SPC CPS

SECRETARIAT OF THE PACIFIC COMMUNITY
SECRÉTARIAT GÉNÉRAL DE LA COMMUNAUTÉ DU PACIFIQUE

Tuna Stock Assessment Workshop

22–27 June 2015
SPC Headquarters, Noumea
New Caledonia

Workshop Manual

Funded by

Western and Central Pacific Fisheries Commission

NEW ZEALAND
MINISTRY OF FOREIGN AFFAIRS & TRADE
Aid Programme

Australian Aid

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2. The Western and Central Pacific Fisheries Commission

3. The New Zealand Aid Programme

4. The Australian Government

5. The PEW Charitable trusts

STOCK ASSESSMENT WORKSHOP - AGENDA

Session times / Dates	Day 1 Monday 22 June	Day 2 Tuesday 23 June	Day 3 Wednesday 24 June	Day 4 Thursday 25 June	Day 5 Friday 26 June	Day 6 Saturday 27 June
Session 1 (0830 - 1000)	01-Introduction and workshop objectives -JH Prac Background - Why are we here? What is stock assessment, in simple terms? - SB	04-Data - PM (HA) 05-Growth - SB	08-CPUE - SM (SB) CPUE Prac	12-Bringing it all together in a model - HA Prac	16-Bioeconomics - GP (HA) Prac	Introduction to SEAPODYM - SN Prac/Discussion
Morning Tea (1000 - 1030)						
Session 2 (1030 - 1200)	02-Fish populations and fisheries - Fish and "fished" population dynamics - SB 03-Key Principals -HA	Growth Prac 06-Recruitment - HA	09-Selectivity -SB Prac	13-Projections - RS (HA) TUMAS prac session SH	Participant presentation preparation	Baseline information on bycatch for EEZs - SN Estimating the ecosystem effect of fishing - SN Prac/Discussion
Lunch (1200 - 1300)						
Session 3 (1300 - 1430)	Key Principals -HA	Recruitment Prac	10-Management outputs - RS (SB) 11-Biological ref points - Intro - HA	14-Country level implications - PM Prac (RS)	Participant presentation preparation	National summaries of SEAPODYM biomass- SN Prac/Discussion
Afternoon tea (1430 - 1500)						
Session 4 (1500 - 1630)	Discussion	07-Mortality - SB Mortality Prac	Prac	15-Stock assessment presentation - SH (HA) Discussion Critique	Participant presentations	Artisanal fisheries - SB Range contraction - LB
Tutor session (1630-1700)	Intro to Participant presentations (SKJ, BET or ALB) (5-10 min) Tutor session	Tutor session	Tutor session	Tutor session	Test & Survey	BBQ

SB = Steve Brouwer; SH = Shelton Harley; HA = Steven Hare; RS = Rob Scott; GP = Graham Pilling; SM = Sam McKechnie; LB = Laura Temblay-Boyer; AW = Ashley Williams; JH = John Hampton; SN = Simon Nicol; PM = Pam Maru; names in () = backup

Table of contents

Chapter 1

Introduction and overview

Who are we?

The Oceanic Fisheries Programme (OFP)

The OFP mission: Provide scientific information and advice for managing fisheries exploiting the region's tuna resources.

- OFP, SC and WCPFC relationships
- The structure of the OFP is in four sections (40+ staff):
  - Stock Assessment and Modelling
  - Data Management
  - Fisheries Monitoring
  - Ecosystem Monitoring and Assessment

The programme manager is Dr John Hampton

House keeping

Amenities (see maps in your folders)

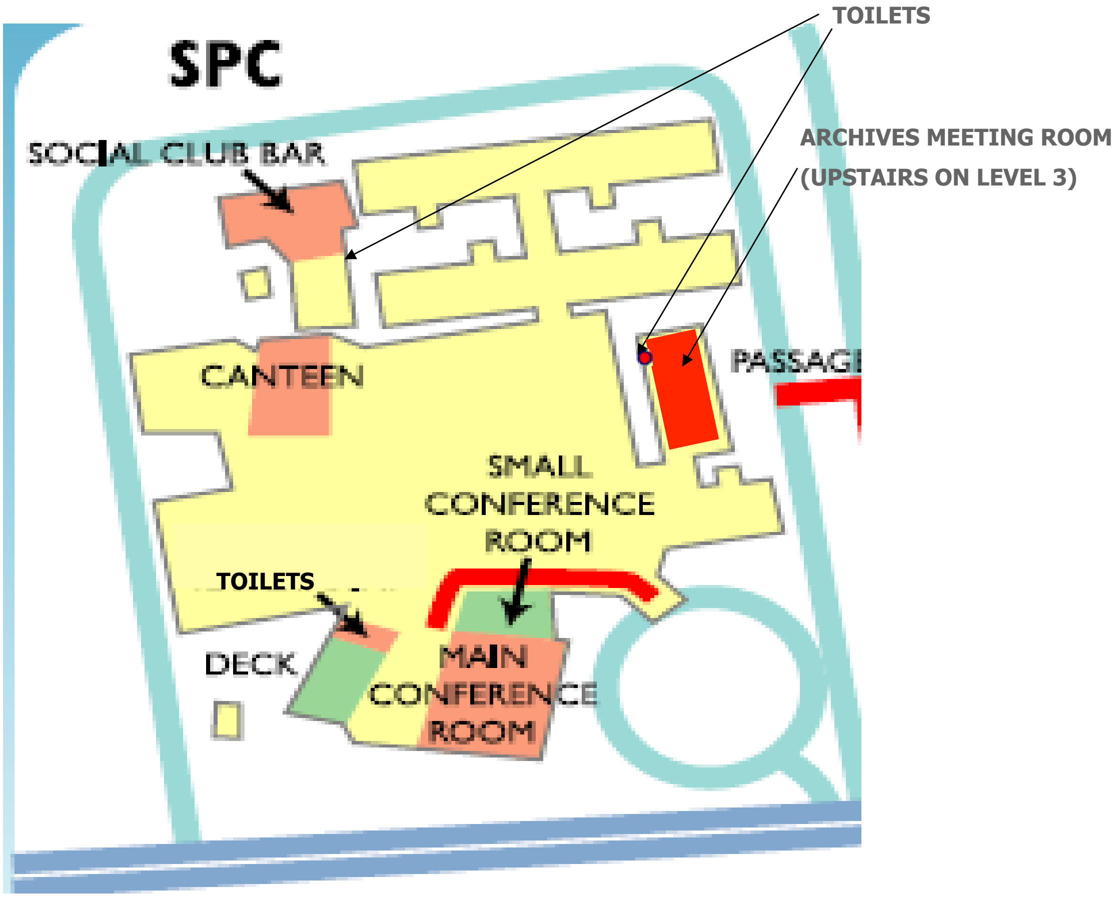
- Toilets
- Shops and Restaurants
- Services
  - Internet access
  - Postal

Social events – 27th June 5pm - BBQ! At the SPC bar/social area!

