Stock Assessment – Basic Principles

What is a fish stock?

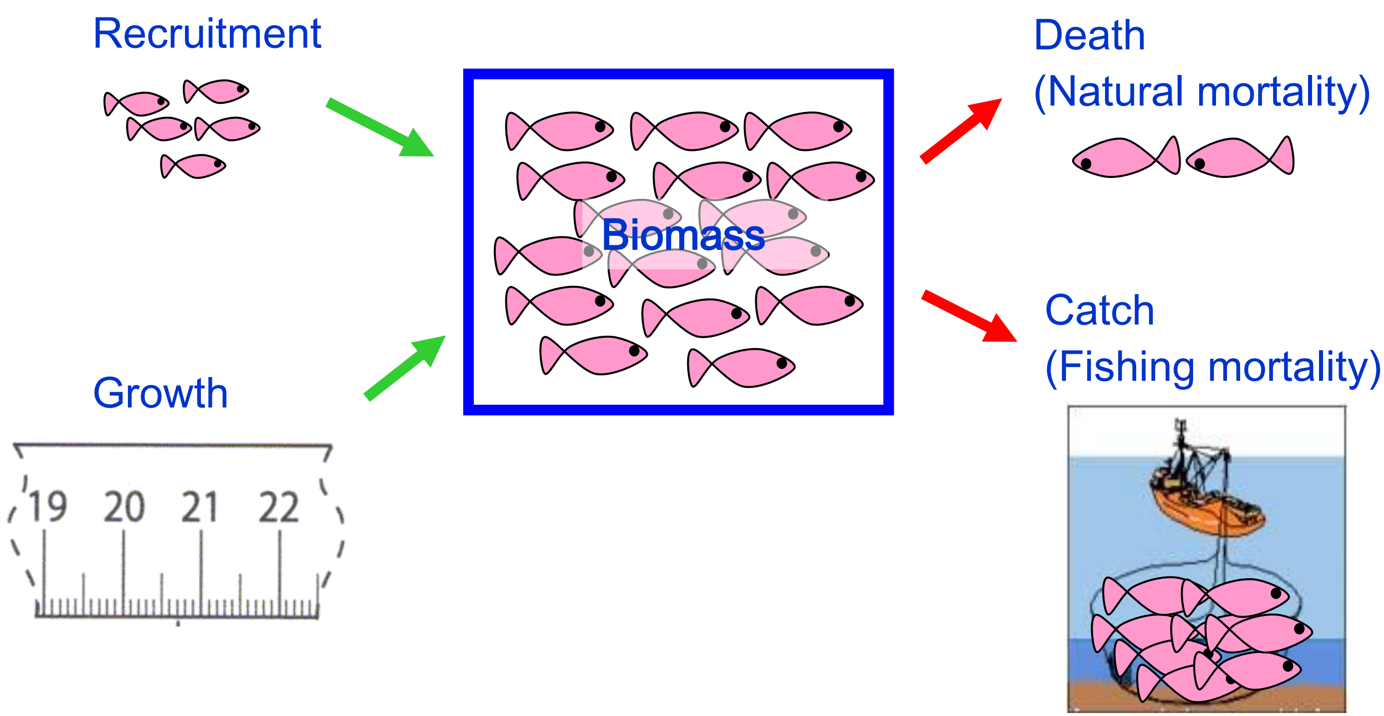
Key Concept 1 – A stock assessment model is used to assess a fish population that has little or no mixing or interbreeding with other populations.

"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.

