our understanding of species biology. Compare and contrast the tropical tunas and sharks

Stability and Resilience

Examples:

	Tropical Tunas	Sharks
Reproductive mode	Broadcast spawning	Internal fertilisation
Fecundity	Millions of eggs	2-40 eggs or young
Growth rate	Fast	Varies, typically slower
Age to maturity	1-5 years (most spp)	6-7 years, up to 20 for some
Life span	4-12 years	20-30 years

What can we imply or predict from these parameters regarding the relative resilience of these species to fishing pressure?

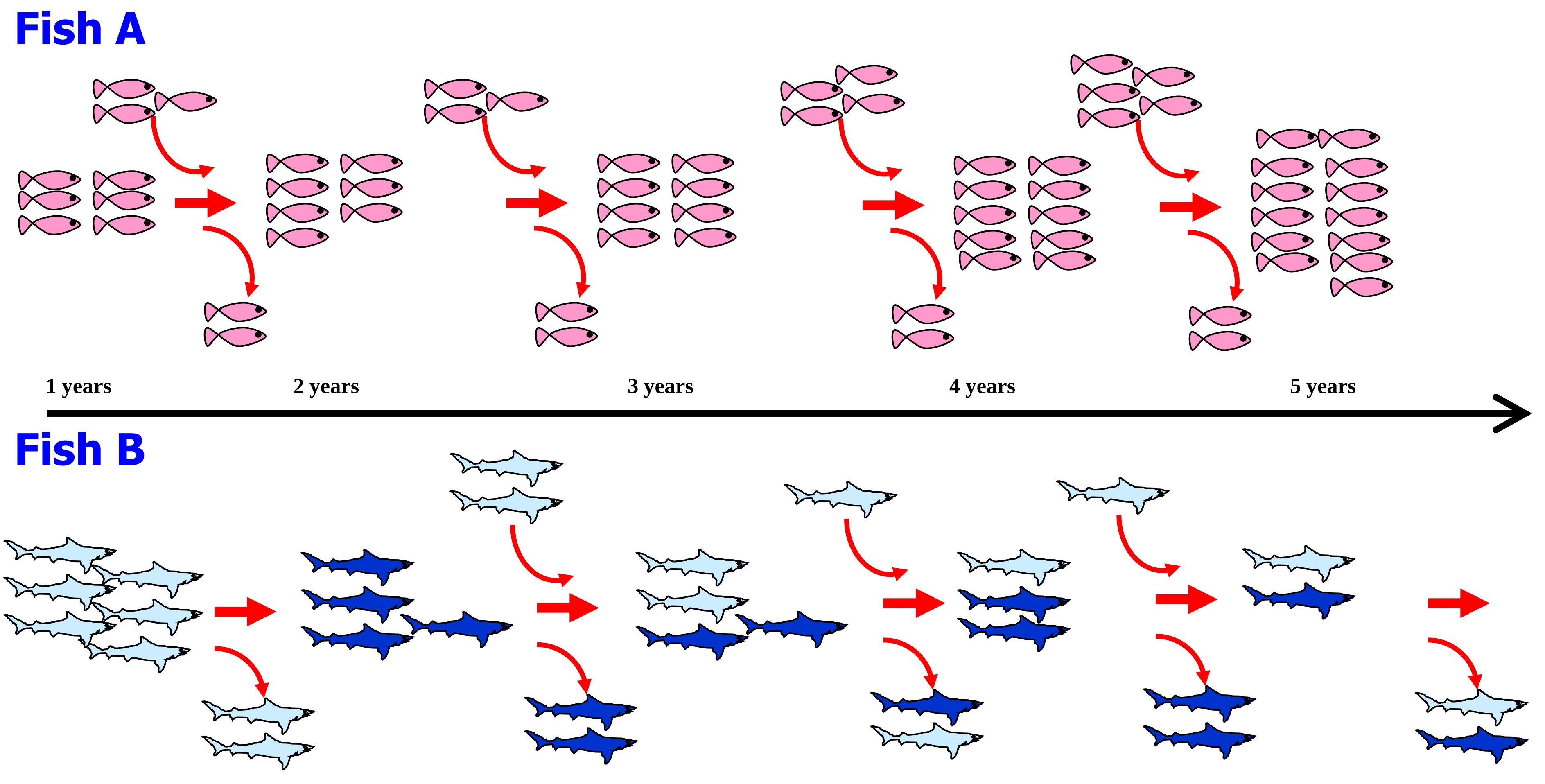
Ref: Last and Stevens (1994)

Variations among IO tuna

	Yellowfin	Bigeye
Reproductive mode	Serial spawning	Multiple spawners
Fercundity	2 million+	2 million+
Growth rate	45-50cm (1yr)	40cm (1yr), 80cm (2yr)
Age to maturity	2-3yr (100-110cm)	3yr+ (100-130cm)
Life span	7-8yr	12+
Recruitment to fishery	0.5-1yr(PS), ~2+yr(LL)	0.5-1yr(PS), 2+yr(LL)
	Albacore	**Skipjack**
Reproductive mode	?	Serial spawners
Fercundity	0.8-2.6 million	2 million+
Growth rate	30cm (1yr)	44-48cm (1yr), 61-68 (2yr)
Age to maturity	4-5yrs (80cm)	<1yr (44cm)
Life span	~9yr	~4yr
Recruitment to fishery	~2yr(troll), 5+(LL)	0.5-1yr(PS)

Resilience: the importance of biology

Age to maturity: 1 year (Fish A), 2 years (Fish B)
Fishing Mortality: 2 per year (both)
Natural Mortality: 0 per year (both)
Recruitment: half spawners per year (both)
Growth: 0 per year (both)



Overfishing

OK, then, what is "sustainability"?

A sustainable catch can exist at many different levels of stock size. If stock size declines, sustainable catches might still be made, but at a lower level than previously. However, by definition, a sustainable catch is not **overfishing** (c.f., WCPFC definition).

For better or for worse, one of the most common objectives in fisheries management is to achieve Maximum Sustainable Yield (MSY). While there is a particular, technical definition of MSY, one possible working definition is:

> ***"The greatest amount of fish you can take out of the water without impairing the ability of the fish left in the water to replace the fish you've taken out"***

Two criticisms of MSY-based management reference points are that (i) MSY and $B_{MSY,}$ the biomass level that supports the MSY catch, can be difficult to estimate precisely and (ii) as B_{MSY} tends to be quite a low proportion of unfished stock size (typically, 30 to 40%) in practise there can be an unacceptably-high risk of "overshooting" B_{MSY} and driving the stock down to a really low level ($<< B_{MSY}$).

Overfishing

(ii) Growth overfishing

This occurs when too many small fish are caught, usually because of excessive effort and low gear selectivity (e.g. too small mesh sizes) and the fish are not given the time to grow to the size at which the maximum yield-per-recruit would be obtained from the stock.

A reduction of fishing mortality on juveniles, or their outright protection, might lead to an increase in yield from the fishery. Growth overfishing, by itself, does not affect the ability of a fish population to replace itself.

(iii) Ecosystem overfishing

This occurs when the species composition and dominance in a marine ecosystem is significantly modified by fishing. E.g., reductions of large, long-lived, demersal predators and increases of small, short-lived species at lower trophic levels follow heavy fishing pressure on the larger predator species.

Session summary

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

1. Populations vary naturally. The scale of that variation often depends on the time scale considered.

2. The impact of fishing on a populations dynamics and size over time will depend in part on the inherent biological properties of the population and what that confers about resilience.

3. A key task for stock assessment scientists is to be able to estimate the relative impact of fishing on the stock—whether declines are due to fishing or environment will effect the management decisions made.

4. Understanding the likely impact of fishing on a population requires understanding the biology of the species itself.

Fish Population dynamics

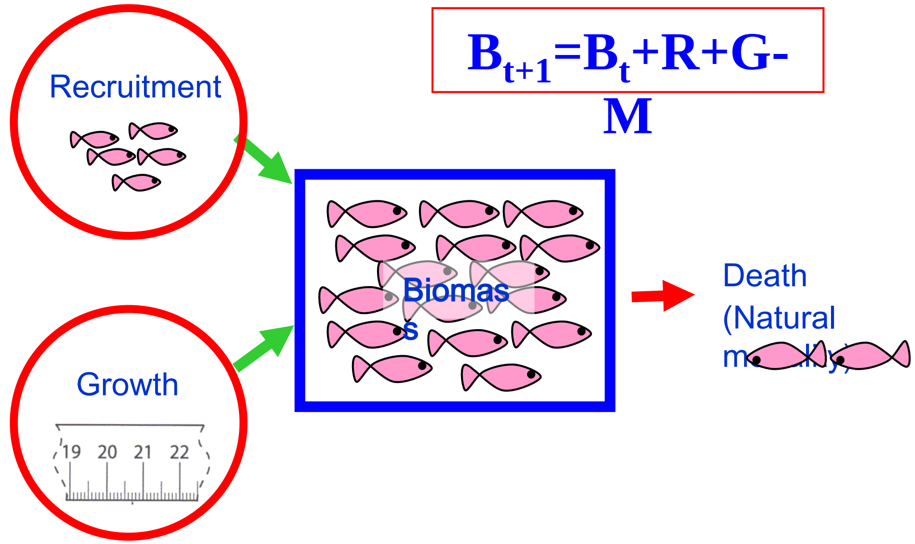
Unexploited Fish Population dynamics

In unexploited fish populations there are three key processes governing population size (in biomass), being RECRUITMENT, GROWTH and NATURAL MORTALITY.

These processes do NOT operate in equiliberium (there is no "balance of nature" in the absence of mans influence), with environmental influences upon each process resulting in natural fluctuations in population size over time (e.g. proof from sediment scales studies of sardine and anchovy).

Typically, environmental impacts on RECRUITMENT are believed to play the most significant role in natural fluctuations in tuna populations.

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



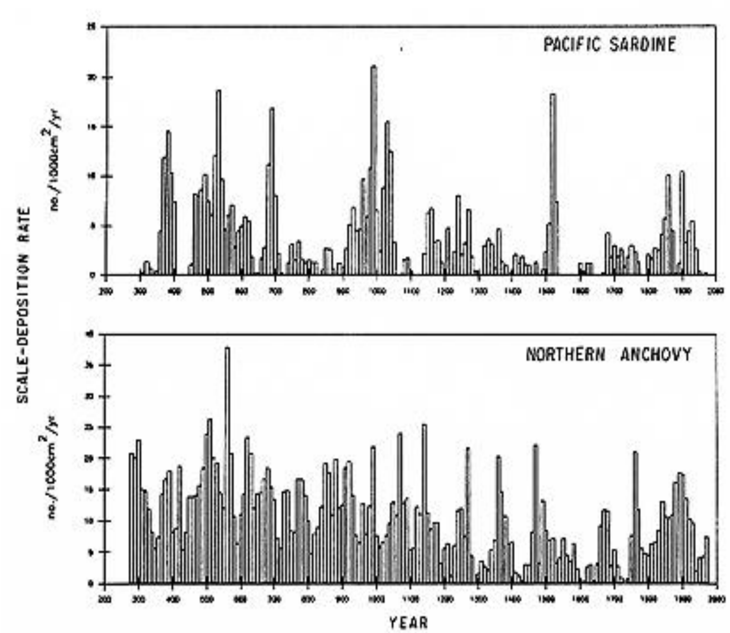


Figure 11. Time series of sardine and anchovy scale deposition rates. (from Baumgartner et al. 1992)

Exploited Fish Population dynamics

The resilience of a fish population to fishing is very much dependant on its biological features relating to growth, maturity, fercundity, natural mortality, life span etc.