Morning and afternoon tea and lunch provided

Map of Anse Vata

Map of SPC



Workshop Materials

1. Workshop Booklet containing:
   a. Timetable/Agenda
   b. Copy of presentations (for all* days)
   c. Survey and evaluation forms**

2. You will be provided a notebook and additional reference materials during the workshop

3. You will have wireless access to a common intranet storage site from which you can copy any files that we will be distributing throughout the workshop, or you can use to distribute files amongst yourselves when working in groups. You can also create your own storage folder on that site if you wish.

Background - Why are we here?

Background - Why are we here?

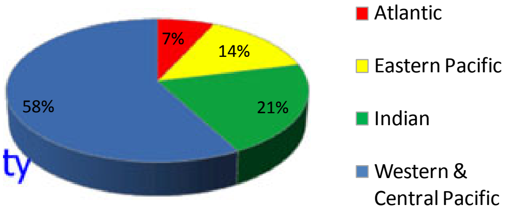
- The first question is really:
  - ***What IS stock assessment??***

  A very simple definition is that stock assessment is the study of the status (health) of fish stocks, and of the implications for the stock and the fishery if the fishery were to be managed in the same or a different manner in the future (we will expand on this later).

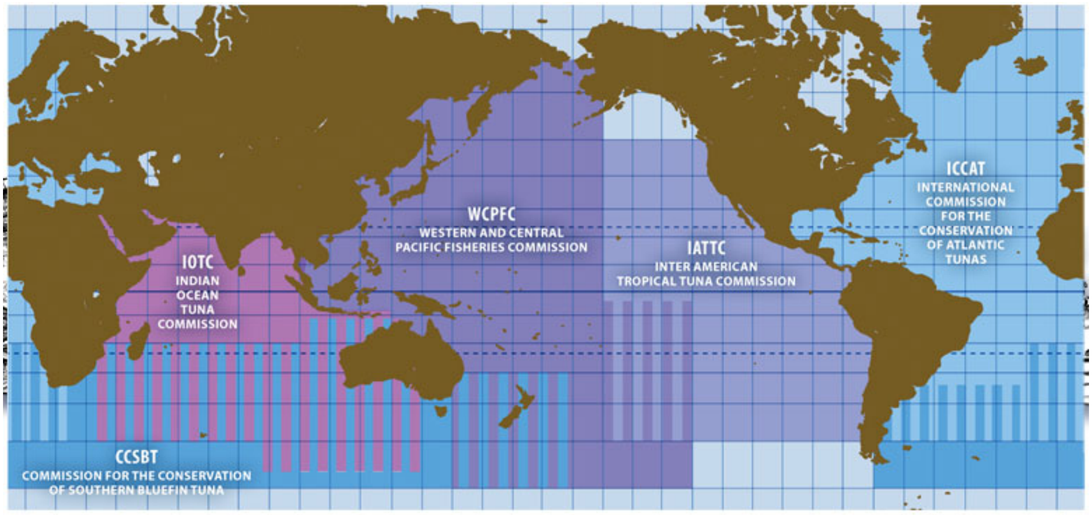
- Why do you need to know about stock assessment , in other words…
- *…Why are you here??*

Background - Why are we here?

• Pacific Island Nations and other Pacific nations, are custodians of worlds largest tuna resource (over ½ the worlds tuna catch ~5 billion dollars)



• Many countries hold concerns over the sustainability of a resource (the only resource for many) that is critical to economic development



Background - Why are we here?

• There are numerous legally binding agreements…

1. UN Convention on the Law of the Sea (UNCLOS)
2. UN Fish Stocks Agreement
3. Western and Central Pacific Fisheries Convention (WCPFC)

…and treaties (FSM Arrangement, Palau Arrangement, etc.)

• But often an absence of capacity to fulfill obligations within these agreements (lack of legal and scientific capacity)

Background - Why are we here?

1. UN Convention for the Law of the Sea

Article 61 (parts 2 and 3) – Conservation of living resources –

"*The coastal State, taking into account the best scientific evidence available to it, shall ensure through proper conservation and management measures that the maintenance of the living resources in the exclusive economic zone is not endangered by over-exploitation……..*

Such measures shall also be designed to maintain or restore populations of harvested species at levels which can produce the maximum sustainable yield, as qualified by relevant environmental and economic factors, including the economic needs of coastal fishing communities and the special requirements of developing States."

Background - Why are we here?

2. UN Fish Stocks Agreement

Article 2 - Objective
"….. to ensure long-term conservation and sustainable use of straddling ….and highly migratory fish stocks through effective implementation of [UNCLOS]"

Article 5 - General principles
"So as to conserve and manage HMS stocks, any states fishing on high seas shall:

- Adopt measures for long-term sustainability, based on best available scientific advice, applying the precautionary approach and assessing the impacts of fishing, conserve ecosystems and associated impacted species, minimize discards, waste, catch by abandoned gear, catch of non-target species, protect biodiversity.

- Take measures to prevent/eliminate overfishing and excess fishing capacity"

Background - Why are we here?

3. Western and Central Pacific Fisheries Convention

The WCPF Convention brings all these approaches (UNCLOS, UNFSA) to operate in the Pacific Islands region.

Article 5 – Principles/measures for conservation and management

In order to conserve and manage highly migratory fish stocks .....the members of the Commission shall, ...:

(a) adopt measures to ensure long-term sustainability of HMS ...

(b) ensure ...measures are based on the *best scientific evidence available and are designed to maintain or restore stocks at levels capable of producing maximum sustainable yield*, ...;

(c) apply the precautionary approach .....;

(d) *assess the impacts of fishing....on target stocks, non-target spp.*

Background - Why are we here?