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



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……………

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

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

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

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

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

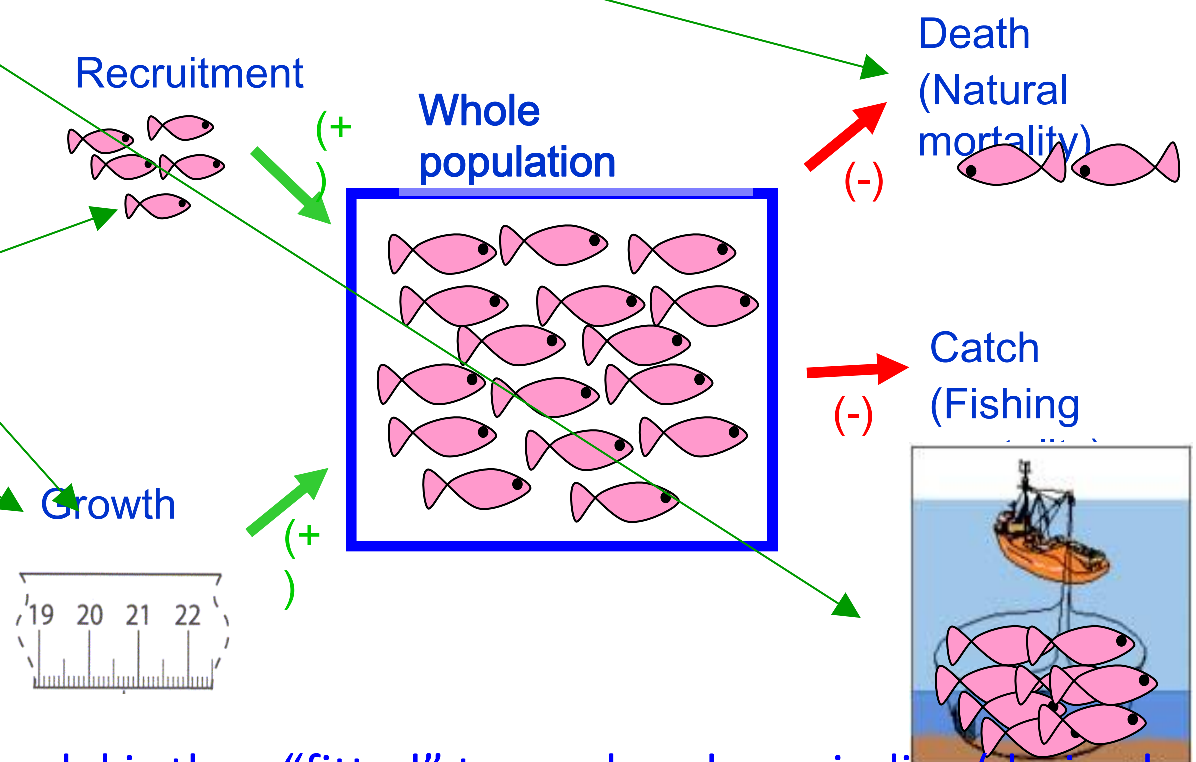
$$VB_t = \Sigma_a N_{t,a} w_a s_a$$

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

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

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

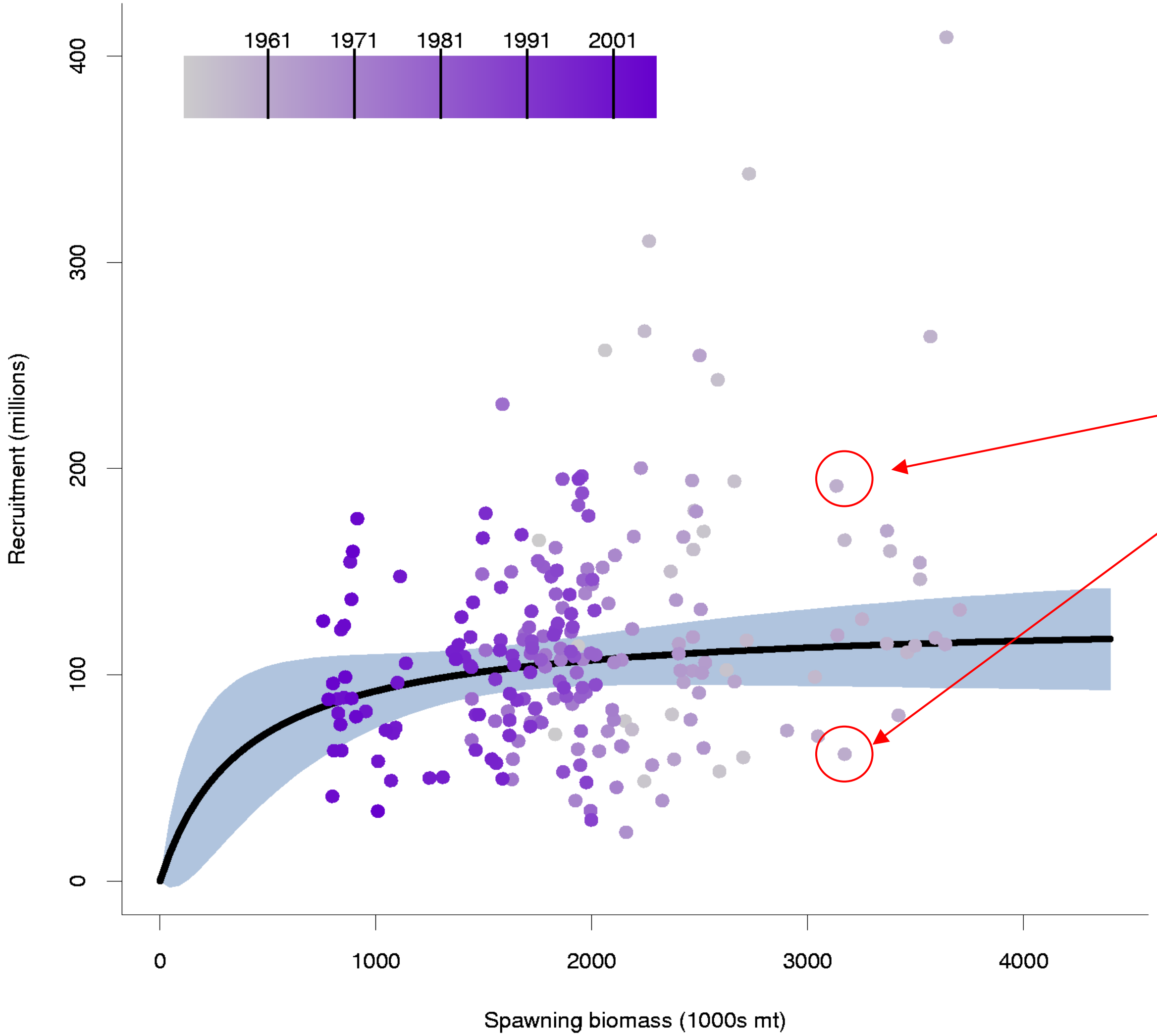
1. Recruitment is the number of fish alive at a specified stage after hatching – For the tuna assessments conducted in the WCP-CA, its the stage at which they are first detected in the fishery catch (e.g. for YFT, BET, SKJ at 0.6 months in the purse seine fishery).
2. In the WCP-CA recruits are identified 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

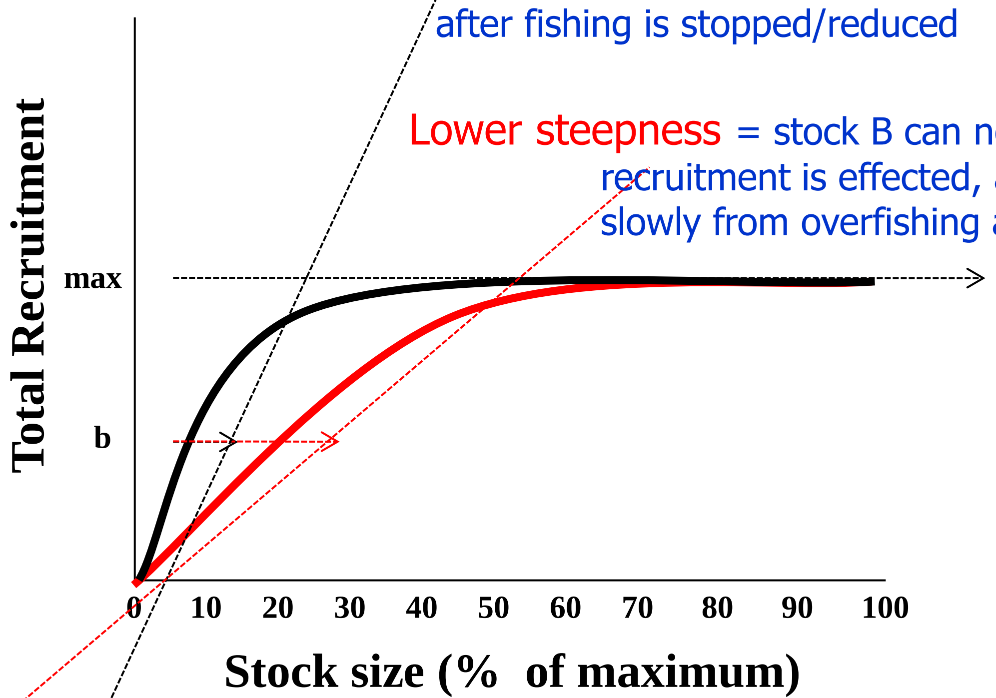
9. Recruitment overfishing – describes the point at which there are no longer enough adults to produce the number of recruits required to replace fish lost from the population by natural and fishing mortality.

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



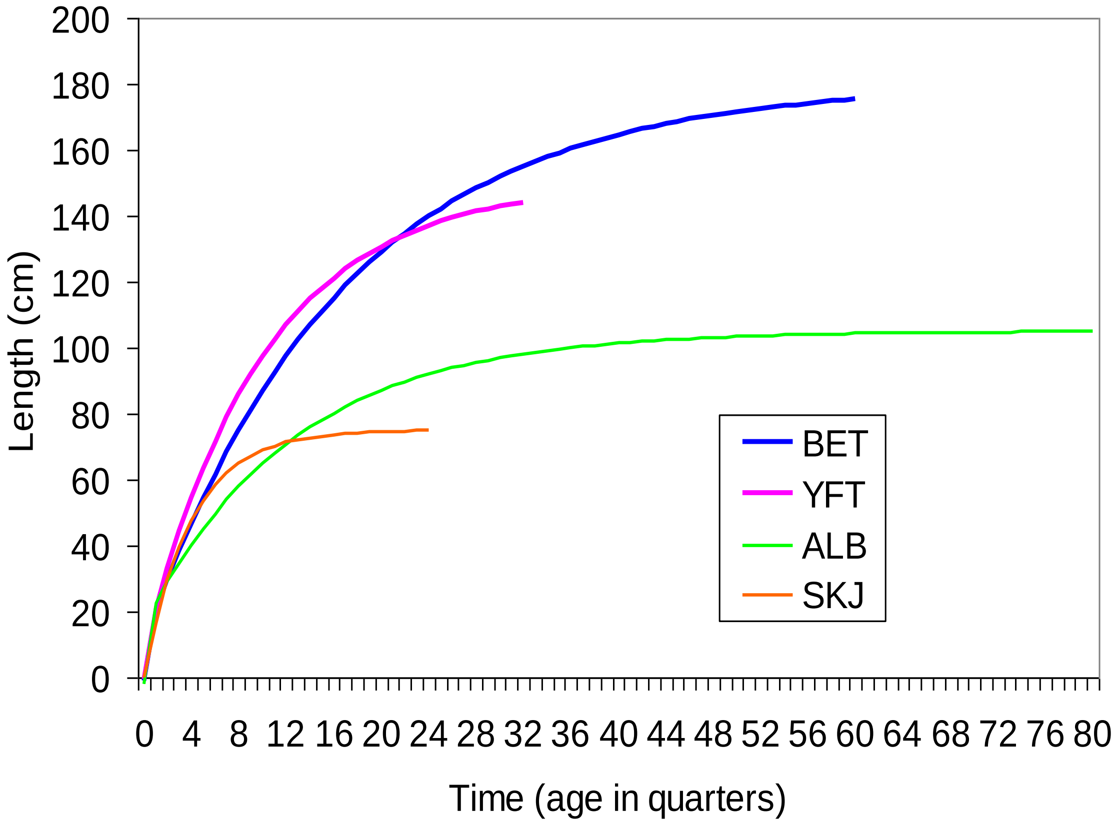
The problem – "steepness" is often very uncertain in stock assessments, so the point at which recruitment is effected (and overfishing occurs) is also uncertain.