Stock Status

	Yellowfin	**Bigeye**
Reproductive mode	Serial spawning	Multiple spawners
Fercundity	2 million+	2 million+
Growth rate	45-50cm (1yr)	40cm (1yr), 80cm (2yr)
Age to maturity	2-3yr (100-110cm)	3yr+ (100-130cm)
Life span	7-8yr	12+
Recruitment to fishery	0.5-1yr(PS), ~2+yr(LL)	0.5-1yr(PS), 2+yr(LL)
	Albacore	**Skipjack**
Reproductive mode	?	Serial spawners
Fercundity	0.8-2.6 million	2 million+
Growth rate	40cm (1yr)	44-48cm (1yr), 61-68 (2yr)
Age to maturity	4-5yrs (80cm)	<1yr (44cm)
Life span	18+yr	~4yr
Recruitment to fishery	~2yr(troll), 5+(LL)	0.5-1yr(PS)

Bigeye: Overfishing

Skipjack: No overfishing

Fish population dynamics summary

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

1. Populations vary naturally. The scale of that variation often depends on the time scale considered.

2. The impact of fishing on a populations dynamics and size over time will depend in part on the inherent biological properties of the population and what that confers about resilience.

3. A key task for stock assessment scientists is to be able to estimate the relative impact of fishing on the stock….whether declines are due to fishing or environment will effect the management decisions made.

4. Understanding the likely impact of fishing on a population requires understanding the biology of the species itself.

Stock Assessment – Basic Principles

What is a fish stock?

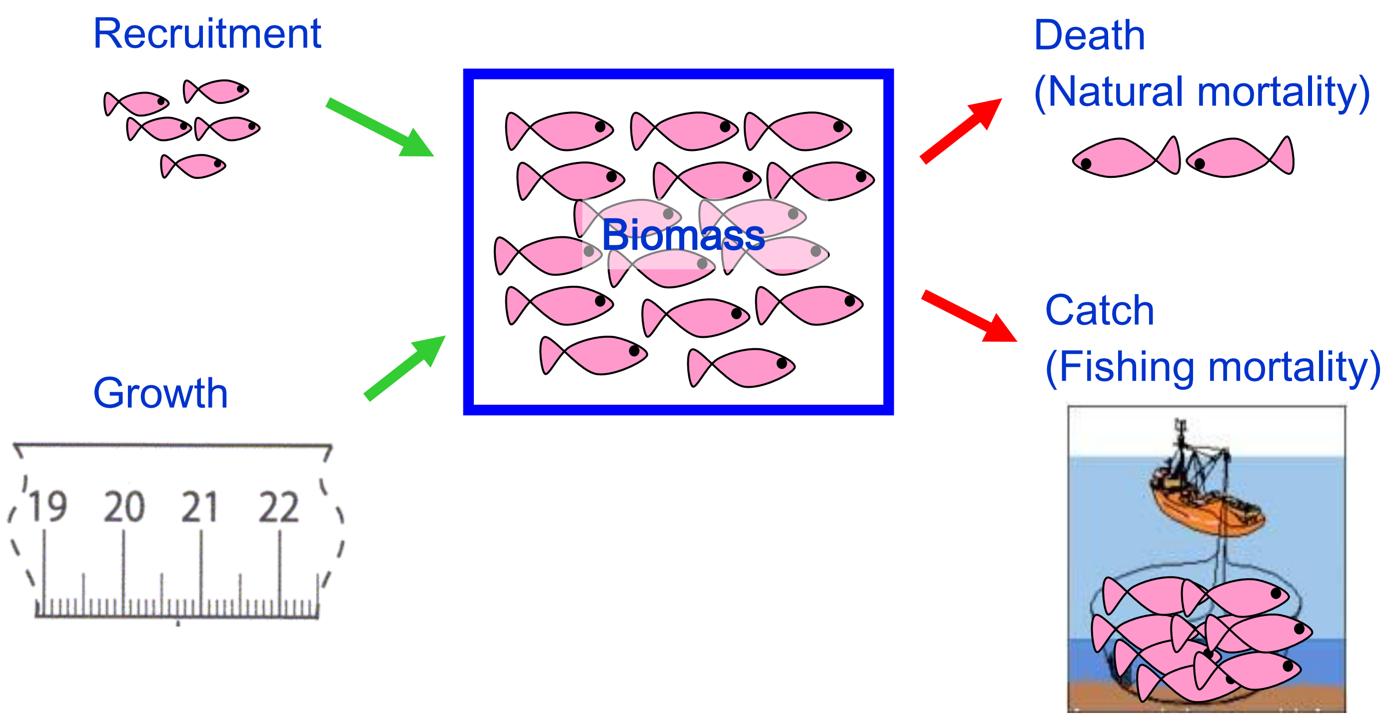
Key Concept 1 – A stock assessment model is used to assess a fish population that has little or no mixing or interbreeding with other populations.

"A unit stock is an arbitrary collection [of a single species] of fish that is large enough to be essentially self reproducing (abundance changes are not dominated by immigration and emigration) with members of the collection showing similar patterns of growth, migration and dispersal. The unit should not be so large as to contain many genetically distinct races of subpopulations within it." Hilborn and Walters (1991)

What are the key population and fishery processes a stock assessment model must account for?

Stock size fluctuations (in a closed population) can be estimated by accounting for four key processes, additive processes (growth, recruitment) and subtractive processes (fishing mortality, natural mortality) over time.

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



What is a stock assessment model?

A stock assessment model is a mathematical simplification of a fish population and how it interacts with a fishery.

It attempts to provide a realistic representation of the interaction between the key population dynamics and fishery interaction processes to allow the provision of advice to managers and politicians in relation to fishing impacts specifically, as in general, changes in populations over time are likely to be influenced by both fishing and by environment/other factors impacts on RECRUITMENT, GROWTH and NATURAL MORTALITY!

It is the role of stock assessment models and modellers to tease apart the respective influences of fishing, recruitment, growth and natural mortality to enable appropriate management responses to changes in population size and status.

Once fitted, the model can then be used to provide managers information about fishery impacts, and to make predictions about future impacts under different management scenarios (e.g. different effort levels).

Stock Assessment Model – Basic Principles

For example……………

$$N_{t+1,a+1} = N_{t,a}e^{-(M+F)}$$

$$C_{t,a} = N_{t,a}F_{t,a}w_a$$

$$F_{t,a} = s_a q_t E_t$$

$$B_t = \Sigma_a N_{t,a} w_a$$

$$AB_t = \Sigma_a N_{t,a} w_a o_a$$

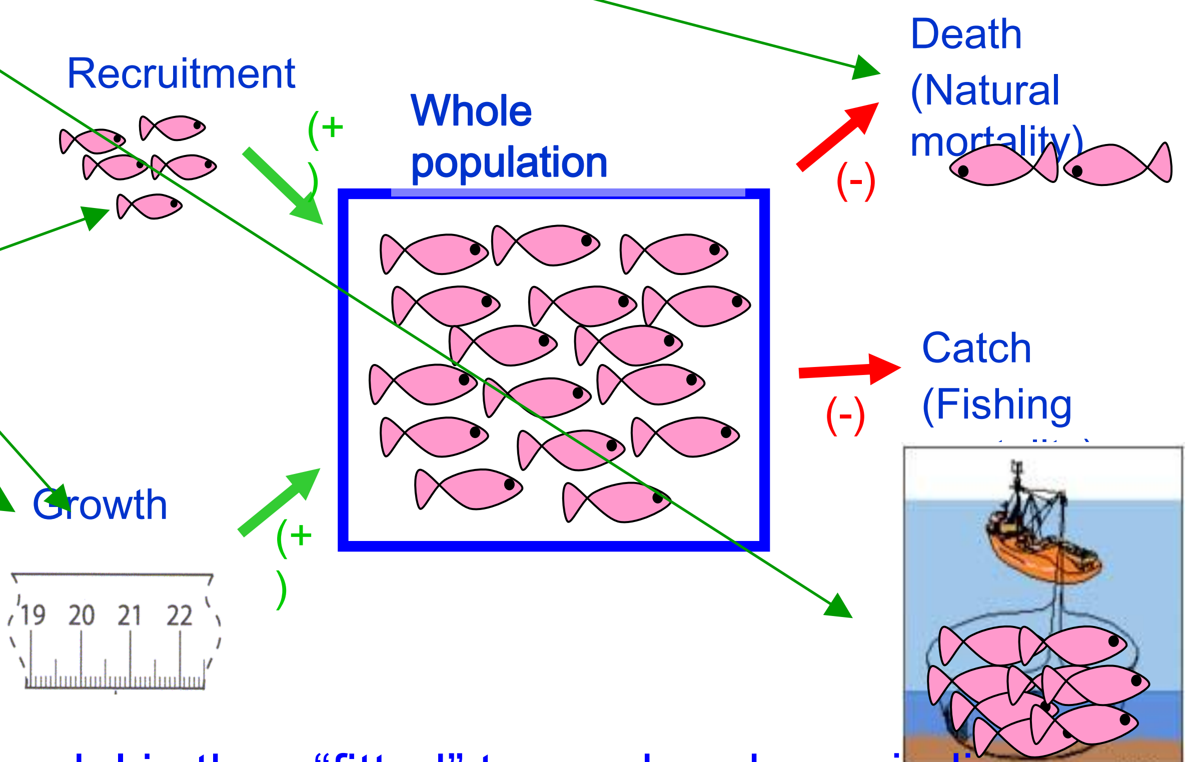
$$VB_t = \Sigma_a N_{t,a} w_a s_a$$

$$N_{t+1,1} = (AS_t)/(b+S_t)$$

$$W_t = W_\infty[1 - e^{-K(t-to)}]^b$$

Where:
N = Numbers
C = Catch (in weight)
F = Fishing mortality
B = Biomass
AB = Adult biomass
VB = Vulnerable biomass
t = time
a = age

So we require estimates of:
M = natural mortality
s = selectivity at age
q = catchability at time t
E = effort
w = weight at age
o = maturity at age
a = Maximum recruitment
b = Stock size at half maximum recruitment



This model is then “fitted” to an abundance indice (derived from CPUE) to help the model track actual changes in biomass of the population (* can also fit to size and tag data)

Who is involved in the Stock Assessment process?

Stock assessment is a multi-step process that starts with management questions, and includes processes involved in data collection, model selection, stock assessment modelling, and subsequent advice to decision makers.

Process	**Primary Responsibility**
1. Determine the questions to be answered	Managers & Policy makers
2. Choose an appropriate model	Scientists
3. Design and implement an appropriate data collection system	Scientists, managers, fishers
4. Collect the required data:	Fishers, scientists, managers
5. Build the model	Scientists
6. Run the assessment	Scientists
7. Interpret the assessment Results	Scientists, managers, policy makers
8. Scientific advice to decision makers	Scientists
9. Decision makers make decisions	Managers & Policy makers

This workshop has focussed predominantly on processes 2-5.