Therefore.....

- There is a clearly specified need for stock assessment upon which to base management decisions regarding stocks in the region.......
- However, decision makers often lack the background experience and knowledge to interpret results from stock assessments.
- If you are unable to interpret stock assessment results it is very difficult to use them in your domestic and regional decision making processes, as is required by the aforementioned agreements.
- This is a major problem that has been identified by many of your countries as needing to be addressed *immediately* to increase your countries and the regions capacity to utilise scientific information for the sustainable management of your tuna resources.

Background - Why are we here?

Therefore these workshops have been developed as one method by which we might increase...

..."National capacities to use and interpret regional stock assessments and fisheries data at regional and national levels, to participate in Commission scientific work, and to understand the implications of Commission stock assessments."

This is why you are here!

What are we hoping to achieve this week?

(A discussion of workshop objectives)

What are we hoping to achieve this week?

OFP-SPC has developed a program of stock assessment learning for fisheries officers from developing Pacific countries and territories which involves four components:

1. Annual stock assessment workshops
2. Online learning/revision exercises between workshops*
3. Opportunistic training during in-country visits
4. In-meeting support (e.g. scientific support at SC and other meetings)

The ultimate **long-term** aim of this program is to allow participating officers to be able to pick up a full stock assessment paper, read it, understand it, criticize it if necessary, convey its meaning to their government, and incorporate that understanding into both their domestic and regional fisheries management decision making processes.

What are we hoping to achieve this week?

With that long-term goal in mind, the program has been structured around delivering understanding regarding 5 key questions:

1. What are stock assessment models and what are they used for? (PURPOSE)
2. How does a stock assessment model work? (MECHANICS)
3. How can we determine if it is a "good" model or assessment? (CRITICAL APPRAISAL)
4. What is the key information for fisheries management and how do I interpret it? (INTERPRETATION)
5. What are the potential implications of the assessment and associated management options analyses for the region and my country? (INTERPRETATION)

In this workshop, we are going to mostly focus on questions 1,2 and 4. It is important to understand the purpose and mechanics of stock assessment prior to dealing with issues 3-5 in detail (next year).

End of week presentation

At the end of this week, each of you will be **working in groups of four people to prepare and give a presentation** which demonstrates your understanding of stock assessment concepts and principles and how assessment outputs are relevant to your country; or,

These serve as a means for both you and the OFP-SPC to assess how you have progressed through the week, and offers you an opportunity to consolidate your understanding of the key principles prior to finishing the workshop.

The presentations are scheduled to occur on Friday afternoon.

You do not need to immediately nominate will assessment item you wish to do. We will discuss this with you at this afternoons tutor session.

At the end of each day we will guide you to the relevant sections of the stock assessment papers that were covered by the days lectures and practical.

What do we need to know first before learning about fish stock assessment?

We need to know about .....

1. **Our Fisheries!**

   - gears, species, countries, boundaries, climate and ocean influences

2. **Fish!**

   - their biology and population dynamics

What are the key features of the Western and Central Pacific Convention Area fishery that are relevant to stock assessment?

What are the features of the WCP-CA fishery relevant to stock assessment?

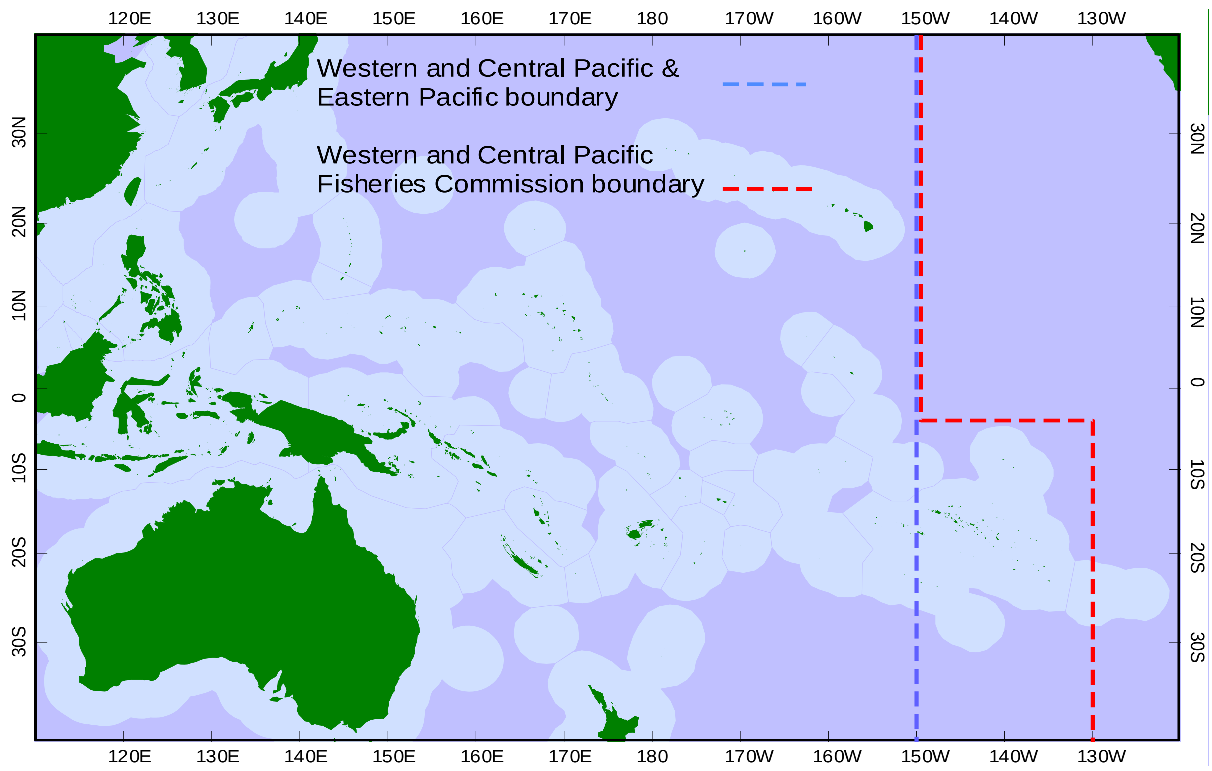
Oceanic fisheries in the WCP-CA are complex

Consider the following:

1. Political and Management Boundaries
2. Fisheries
3. Species and ecosystems
4. Oceanography and climate

Understanding the complexities across these factors is critical to building and undertaking a stock assessment.