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?

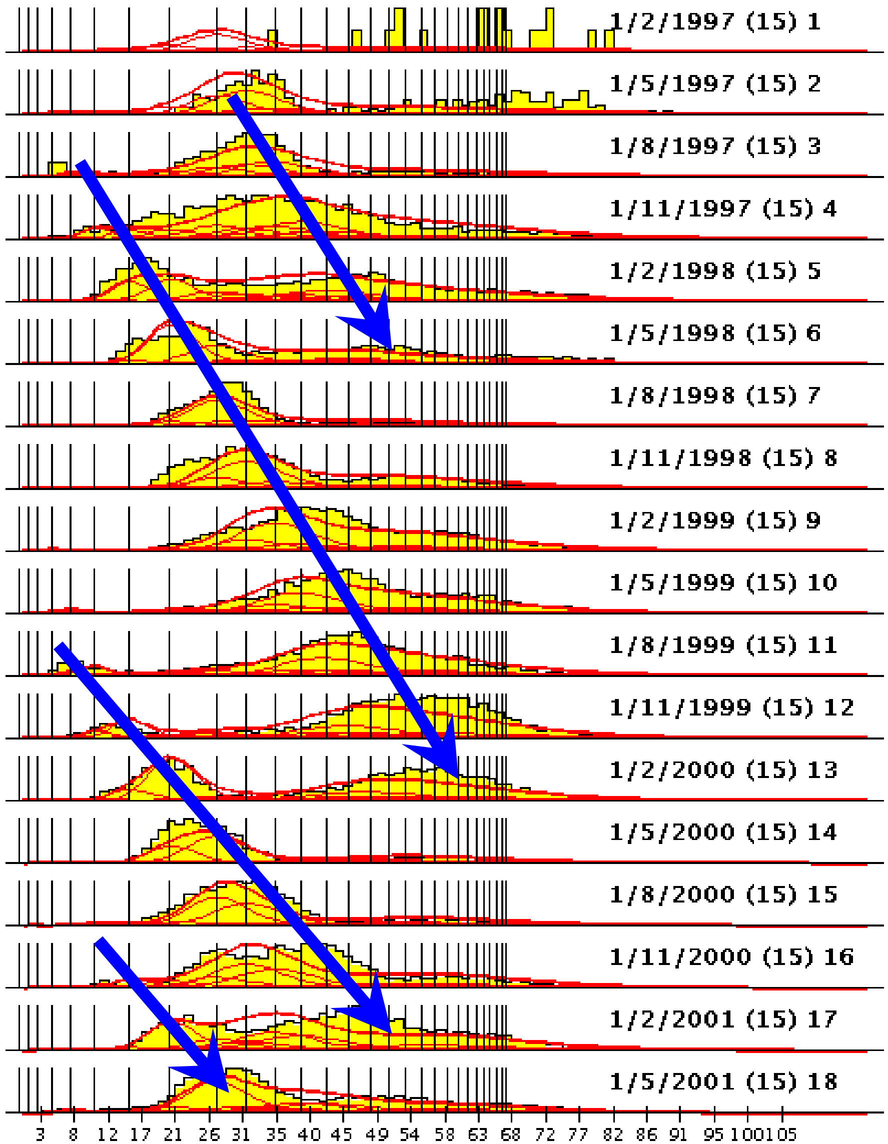
6. Many growth models exist but the VBGF is the most-widely used. The key parameters to estimate are K (growth coefficient) and L_∞ (mean maximum fish length).