Overview of the stock assessment modelling process

SUMMARY

The process of creating a model that is reflective of the real fish population involves three phases:

1. Creating a mathematical model of the system (population and interaction with fishery) using knowledge of basic population and fisheries dynamics.

2. Fixing parameter values for which the values are known (Predetermined through other research perhaps). Where parameters have predetermined values these are called ***constant or fixed values***. In some instances an exact value might not be fixed but a range within which the model is allowed to search for the best value might be specified. This is called setting ***constraints***.

3. Simultaneously fitting the model to the observed data, with unknown parameters being estimated at the same time to be values that ensure the best fit between model and data. This processes requires that there is some kind of criterion by which to judge the quality of the fit (e.g. minimum SSE, maximum likelihood).

Scientists then should check the model fit “diagnostics” to ensure they have the most appropriate model possible.

Recruitment

Recruitment

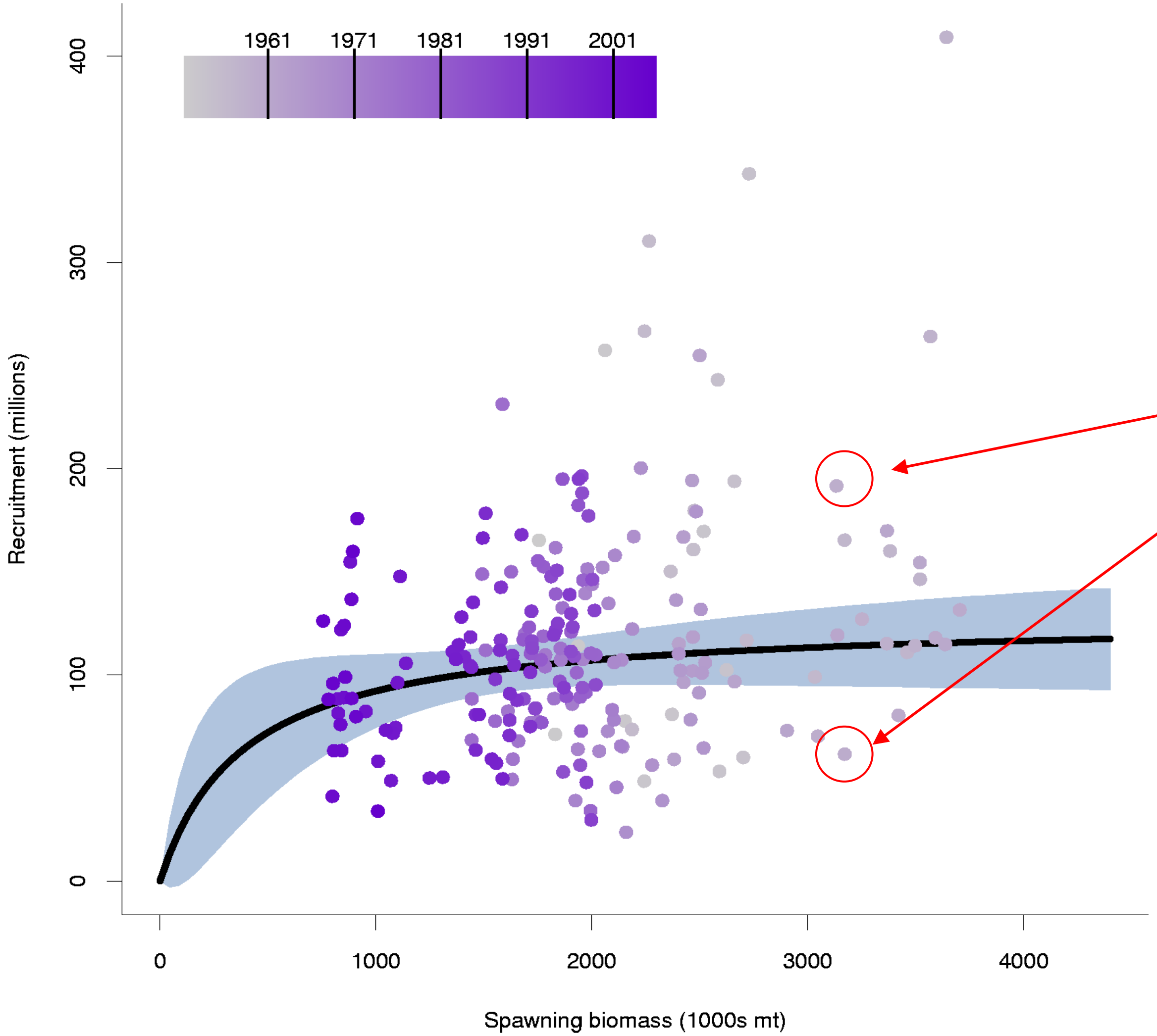
1. Recruitment is the number of fish alive at a specified stage after hatching – For the tuna assessments conducted in the WCP-CA, its the stage at which they are first detected in the fishery catch (e.g. for YFT, BET, SKJ at 0.6 months in the purse seine fishery).
2. In the WCP-CA recruits are identified through size sampling programmes (e.g. port sampling and observer programmes)
3. Its one of the four key processes we need to account for in a stock assessment model if we are to be able to determine the impacts of fishing on that population and if the population is increasing, decreasing etc over time.
4. Recruitment levels can be impacted at multiple points in the life cycle…..the level of egg production by the parents, and the survival of the larvae and juveniles, which is effected by both biotic factors (starvation, predation, disease impacts on larvae, juveniles etc) and abiotic factors (water temperature, convection, oxygen, salinity etc).

Session overview

5. For highly fecund marine species like tuna, typically only a tiny fraction of larvae survive to recruitment stage. Mortality is extremely high in the early days and weeks, due to factors like starvation and predation.
6. Despite this, its critical to note that only a very small change in larval survival rate (e.g. 1 in a million versus 2 in a million) can have a very large impact on subsequent recruitment.
7. One of the key considerations in any stock assessment is the stock recruitment relationship – how is the total recruitment level related to the size of the spawning component of the stock?
8. For species which produce few eggs and have young develop to juvenile stage in egg, or uterus (e.g. sharks), or which provide parental care to young, the relationship between adult stock size and recruits is typically more apparent because survival of those young is relatively high and they are less impacted by environmental factors

Recruitment

"….more commonly the number of recruits is effectively independent of adult stock size over most of the observed range of stock sizes". (Gulland, 1983)



Highly differing recruitments at same stock size can be due to difference in environment and impacts of that on egg production/quality by adults and/or survival of larvae and juveniles

Session overview

5. For species which produce many eggs (e.g. 10's of thousands to millions) and whose young hatch as larvae, the relationship between adult stock size and recruits is typically less apparent because, over most of the range of adult stock size, it is environmental factors (food availability, predation, temperatures etc) which determine survival rates, and those environmental factors are highly variable over time, so larval survival and hence recruitment is also highly variable.

6. However, even for these species, when the adult population drops too low, recruitment will be effected (zero adults = zero larvae).

7. As such, the steepness of the stock recruitment relationship has a large impact on stock assessment outputs – it influences how hard a stock can be fished down, and how quickly it can recover from being overfished.

8. The difficulties in estimating steepness mean that sensitivity analyses should generally be run to test alternate steepness values to that in the base case model

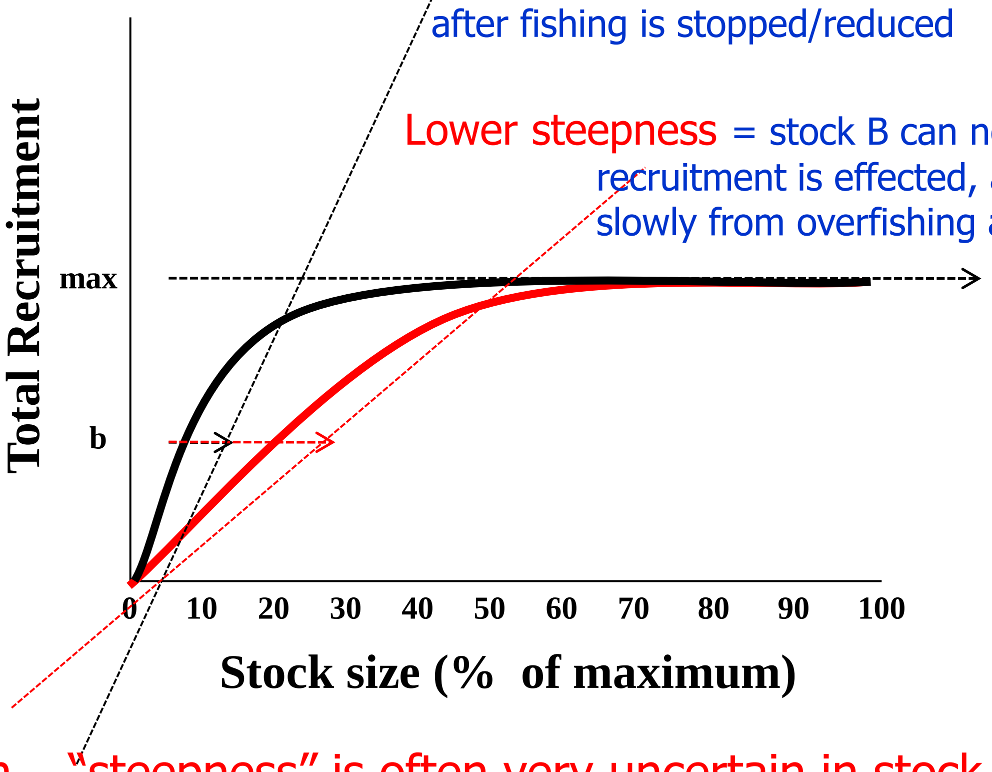
9. Recruitment overfishing – describes the point at which there are no longer enough adults to produce the number of recruits required to replace fish lost from the population by natural and fishing mortality.

Why is the stock recruitment relationship (SRR) so critical to stock assessment?

Critical factor in a stock recruitment relationship……***steepness of the curve***! This will be related to **b**, the stock size when recruitment is half the maximum recruitment.