Political and Management Boundaries



WCPO (Tuna) Fisheries

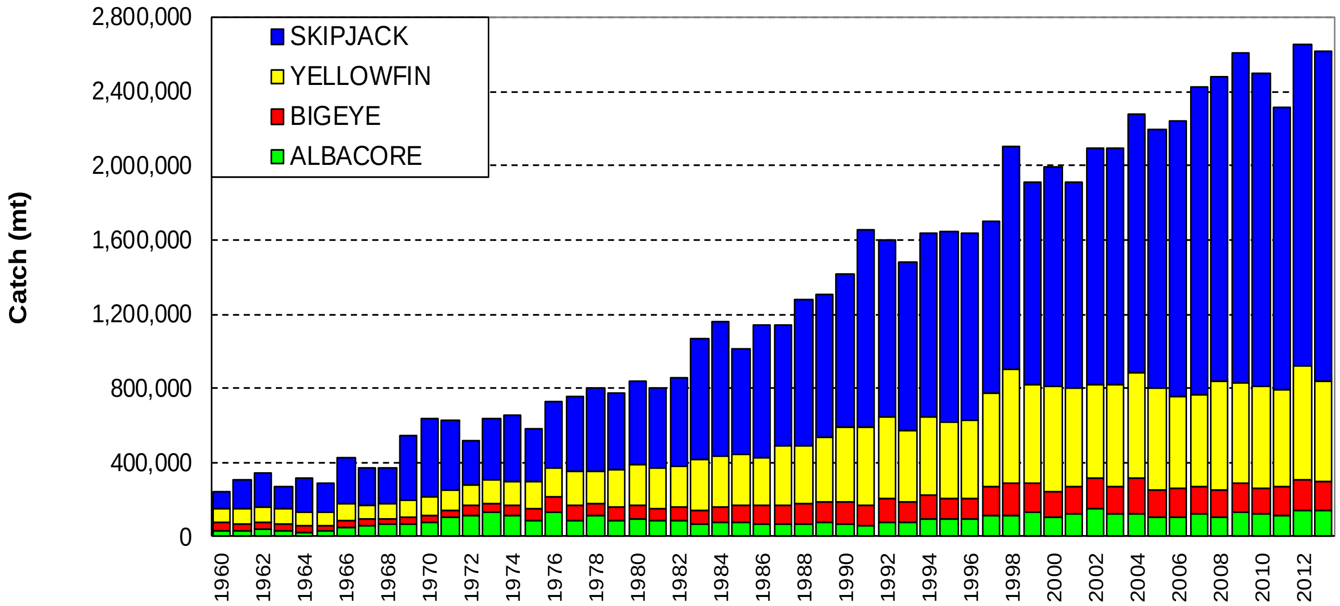
...are highly diverse. How do you define them?

WCPO tuna fisheries can be considered “super fisheries” comprised of many smaller ‘sub-fisheries’.

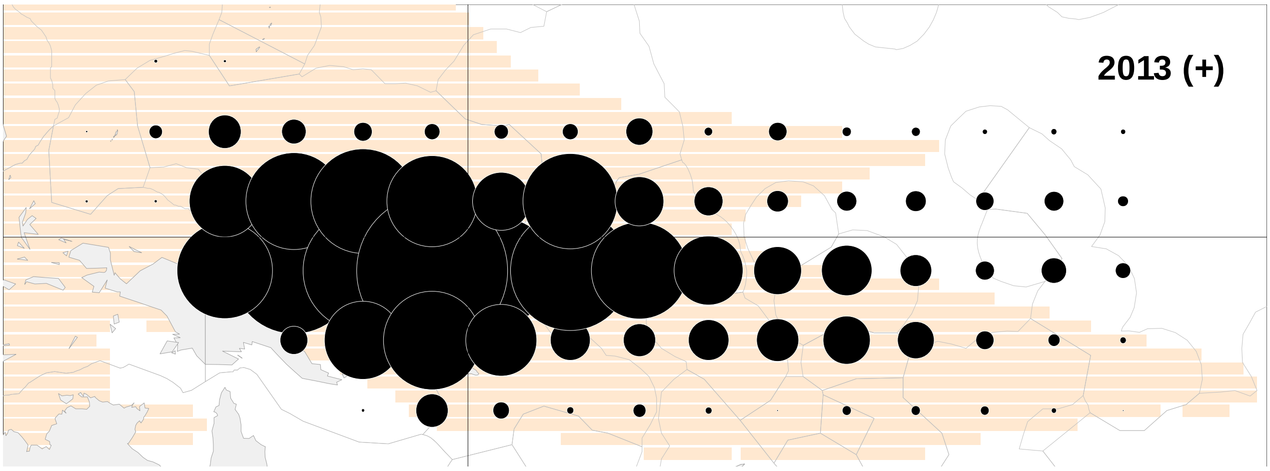
WCPO tuna fisheries are highly complex and pose challenges for stock assessments (e.g. data collection and interpretation). This complexity is one of the reasons for using spatially structured models.

- WCPO-wide ?
- Domestic v Regional v Charter v Bilateral v Near Shore v Distant Water?
- Commercial v Recreational v Artisanal v Illegal?
- Longline v Purse-seine v Gillnet v Troll v Handline v Pole?
- Tropical v Temperate ?