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

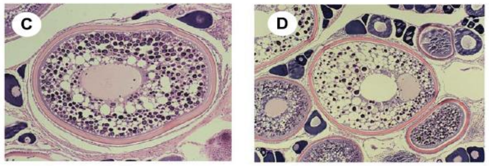
Maturity

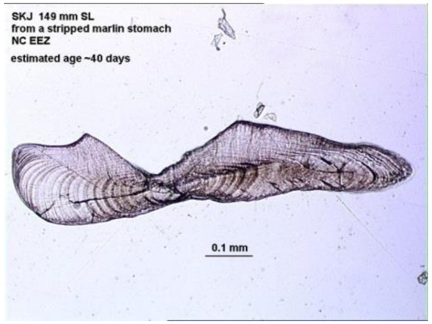
Maturity at age

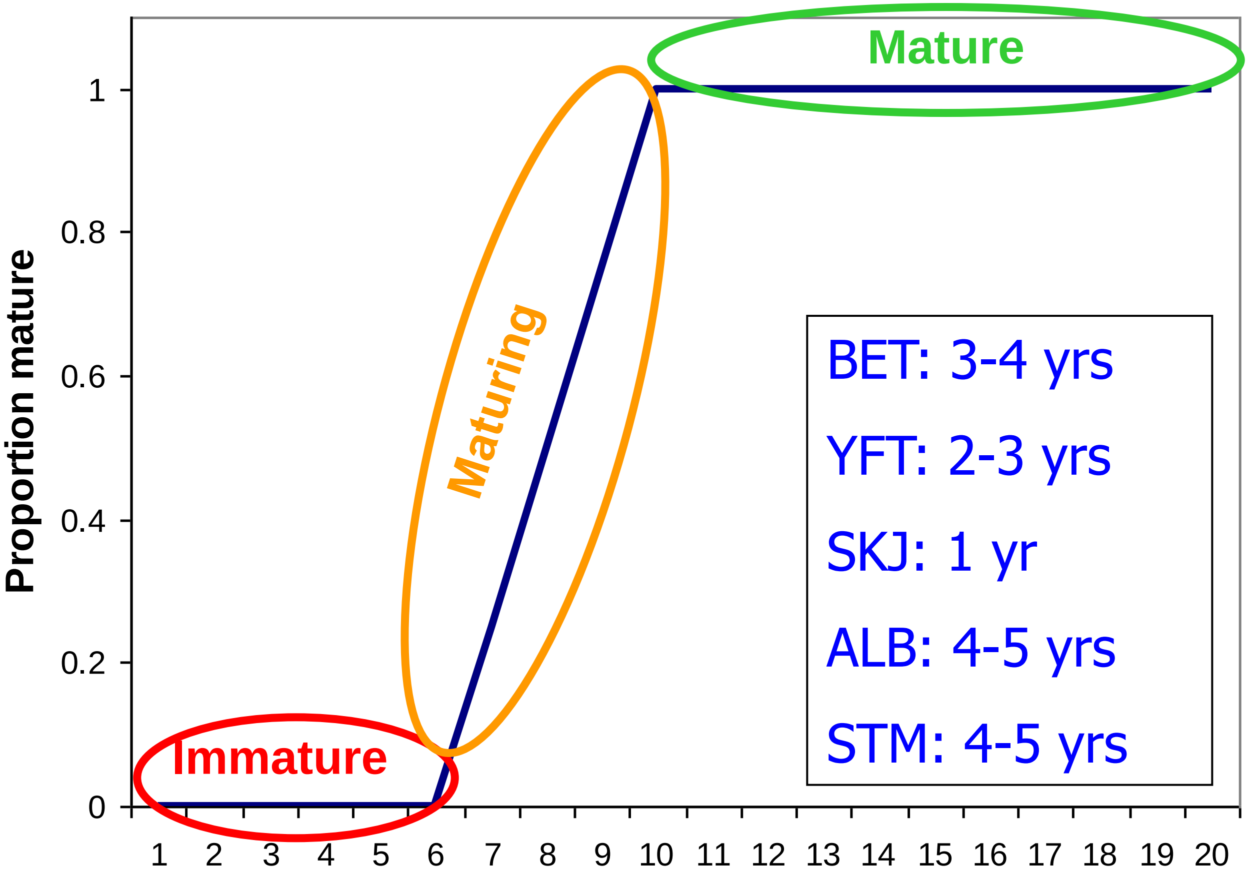
Fish stocks are comprised of immature fish (juvenile), maturing fish and mature (adult) fish. **The maturity schedule of a stock is critical as it will influence future recruitment**.

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

Picture of a striped marlin ovary.



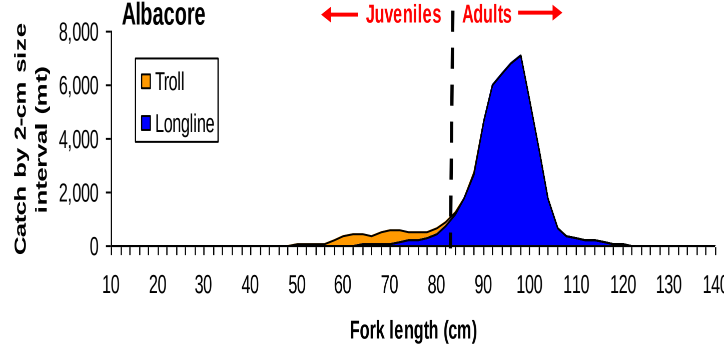


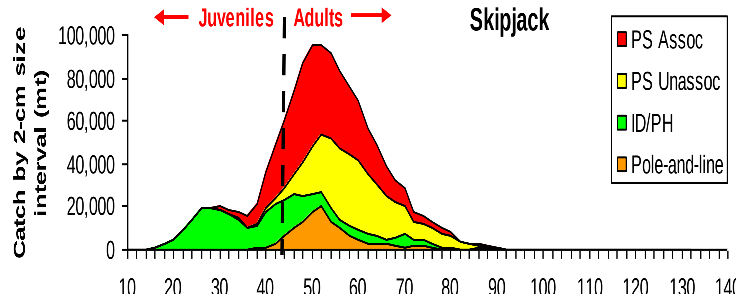


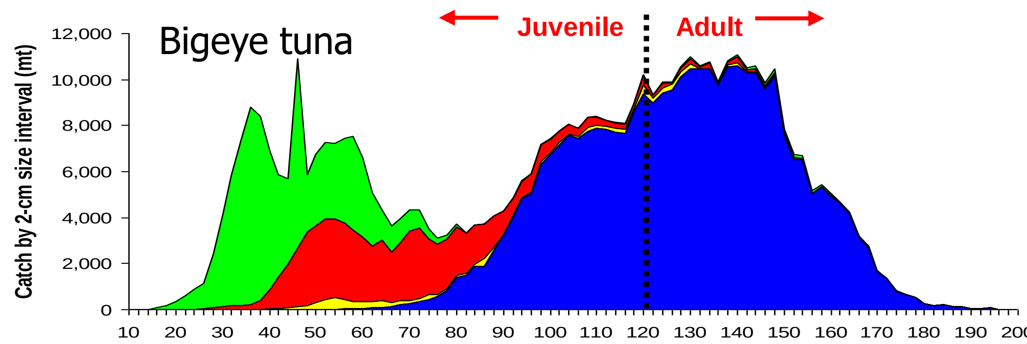
Maturity

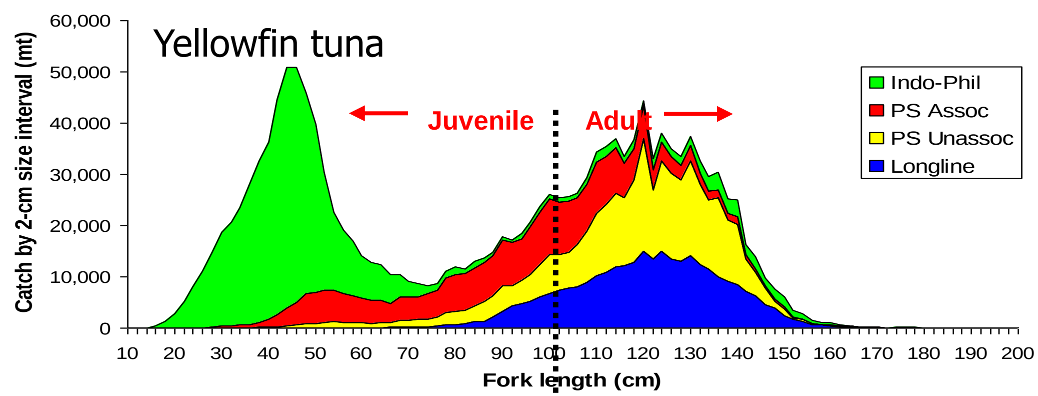
There is a close relationship between the current status of the stocks, age/size to maturity, and the level of catch from juvenile age classes. Those stocks with relatively little juvenile mortality (i.e. which concentrate on catching adults) are in better condition

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)

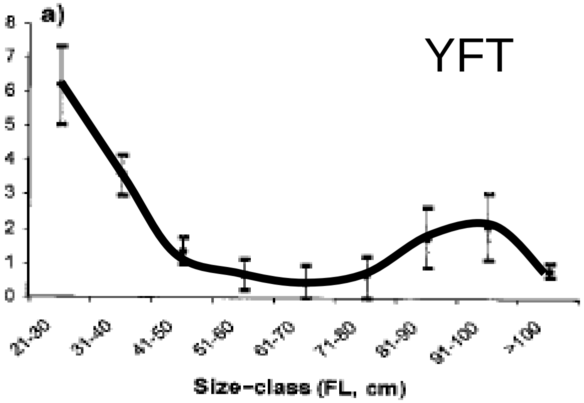
Definition: The process of mortality (death) of fish due to natural causes (e.g. predation, disease, senescence). Expressed as a rate (i.e. proportion of the size/age class dying per time period).