Higher steepness = stock A can be depleted more before recruitment effected, and the stock can recover more quickly from overfishing after fishing is stopped/reduced

Lower steepness = stock B can not be depleted significantly before recruitment is effected, and the stock will recover more slowly from overfishing after fishing is stopped/reduced



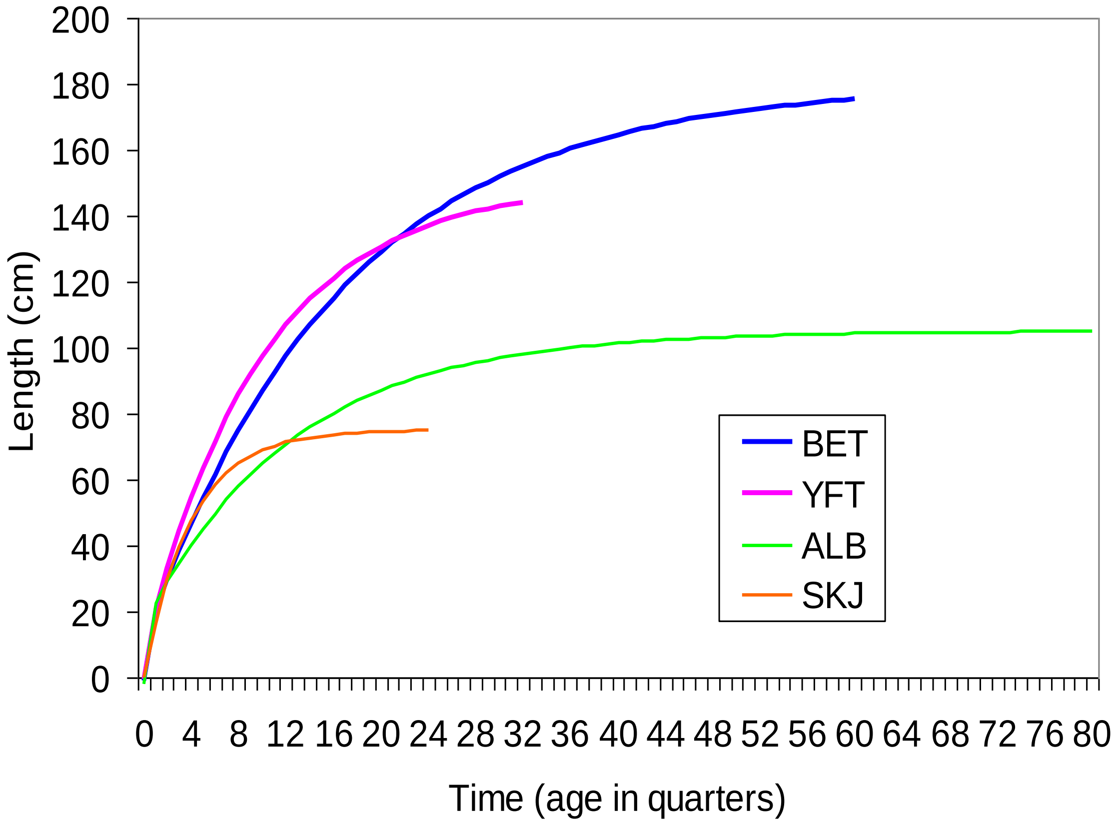
The problem – "steepness" is often very uncertain in stock assessments, so the point at which recruitment is effected (and overfishing occurs) is also uncertain.

Growth, size and age

Growth, size and age

Different species grow at different rates, to different sizes.

Accurately estimating K (steepness of early growth rates) and max size is critical in stock assessment, effecting biomass at age estimates, vulnerability at age, and other parameters



Growth

Why do we worry about fish growth?

1. **Growth is a key factor in the dynamics of fish populations (size, mortality rates, maturity, etc.) and a crude indicator of productivity.**

2. **Estimation of fish growth is essential to age-structured models.**

3. **Assists in identification of cohorts within populations and tracing these cohorts through the fishery.**

4. **Growth can be estimated from modal progressions, mark-recapture, and otolith studies.**

5. **Growth rates are incorporated to allow the model to predict and incorporate changes in fish size with age and therefore improve estimates of biomass**

Growth

Why do we worry about fish growth?

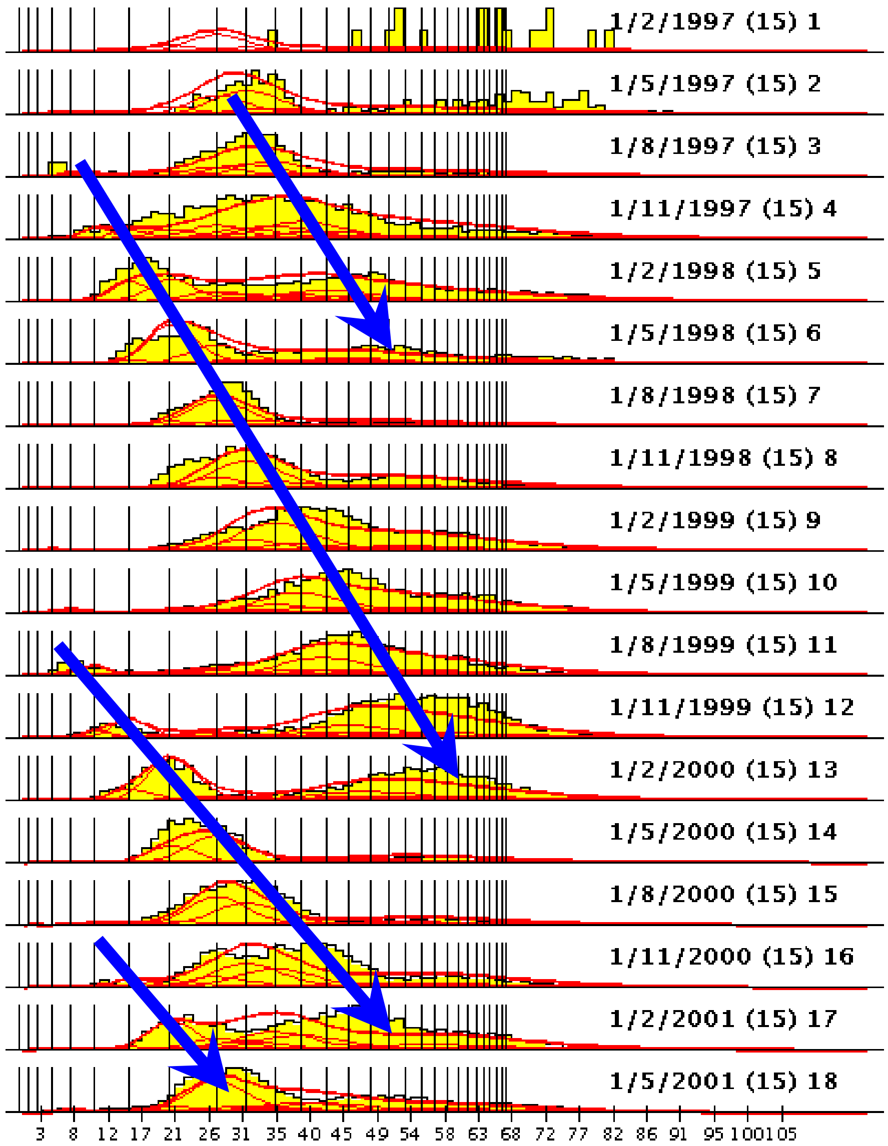
6. **Many growth models exist but the VBGF is the most-widely used. The key parameters to estimate are K (growth coefficient) and L_{∞} (mean maximum fish length).**

7. **The relationship between length and weight is also vital in order to convert ages to lengths and lengths to weights, and thus in the generation of biomass estimates.**

8. **Catch-composition or size data can be obtained from at-sea observer and port sampling programmes.**

9. **Assessment models compare observed and expected size distributions as part of the model fitting process.**

Growth, size and age



In MULTIFAN-CL, the VBGF parameters determined from biological research are critical, and can be used in the model as “seed” values. A range can specified for these values which allows the model some flexibility to search for the most appropriate growth relationship (within biologically meaningful bounds) during the model fitting process.

Alternately the model can estimate growth parameters directly from the size data supplied to the model

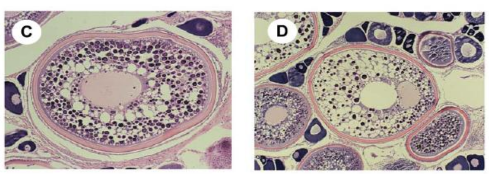
Maturity

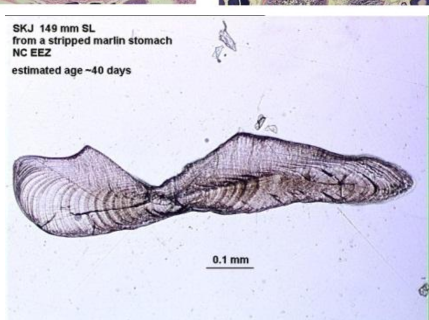
Maturity at age

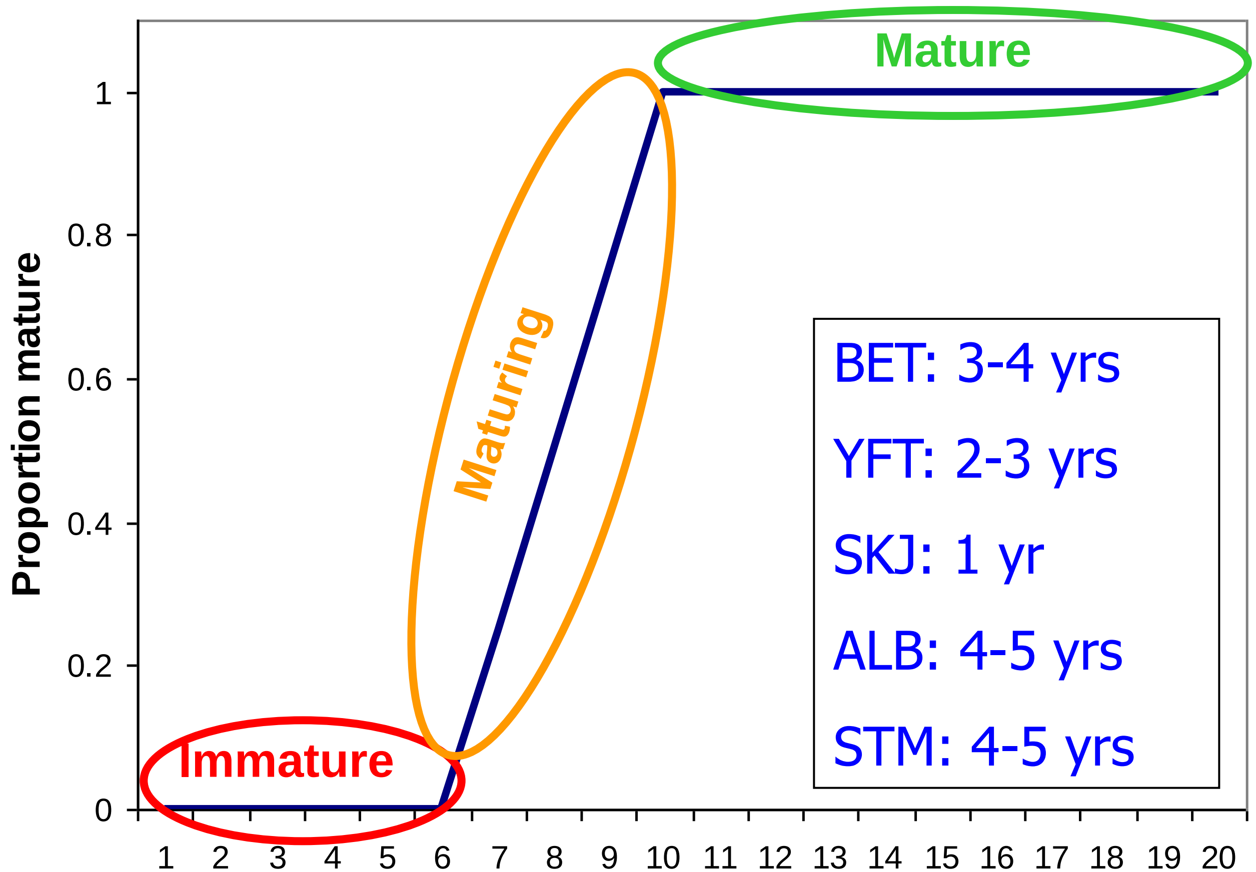
Fish stocks are comprised of immature fish (juvenile), maturing fish and mature (adult) fish. **The maturity schedule of a stock is critical as it will influence future recruitment**.