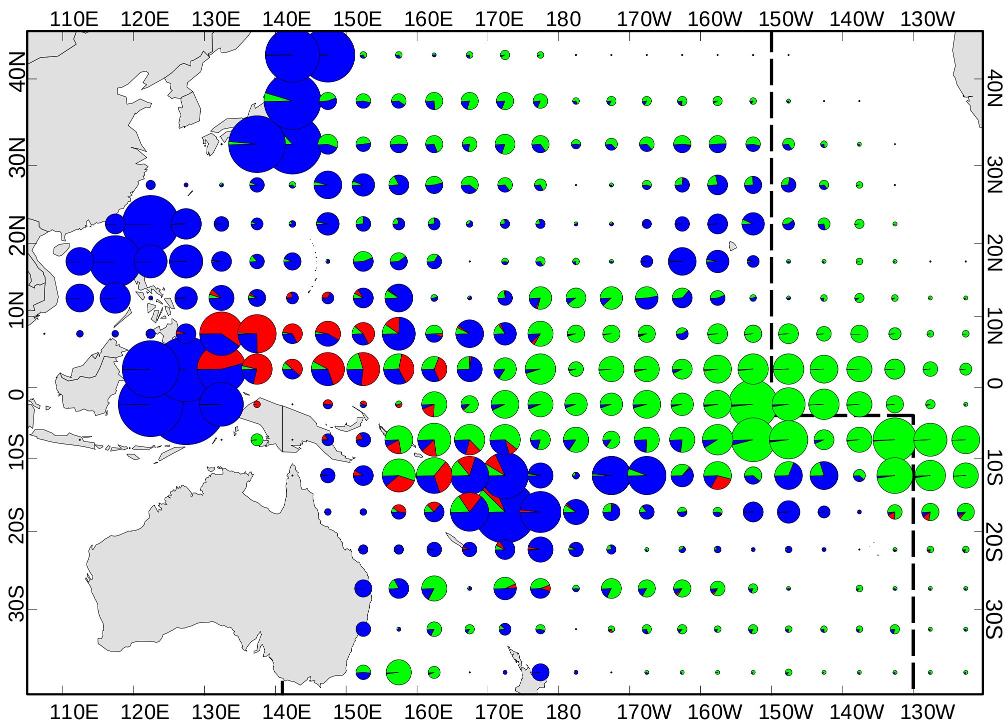
Total Catch



Purse Seine Fishery

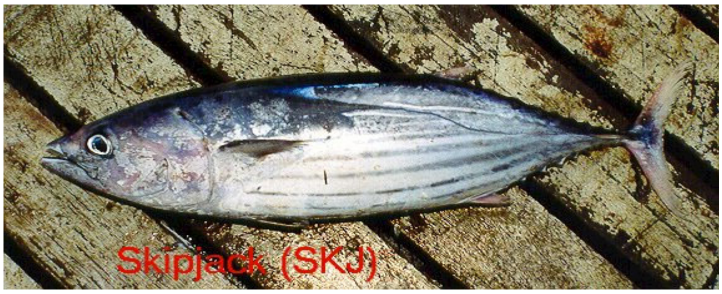


Longline Fishery



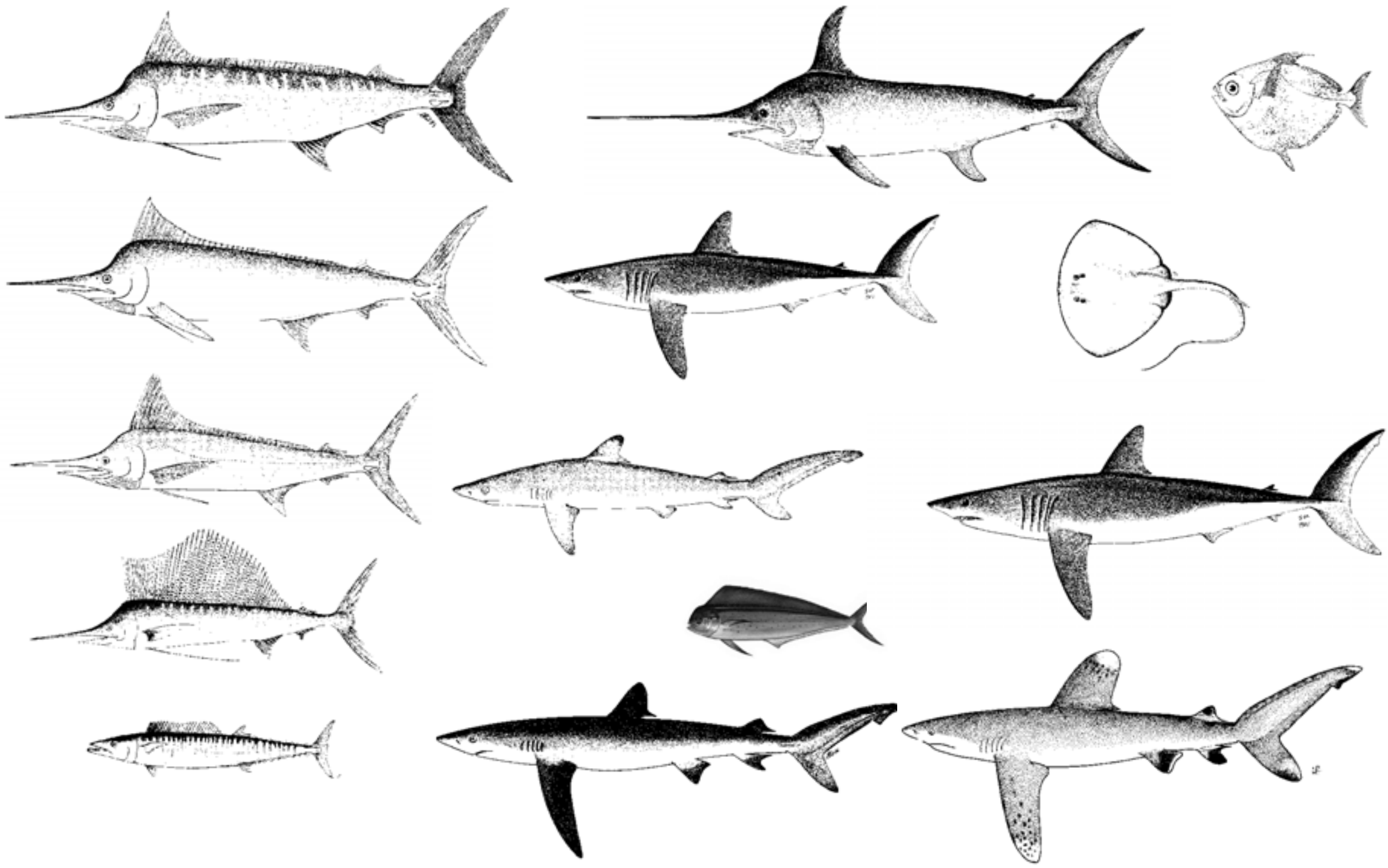
Distant-water fleets (green), foreign-offshore fleets (red) and domestic fleets (blue) for the period 2000–2013

Target Species



Multiple target species and gears complicates fisheries management decision making. Management measures to deal with one species generally have implications for the fisheries for other target species also.