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. $\boxed{\text{Catch curve analyses}}$ 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: $C=qEB$

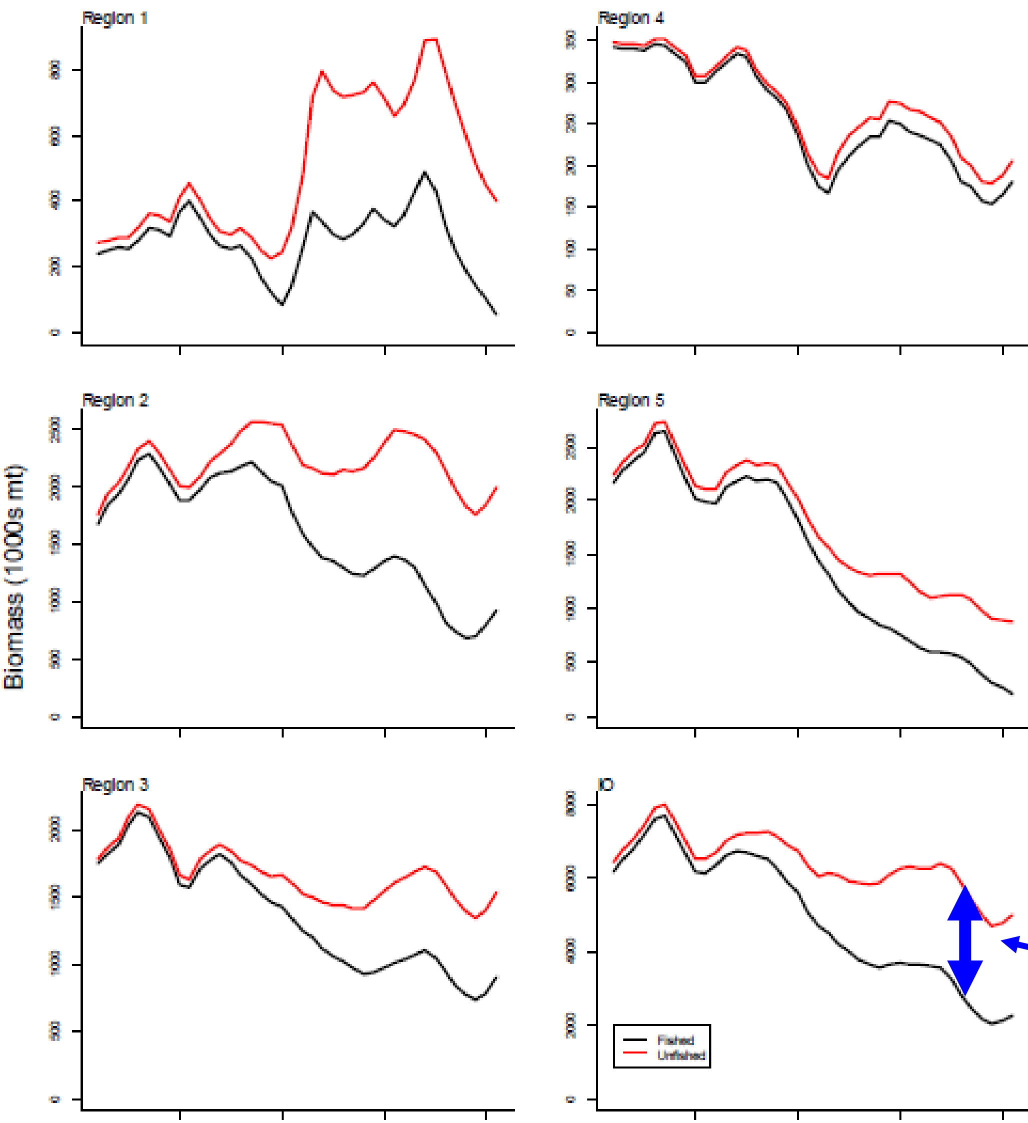
Total F: $F = qE = C/B$

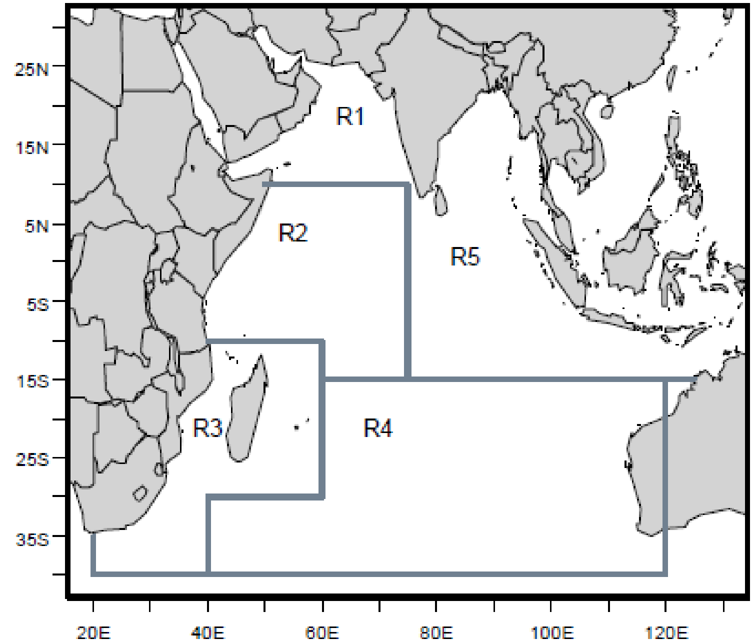
F at Age: $F_{a,t} = q_t E_t S_a$

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

Fishing mortality: YFT 2012





Black: $Z = (F + M)$

Red: M only

"The impact of fishing"

Selectivity

Selectivity

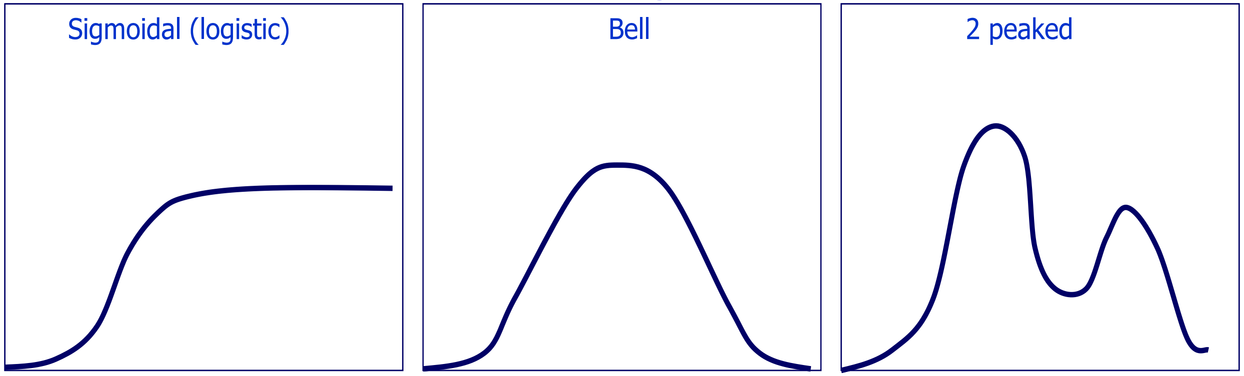
Selectivity is the size or age specific vulnerability of fish to a fishing gear. This selectivity is an important component in age specific fishing mortality estimation