Estimation: ***M**aturity schedule **fixed*** in model, as determined from research into reproductive biology of the species.

Picture of a striped marlin ovary.



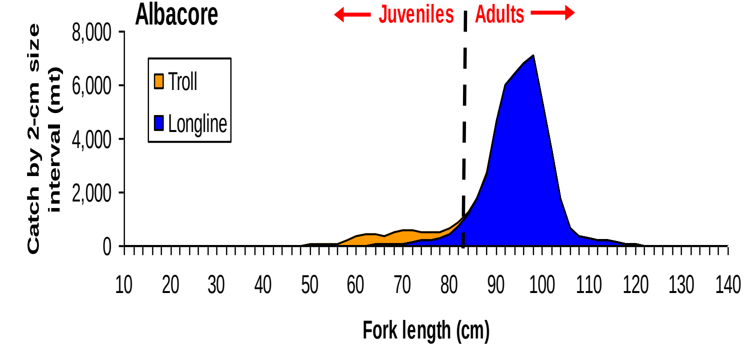


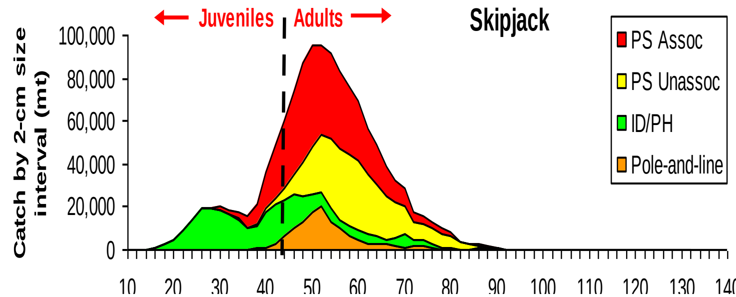


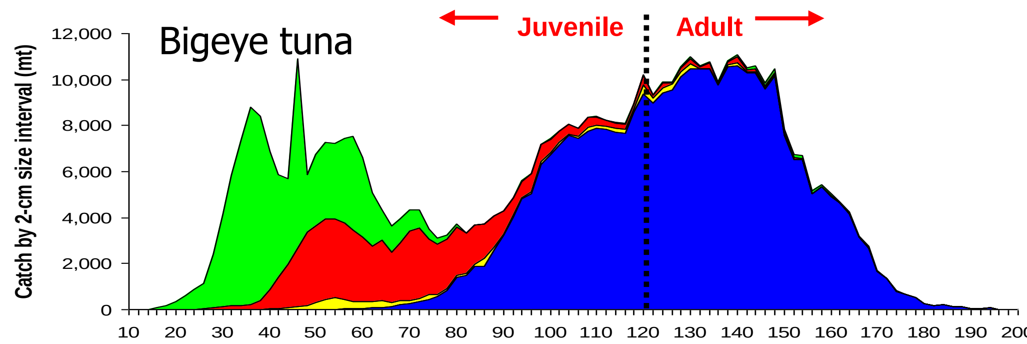
Maturity

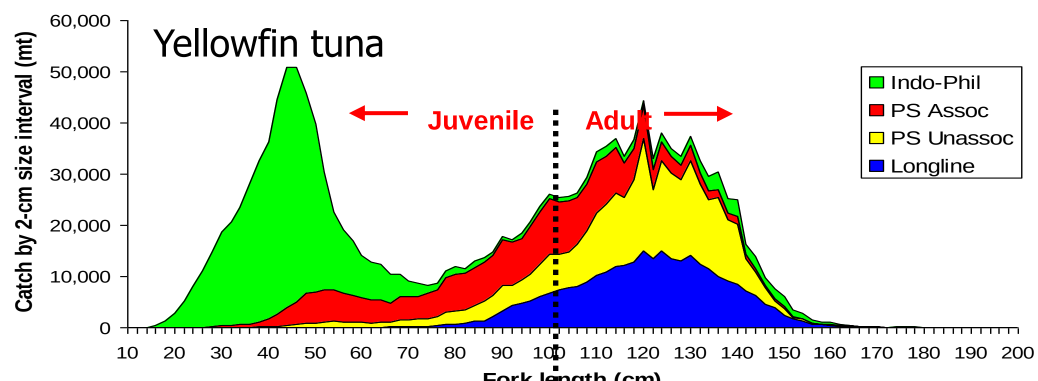
There is a close relationship between the current status of the stocks, age/size to maturity, and the level of catch from juvenile age classes. Those stocks with relatively little juvenile mortality (i.e. which concentrate on catching adults) are in better condition

Note that juvenile BET mortality is not only an issue for PS associated sets and ID/PH fishery, but also the LL fishery









Natural Mortality

Natural mortality (M)

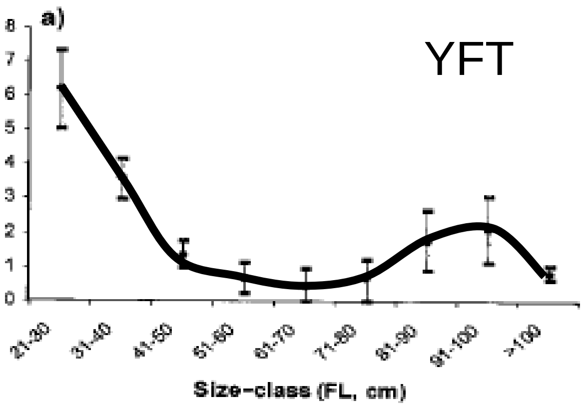
Definition: The process of mortality (death) of fish due to natural causes (e.g. predation, disease, senescence). Expressed as a rate (i.e. proportion of the size/age class dying per time period).

Allows an understanding of the relative impacts of fishing (e.g. compare natural v fishing mortality rates)

$$Z_t = M_t + F_t$$

Estimation: Can be estimated ***within*** the model (model allowed to select a value that maximises the model fit to the data (e.g. CPUE series), possibly with some constraints specified for M to vary within)

….OR …..



….Can be estimated ***outside*** the model and included as a ***constant*** by one of a number of methods:

1. Maximum age (longevity) and Hoenig regression
2. Length based
3. Catch curve analyses for lightly exploited stocks
4. Mark recapture studies

Natural Mortality

Natural mortality (*M*):

1. **It is a critical variable in describing population dynamics.**

2. **It is likely to vary with size or age of fish.**

3. **It can be estimated using a variety of techniques, but can be difficult to estimate, as its effects are confounded by the effects of *F* and *R*. Mark-recapture data are particularly useful.**

4. **A sound understanding of *M* is critical to produce "realistic" stock assessment models, although it can be difficult to select one particular value or set of values in preference to any others.**

Natural Mortality

Natural mortality (*M*):

5. **As a result of this, the impacts of alternative assumed values of *M* on stock assessment model outputs are often examined in sensitivity analyses.**

6. **Age-structured stock assessment models like MULTIFAN-CL can deal with *M* in a variety of ways: e.g., (i) single fixed value of *M*; (ii) age-specific fixed values of *M*; and (iii) estimable values of *M*.**

7. **Changing the value of *M* potentially affects a very wide variety of model outputs including biological reference points such as B_{MSY}, the relative impacts of fishing on different age classes, and so on.**

Fishing Mortality

Fishing mortality

Fishing mortality (*F*):

1. Can be estimated within stock assessment model fits and by other methods outside (e.g. mark-recapture analysis, effort series analyses etc)

2. In an age-structured stock assessment model fit, *F* is usually calculated for each time, age and fishery as a function of selectivity, catchability, and fishing effort.

3. Estimating *F* is critical in the calculation and interpretation of biological reference points, such as $F_{current} / F_{MSY}$.

4. Estimating *F*-at-age is also important in the identification of overfishing (e.g. growth or recruitment overfishing).

5. It can be “switched off” within a model to estimate the impacts of fishing. This is often done with MULTIFAN-CL.

Fishing Mortality

There are a number of key equations which relate catch and fishing mortality rate to fishing effort, biomass, catchability and selectivity.