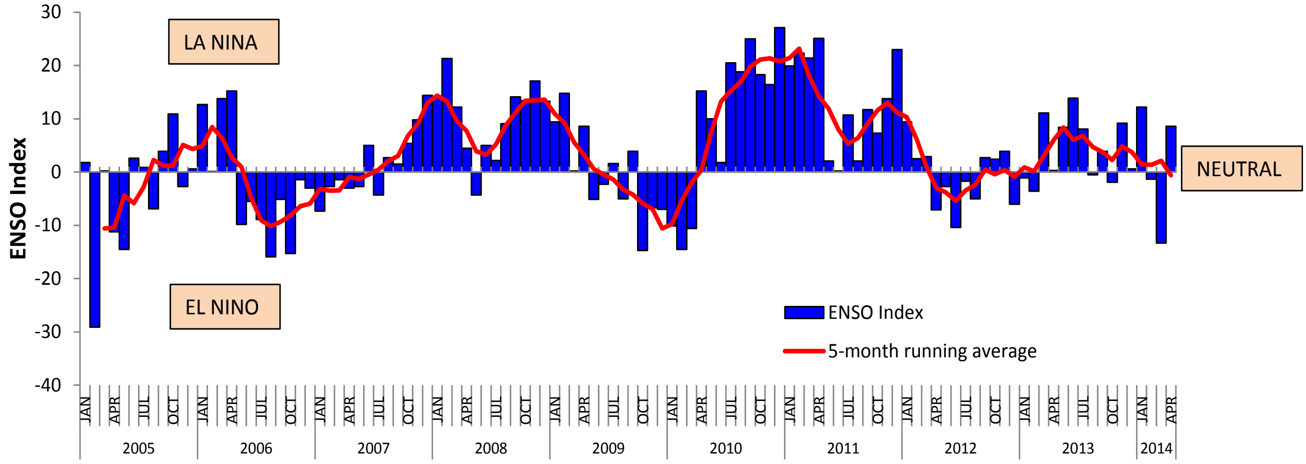
Bycatch Species



Climate and Oceanography – Key Environmental Drivers

- Climate processes
- Surface currents
- Sea Surface Temperature (SST)
- Primary productivity
- Mixed layer depth
- Dissolved oxgen

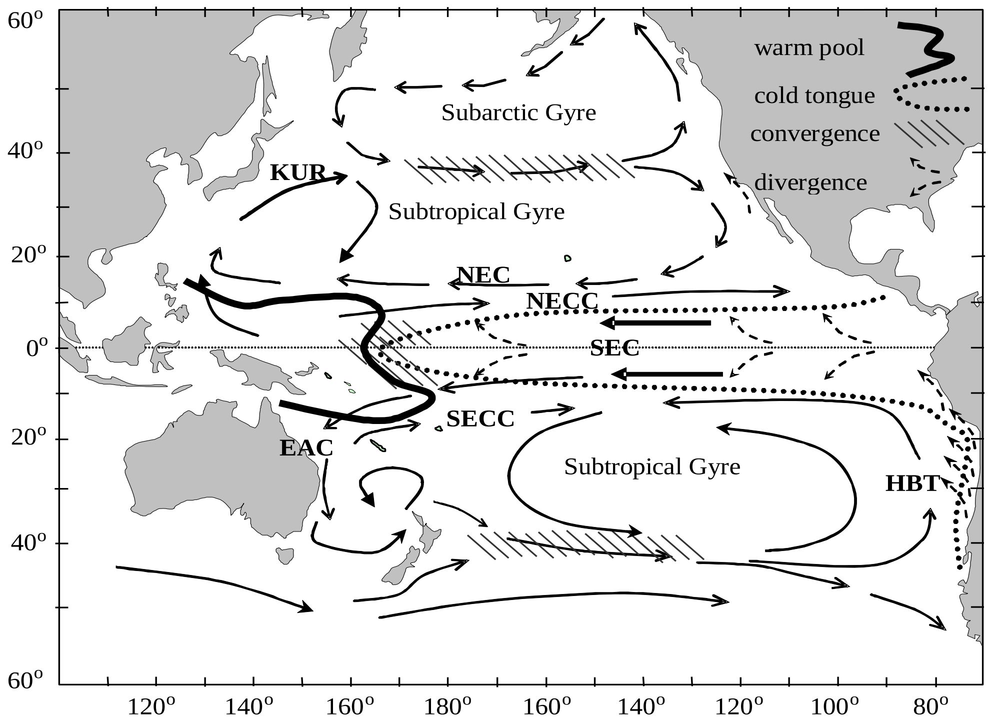
Climate and Oceanography



Global and Pacific climate varies both seasonally and interannually, the latter largely as a result of the El Nino Southern Oscillation phenomena, which see climate conditions shifting between El Nino, neutral and La Nina conditions. These climatic shifts accompany large scale oceanographic shifts, including the east-west movement of the Western and Central Pacific "warm pool" and the ecosystem associated with that.

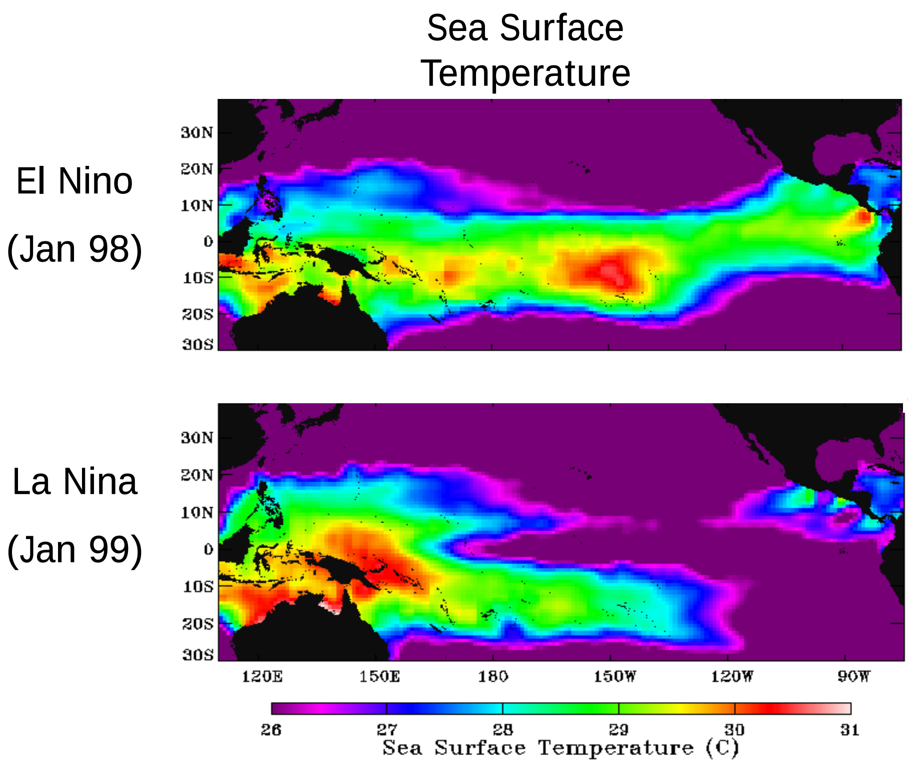
This climatic and oceanographic variability plays a major role in tuna movement and population dynamics, with flow on consequences for the fisheries that target them.