$\mathbf{F_a = qEs_a}$

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:

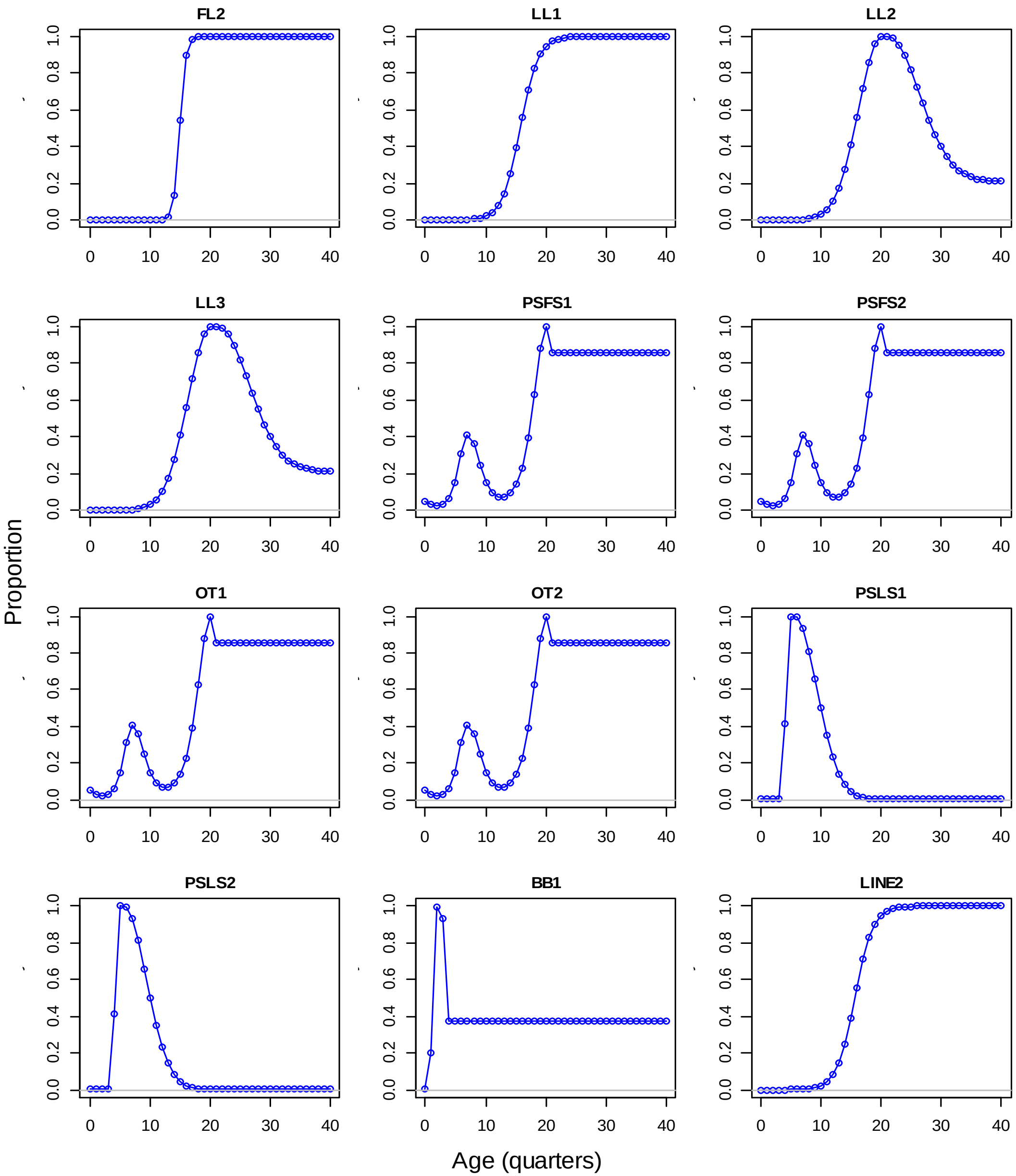
PS (FS/LS) = purse seine

LL= Longline

LINE = Handline

BB = Maldives Baitboat

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

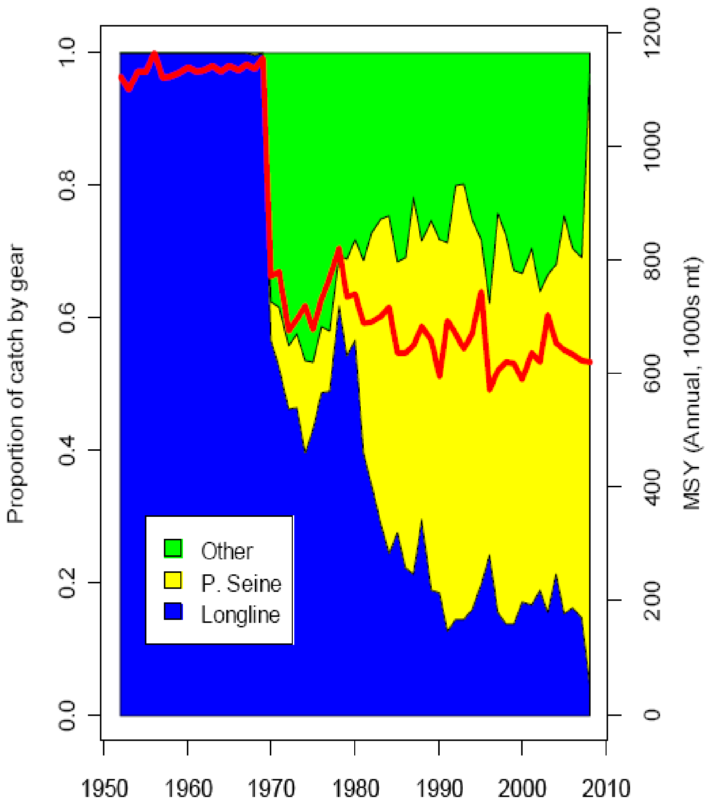


Selectivity and MSY

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

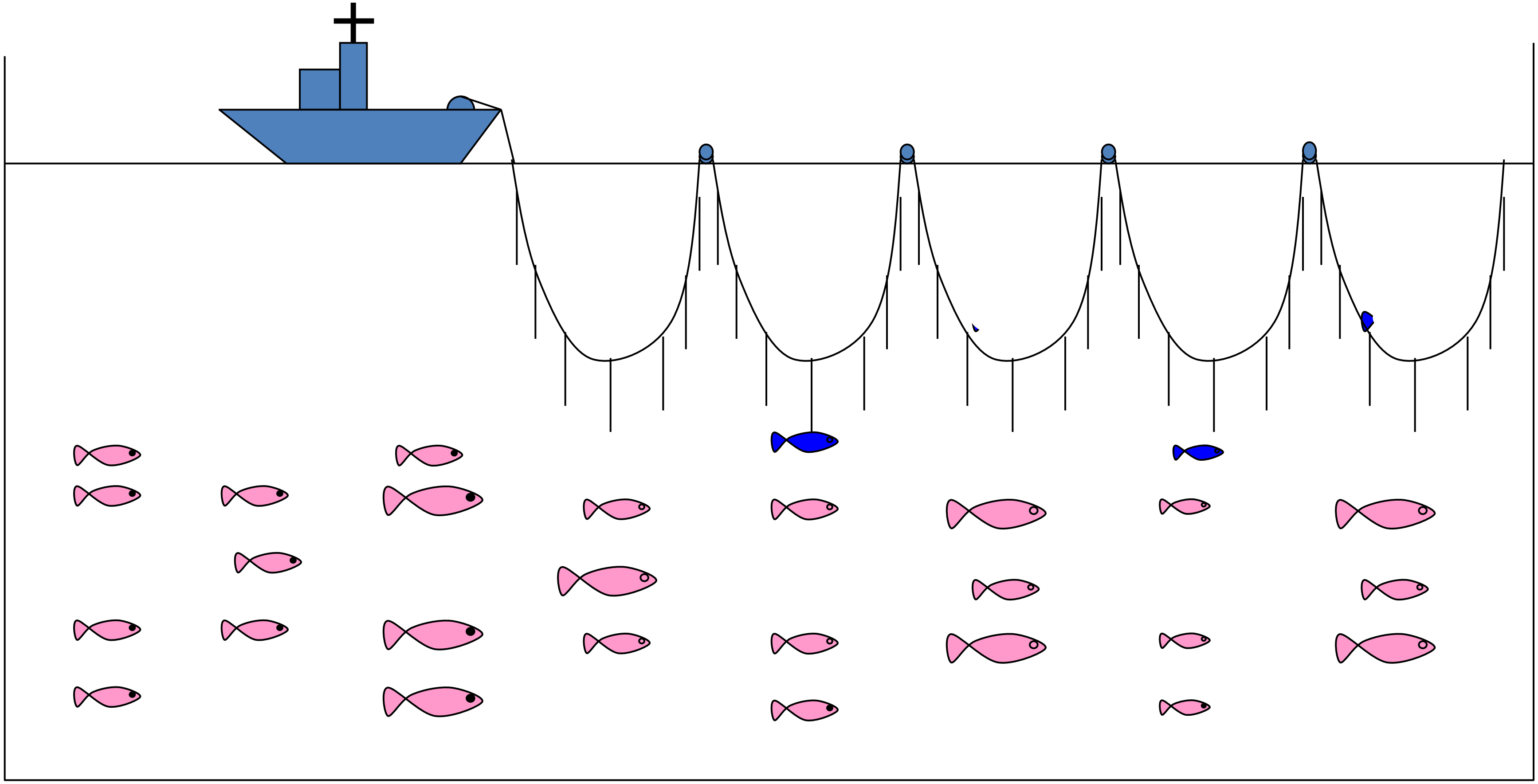