Catch: $C = qEB$

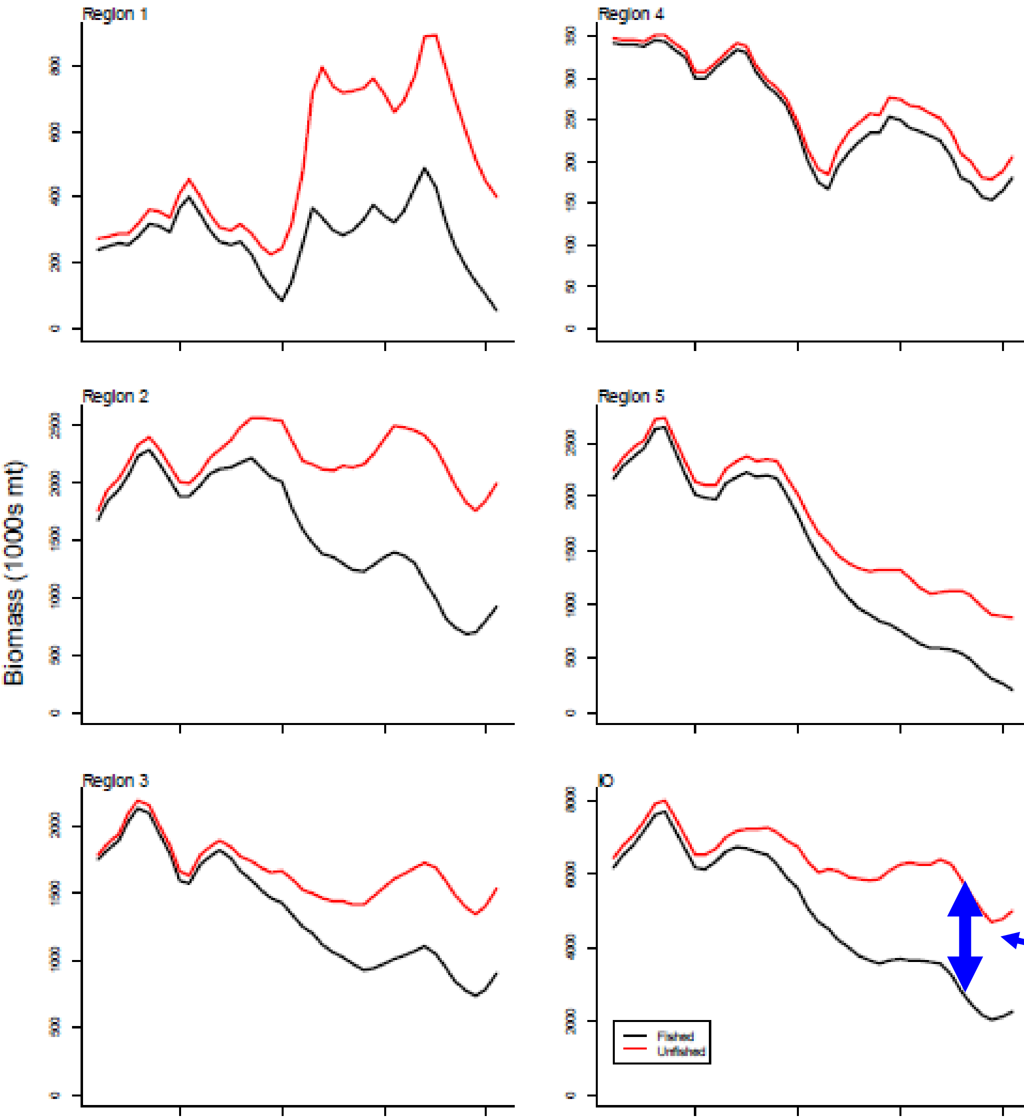
Total F: $F = qE = C/B$

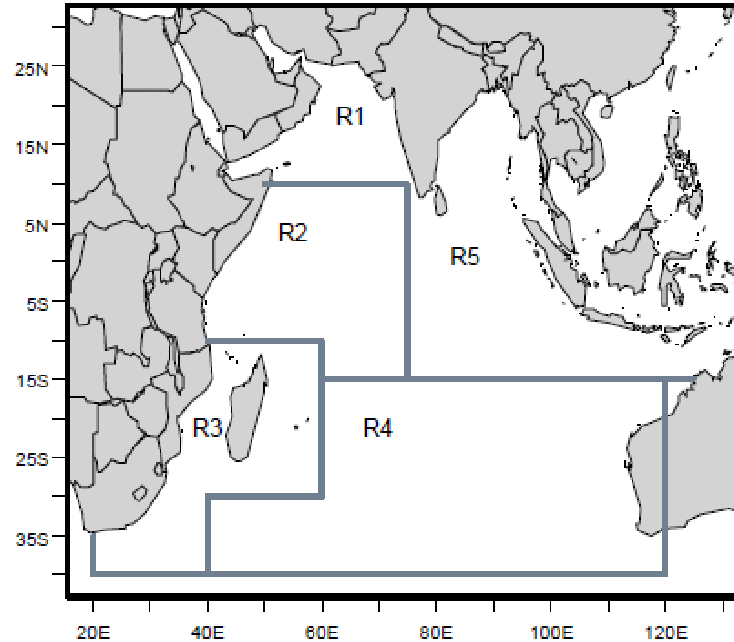
F at Age: $F_{a,t} = q_t E_t S_a$

Where q = catchability, E = Effort, s = selectivity at age

**An increase in q,E or S_a will result in a proportional increase in F_a. This is an important fact for managers to understand. There is the potential to control effort levels, selectivity of the gear and even some elements of catchability (fishing efficiency) – hence when fishing mortality is too high, there are multiple options to reducing that, which do not only rely on effort reductions.

Fishing mortality: YFT 2012





Black: $Z = (F + M)$

Red: *M* only

"The impact of fishing"

Selectivity

Selectivity

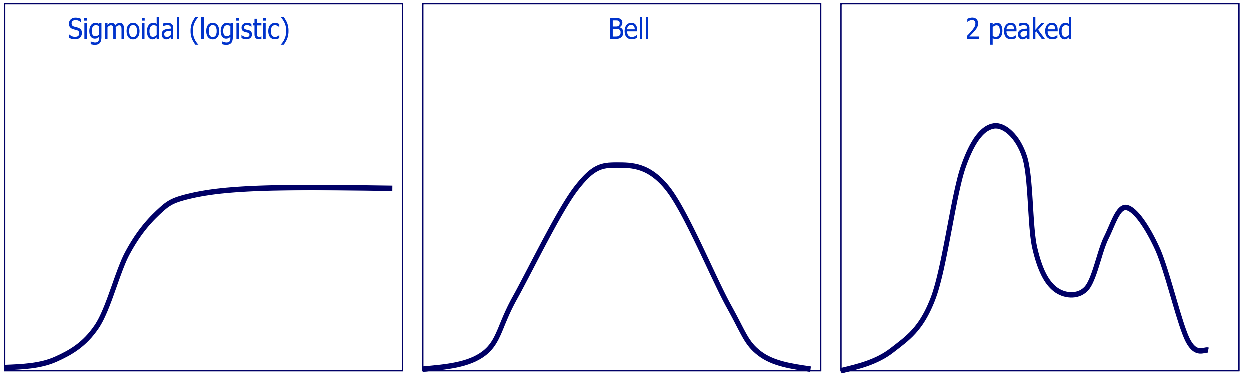
Selectivity is the size or age specific vulnerability of fish to a fishing gear. This selectivity is an important component in age specific fishing mortality estimation

$$F_a = qEs_a$$

The key problem raised by size selectivity of fishing gears is that the size composition of the catch will not reflect the size composition of the population as a whole.

Including a parameter to describe gear selectivity helps us to account for this in our stock assessment models

The size based selectivity of a fishing gear can be described by means of a "selection curve", which gives for each size class (or in age structured models these can be converted to age classes where the relationship between age and size is known) the proportion of the age/size class which is available to the gear….



Selectivity – Bigeye 2013

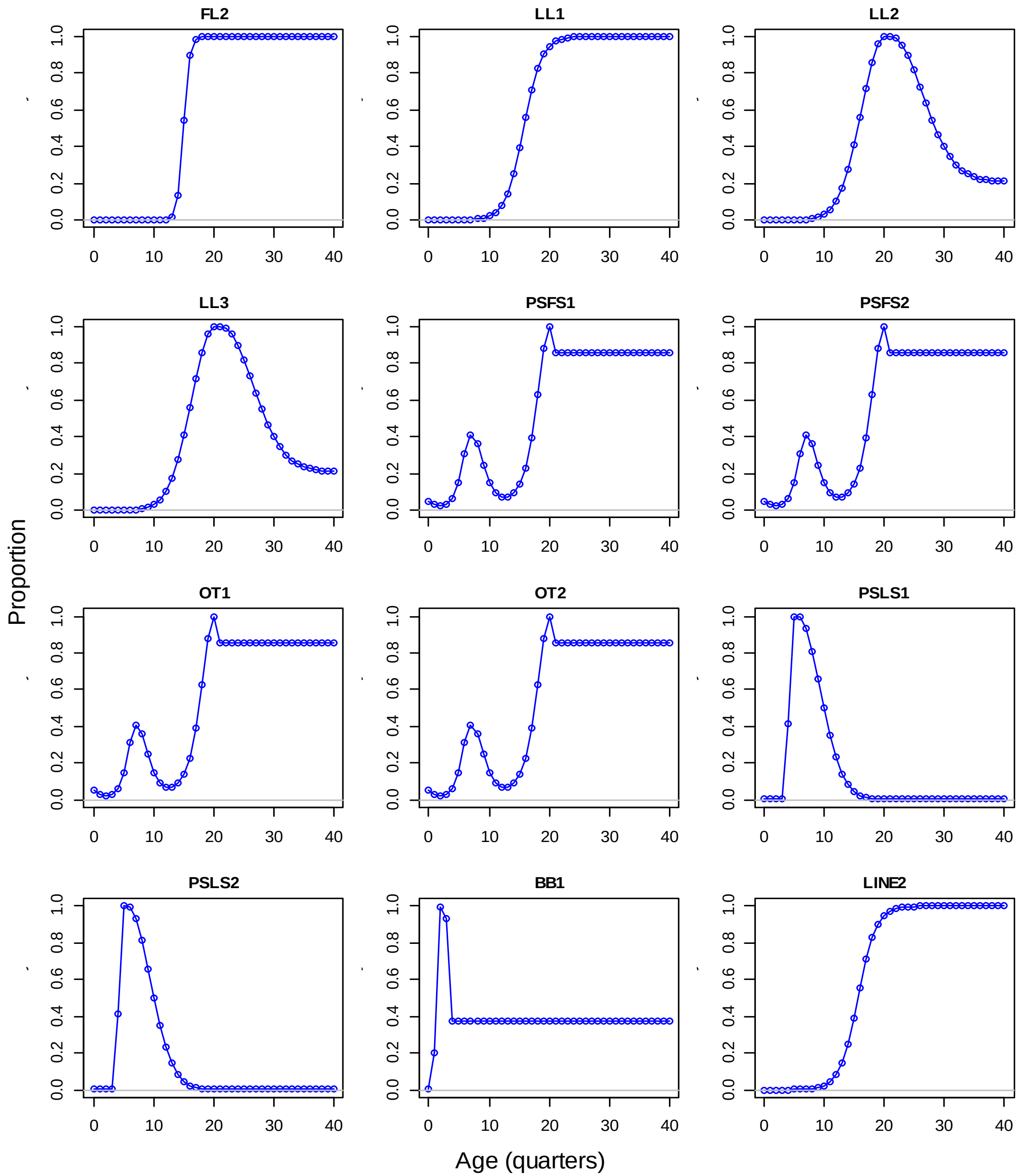
Where:

PS (FS/LS) = purse seine

LL= Longline

LINE = Handline

BB = Maldives Baitboat



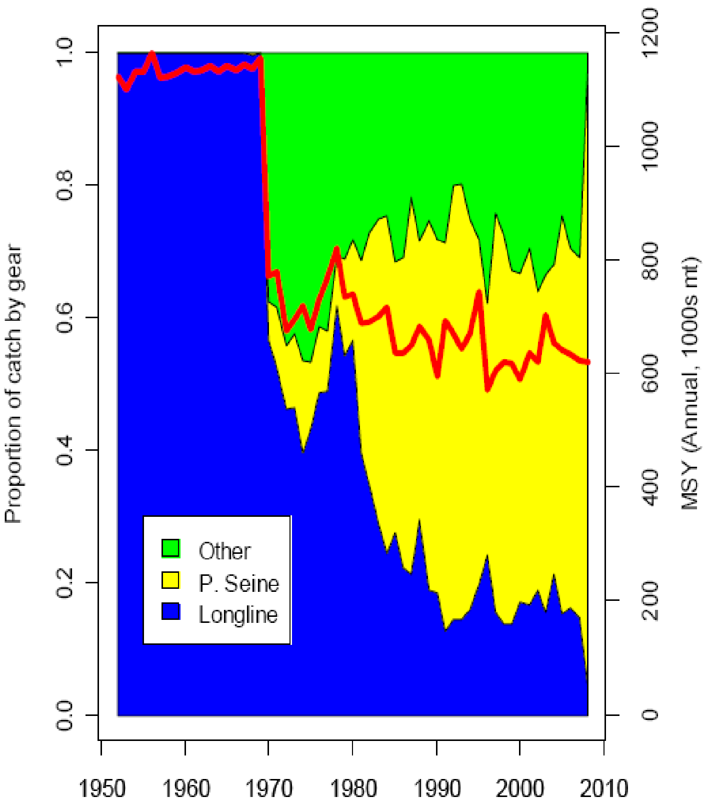
....which gears and fisheries are selecting for small fish? Which are selecting for large fish?

Selectivity and MSY

MSY from any given stock is **selectivity dependent**. In other words, MSY depends on and will change with changes in selectivity of the gear(s) operating in a fishery.

The "maximum" MSY will be achieved if a fishery can fish only on the age group for which there is the greatest positive differential between biomass added by growth, and biomass lost by natural mortality (scaled by numbers at age). This is very difficult to achieve however.

Gears which tend to remove very young fish (before yield per recruit potential is realised) or older fish (where natural mortality based loss of biomass outweighs gains from growth)



Catchability

Catchability – what is it?