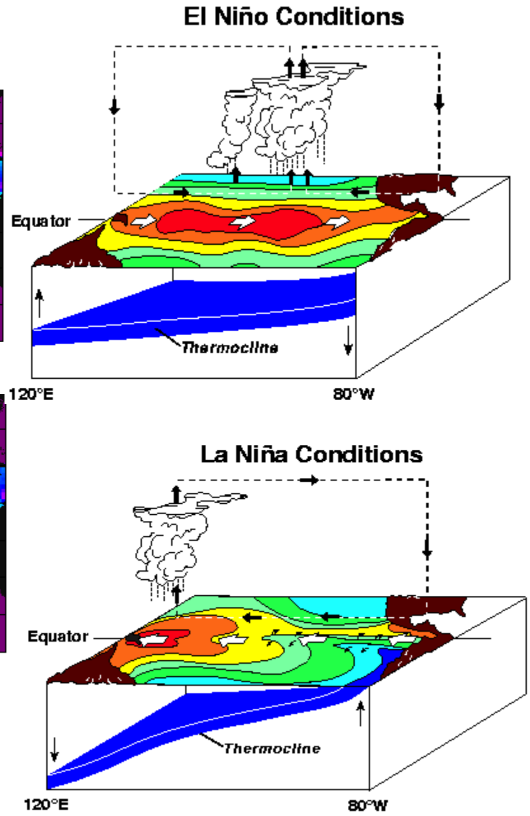
Surface Currents



- Three major current features are the North Pacific Subtropical Gyre, the South Pacific Subtropical Gyre, and the equatorial currents
- The strength and direction of the equatorial and subequatorial currents is dependent on the prevailing winds and climatic conditions
- Major shifts occur in currents due to changes between South East Trade Wind and North West Monsoon seasons
- The strength and direction of the wind driven equatorial and sub-equatorial currents play a major role in the location and size of another major oceanographic feature of the Pacific, the warm-pool/ cold tongue convergence zone.

Sea Surface Temperature and Climate Variability





Primary productivity and climate variability

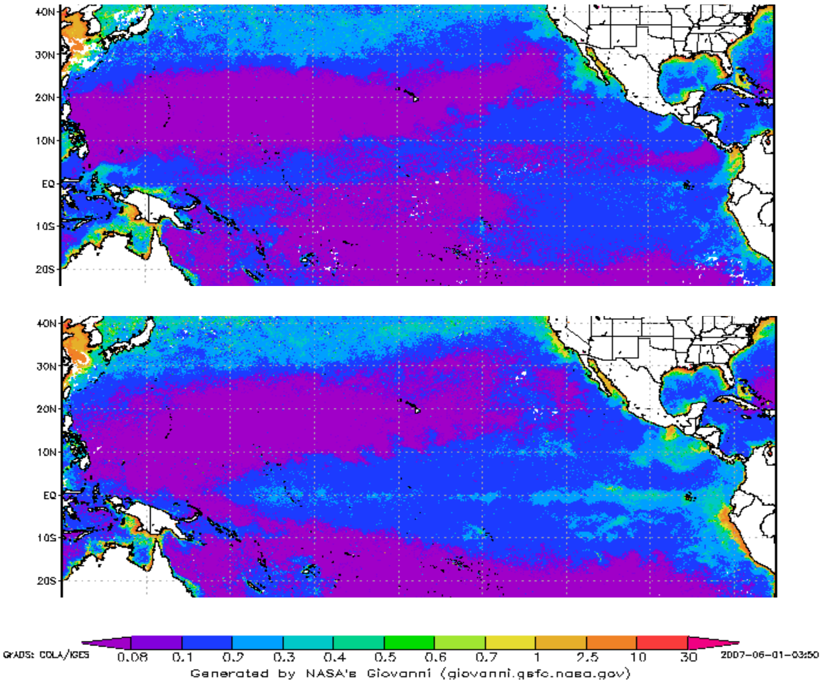
Chlorophyll a

El Nino

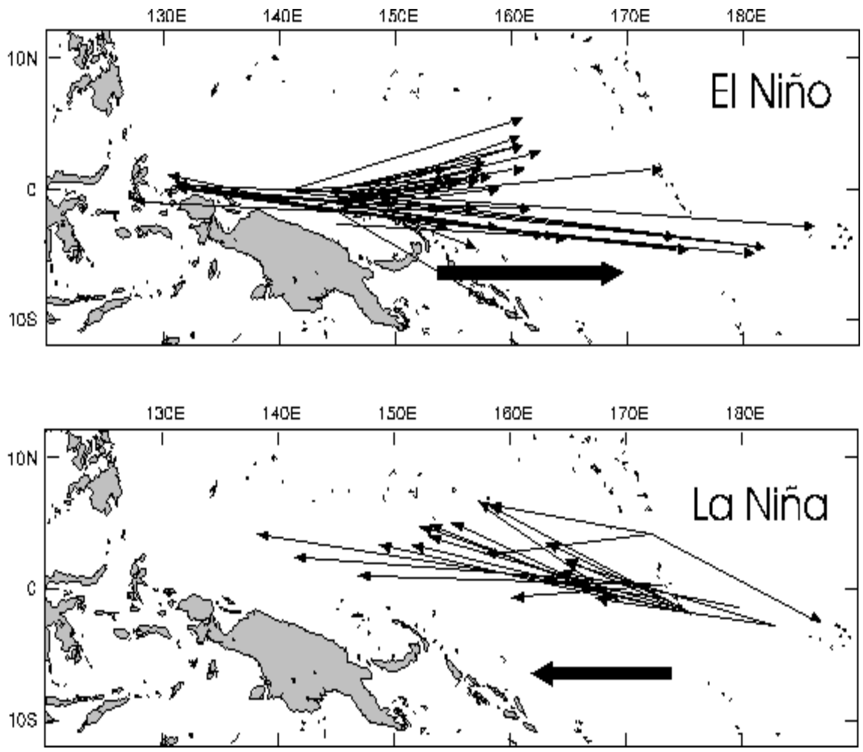
(Jan 98)