These are reasons why we collect information on methods and gears from fishermen, so we can account for changes in fishing over time that might impact catchability.

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

$C/E=qB$

$F=qE$

Catchability



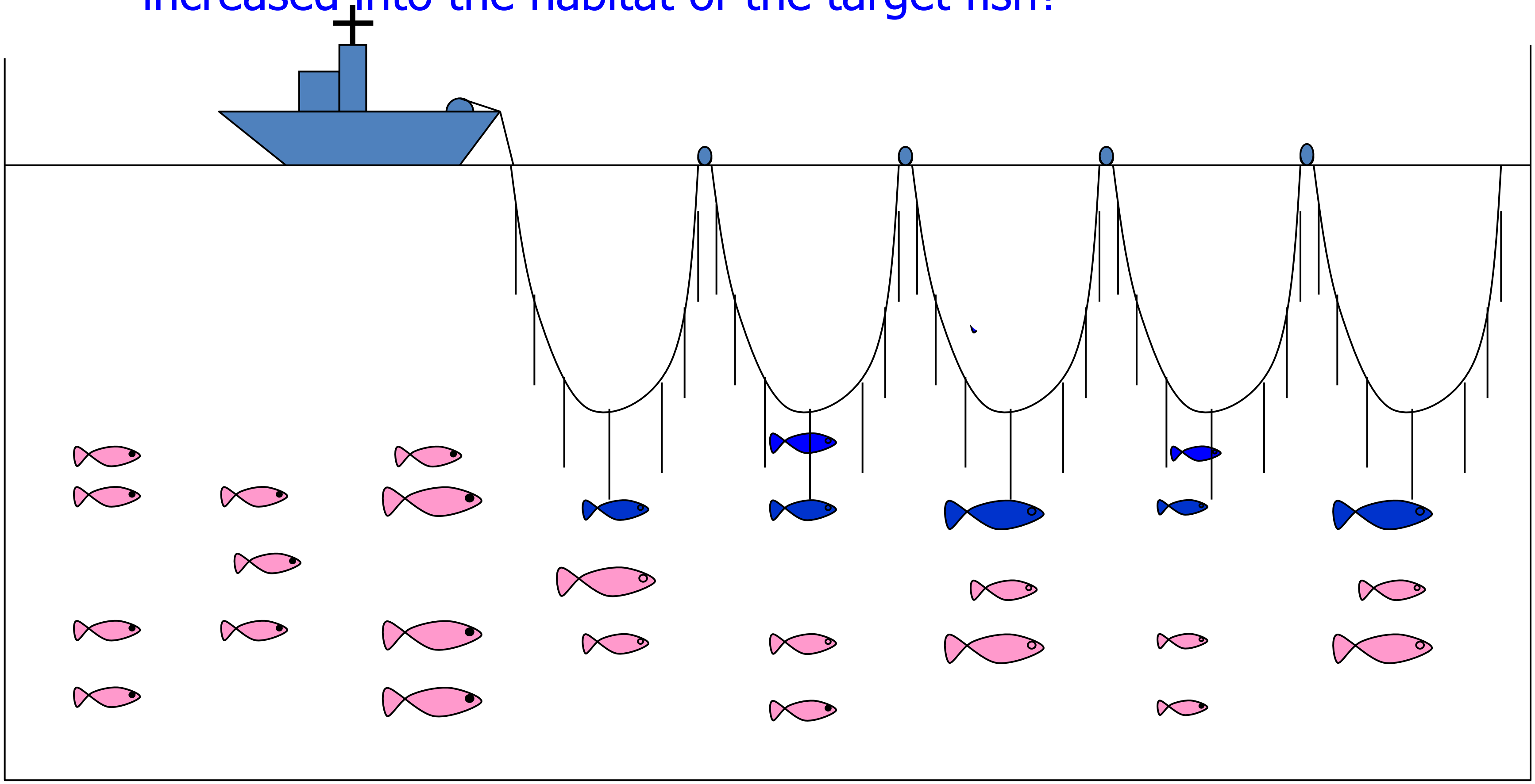
$$q = C/EB$$

$$q = 2/30 \times 28$$

$$= \mathbf{0.00238}$$

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.