Catchability

.....is defined as the average proportion of a stock that is taken by each unit of fishing effort.

$$q = C/EB$$

It will be a value between 0-1 (0 being no catch and 1 being the entire stock), and typically will be very small….e.g.; 0.000001

As noted before "q" is critical in relating fishing mortality to fishing effort and relating the index of abundance (catch rates) to stock biomass

Catchability

The Problem!

Catchability can change (increase or decrease) over time, meaning that our key assumption in stock assessment, that catch per unit effort will vary proportionally with stock size, is no longer true.

What can cause changes in catchability? Some causes include:

1. Changes in fishing method (e.g. depth, time of setting)
2. Changes in fishing technology (e.g. Improved fish finding technologies)
3. Experience and skill increases over time.
4. Environmental changes effecting fish distribution

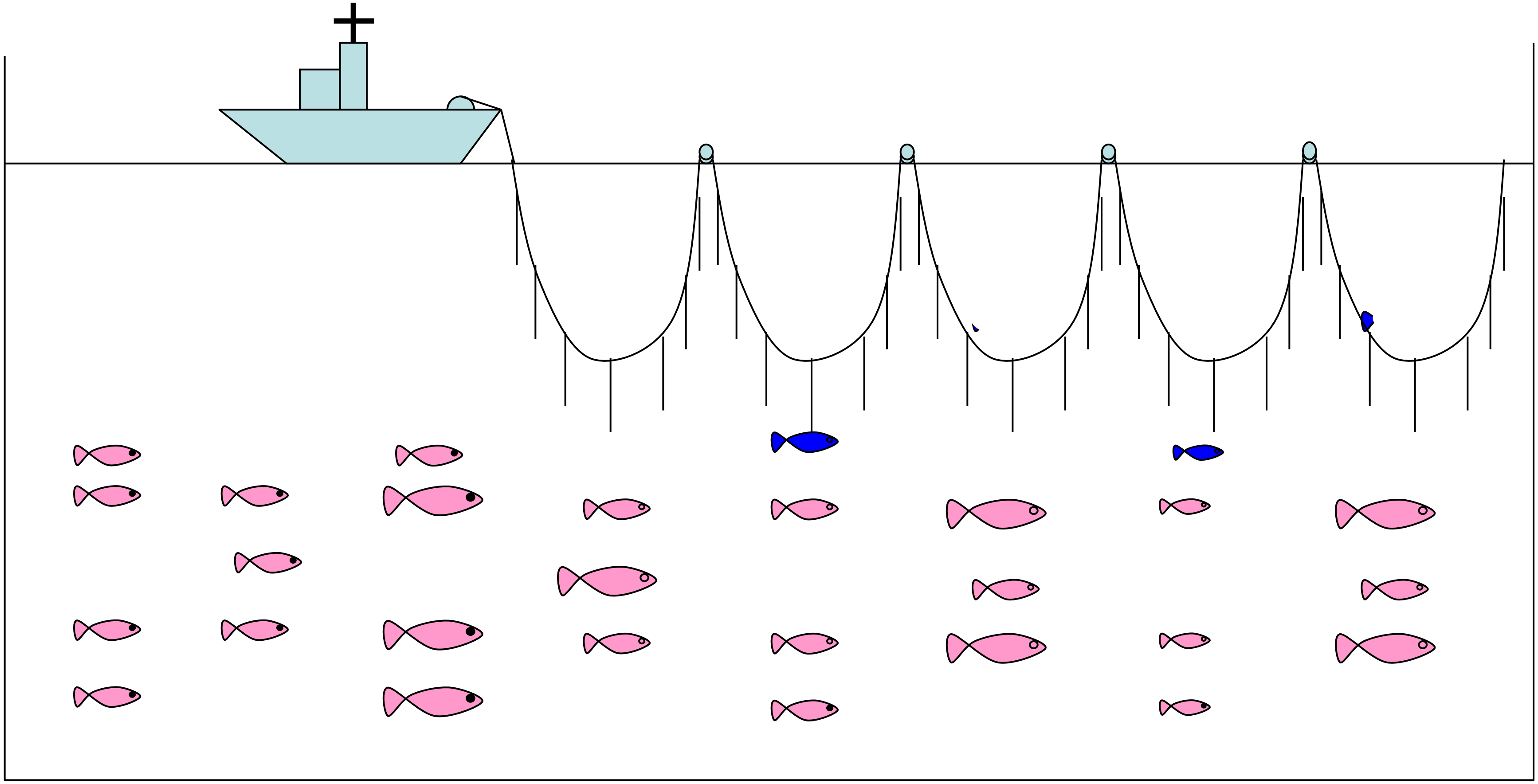
These are reasons why we collect information on methods and gears from fishermen, so we can account for changes in fishing over time that might impact catchability.

q relates CPUE to Biomass and F to Effort, via:

$C/E=qB$

$F=qE$

Catchability



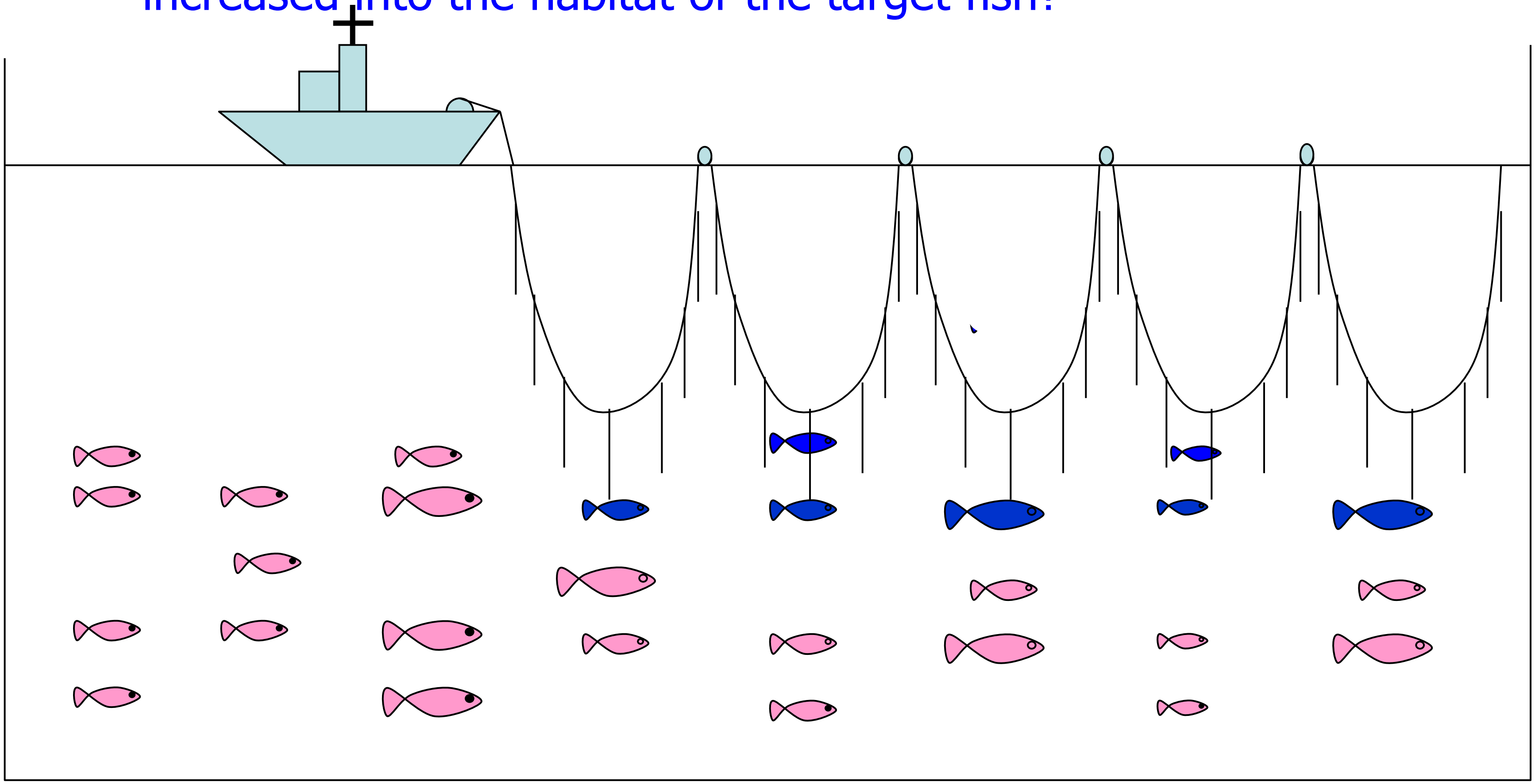
q = C/EB

q = 2/30x28

=**0.00238**

Catchability

What happens to catchability when the depth of the gear is increased into the habitat of the target fish?



$q = C/EB$

$q = 7/30x28$

=**0.00833**

Biological Reference Points

What are biological reference points?

A biological reference point (BRP) is a metric or measure of stock status (health) from a biological perspective, that fisheries managers wish to either achieve or avoid.

Biological reference points often reflect the combination of several components of stock dynamics (growth, recruitment and mortality, usually including fishing mortality) into a single index.

The reference point is often expressed as an associated fishing mortality rate or a biomass level.

e.g. $B_{current}/B_{MSY} = 1$

[Gabriel and Mace, 1999]

What are biological reference points?

Biological reference points are used to provide fisheries managers information regarding:

1. The status (health) of a stock
2. The impacts of fishing on a stock

….and in doing so, assist in the provision of advice to management from the outputs of stock assessments

They can also be used to evaluate the performance of fishery managers, if those reference points are tied into the objectives which the managers are trying to achieve.

What are biological reference points?

In general, consideration of biological reference points requires consideration of both the *reference point* itself and its associated *indicator*.

What do we mean?

1. Reference Point – the pre-determined level of a given *indicator* that corresponds to a particular state of the stock that management either seeks to achieve or avoid. e.g. $\mathbf{B_{current}/B_{MSY} = 1}$

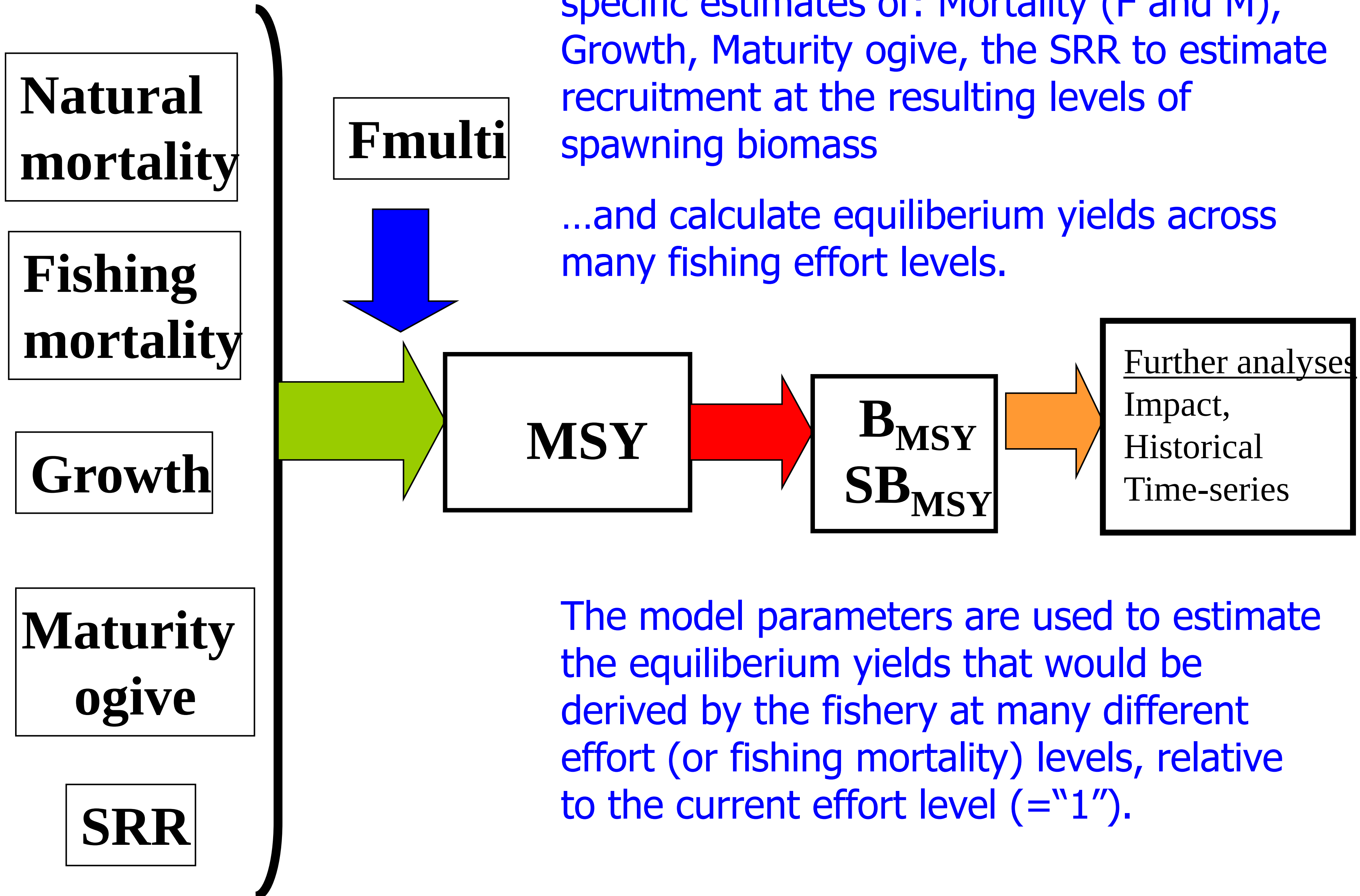
2. Indicator – is a quantity used to measure the status of a stock against a given Reference Point.

e.g. $\mathbf{B_{current}/B_{MSY}}$

How are reference points calculated?

These calculations take into account age-specific estimates of: Mortality (F and M), Growth, Maturity ogive, the SRR to estimate recruitment at the resulting levels of spawning biomass

…and calculate equiliberium yields across many fishing effort levels.



The model parameters are used to estimate the equiliberium yields that would be derived by the fishery at many different effort (or fishing mortality) levels, relative to the current effort level (="1").

How are reference points calculated?

The highest equiliberium yield level estimated is the maximum sustainable yield, with the fishing mortality rate that provides that yield equivalent to Fmsy. The

F level

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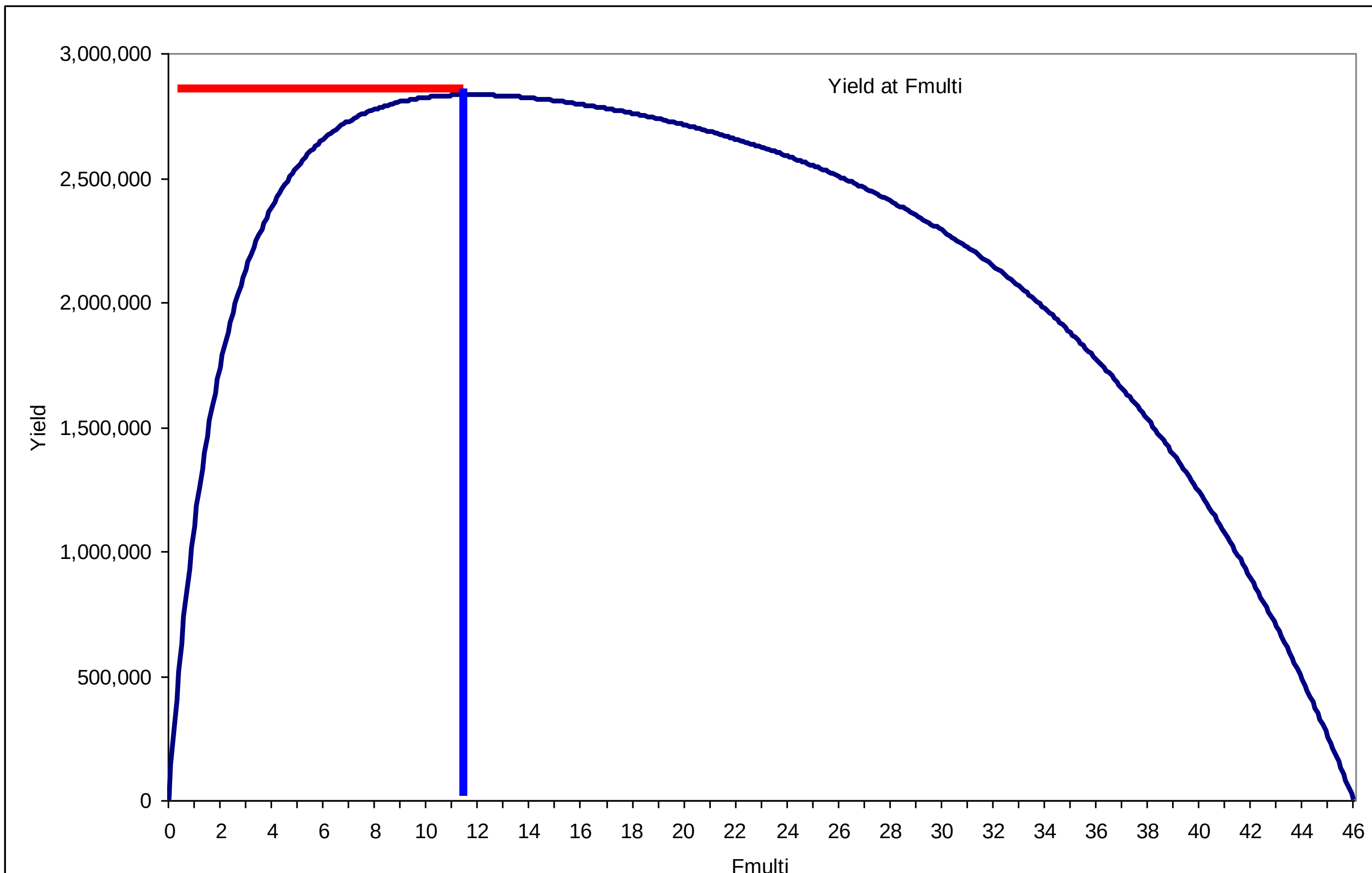
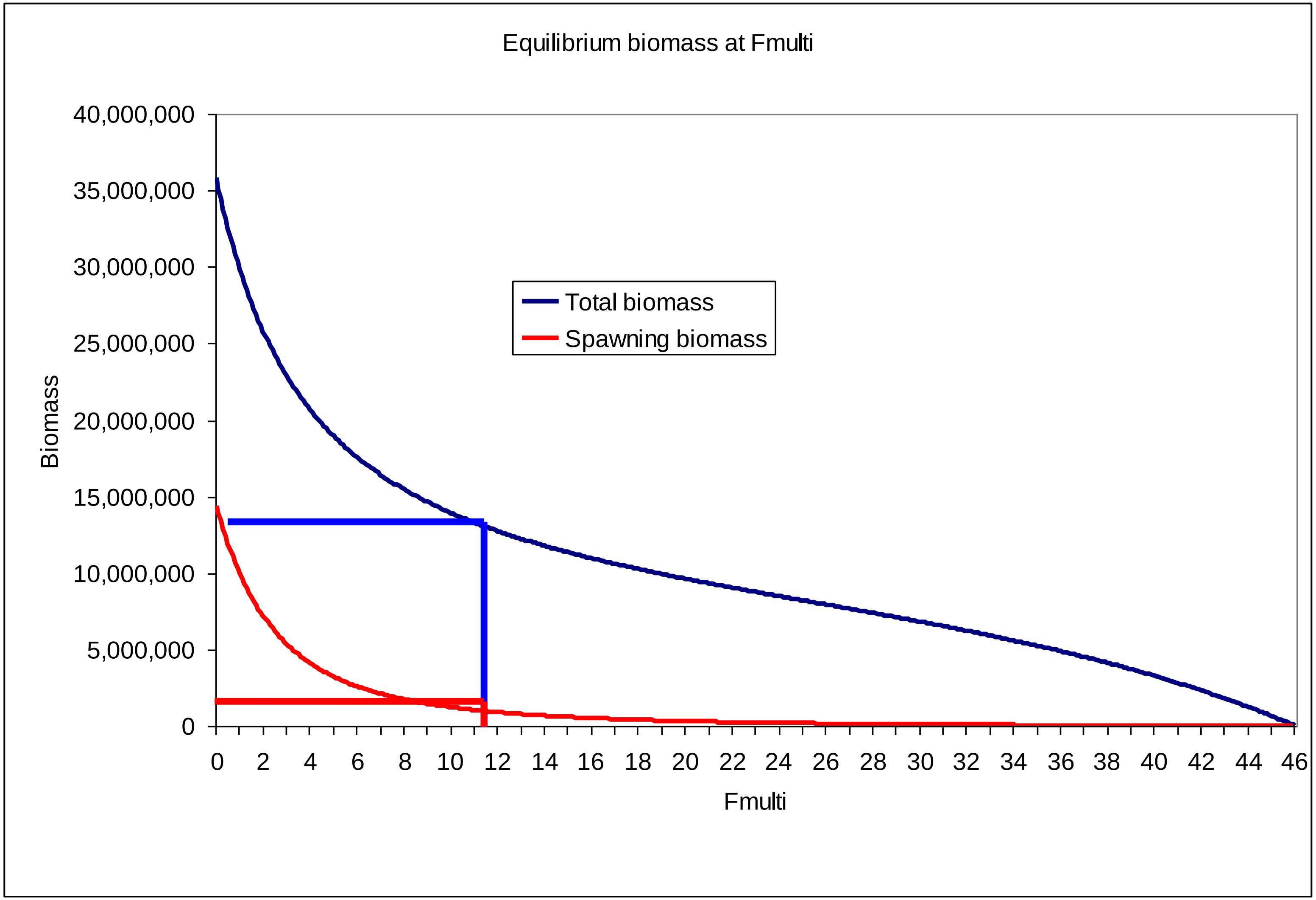


“Dome-shaped” yield curve

How are reference points calculated?

That same Fmulti value can then be plotted to indicate the Bmsy and the SBmsy



What do BRPs indicate about stock status of stocks (in Convention Area)

Bigeye tuna 2011 - (healthy)