Natural mortality

Fishing mortality

Growth

Maturity ogive

SRR

Fmulti

MSY

B_{MSY}

SB_{MSY}

Further analyses

Impact,

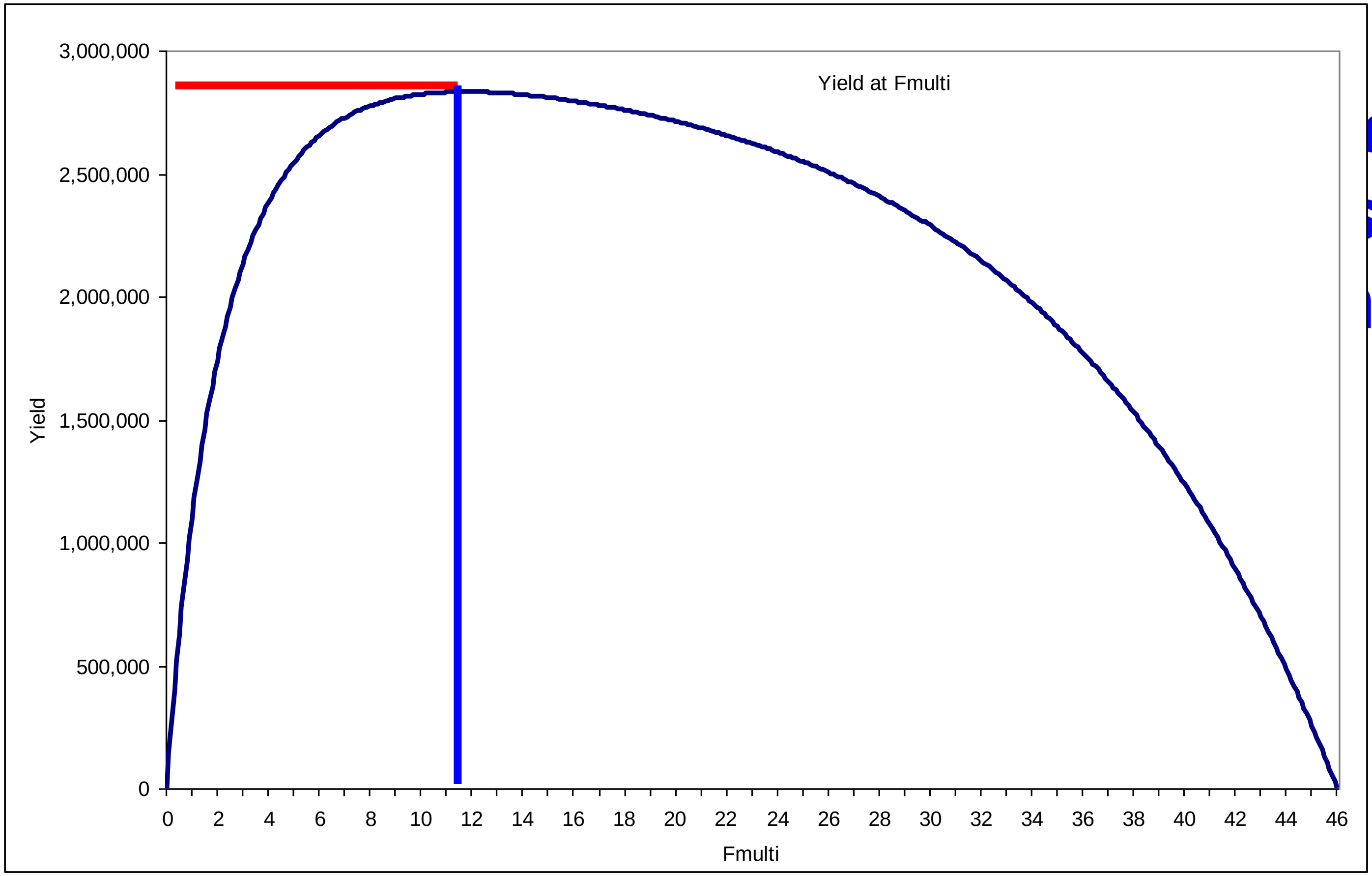
Historical

Time-series

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

***ent* F**

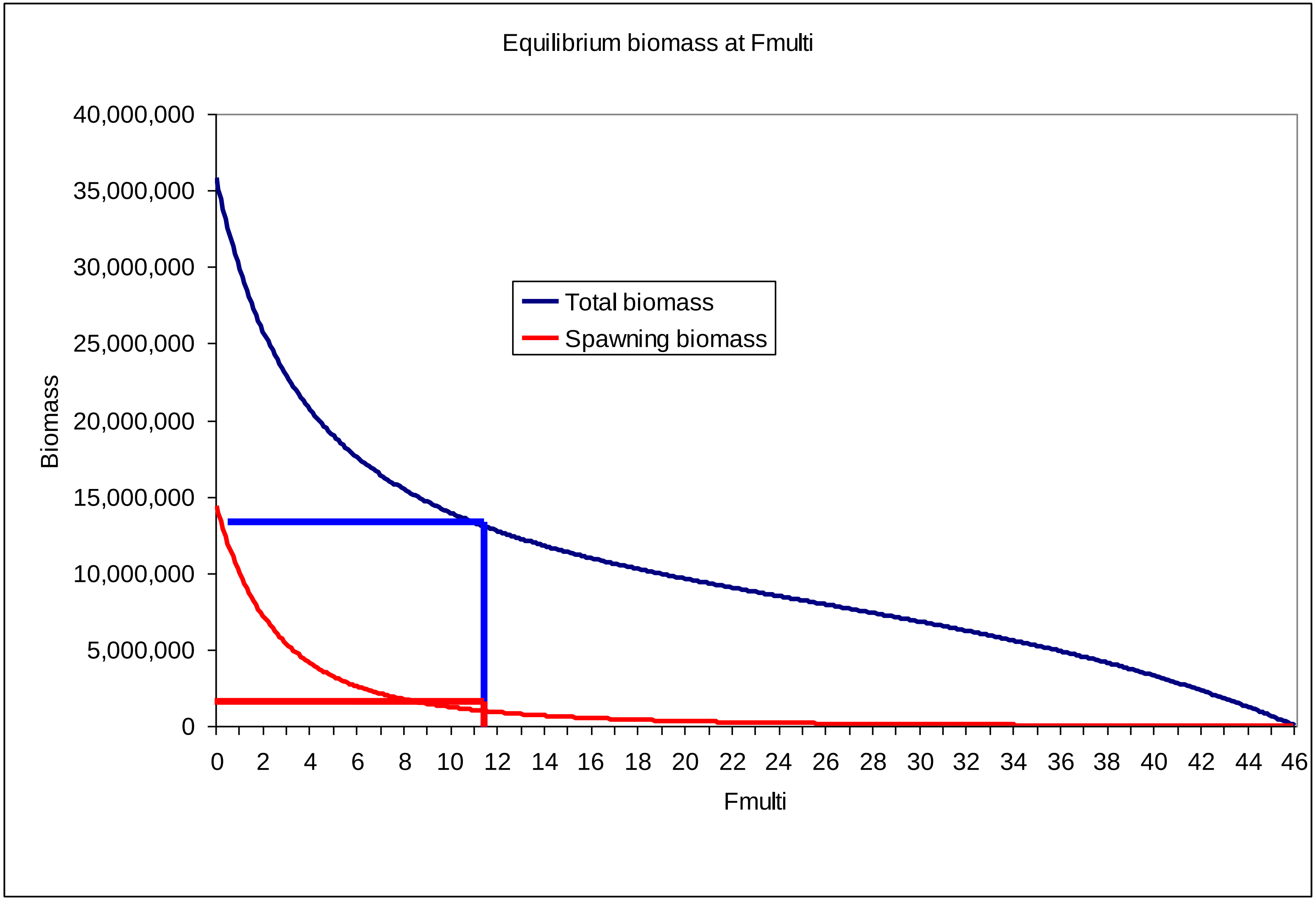
us

ot.

“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)