La Nina

(Jan 99)



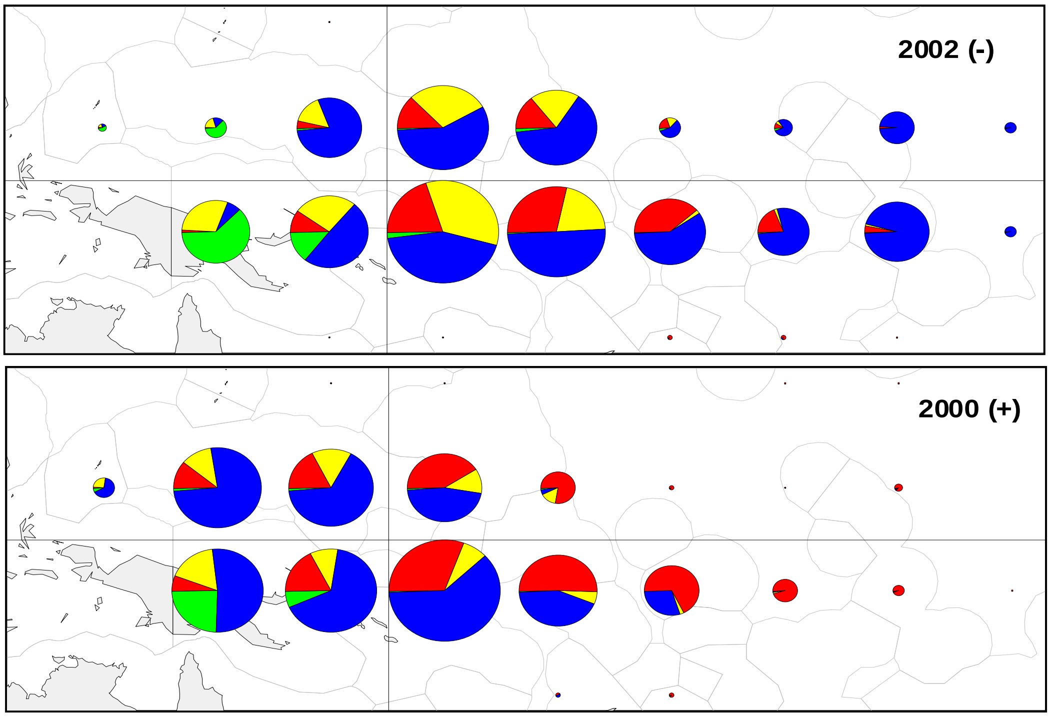
Environmental Impacts on Fisheries



Skipjack movement during El Nino and La Nina periods

Purse Seine Fishery, Climate and Oceanography

Eastwards displacement during El Nino and westwards contraction during La Nina



Blue – unassociated sets ; Red – drifting FADs; Yellow – logs; Green – anchored FADs

Summary

Oceanic fisheries in the WCP-CA are very complex, due to:

1. Multiple Political and Management Boundaries
2. Numerous Fisheries (Gear, Area, Species, Flag combinations)
3. The large number of species (target and bycatch)
4. The complexity of the pelagic ecosystem
5. Oceanography and climate influences on both the fish (recruitment, movement etc.) and the fishery

Understanding the complexities across these factors is critical to building and undertaking a stock assessment.

Chapter 2

An introduction to fish population dynamics

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)

Which is the stock and which is the population?

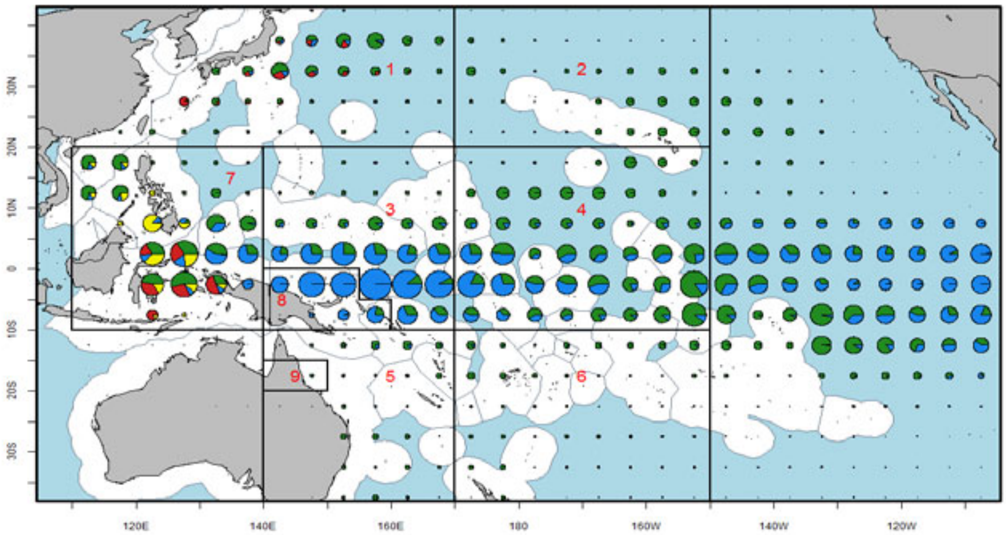


Figure 6. Bigeye tuna catch distribution (2003-2012) by 5 degree squares of latitude and longitude and fishing method: longline (blue), purse-seine (green), pole-and-line (red), and other (yellow). Overlayed are the regions for the assessment model. SC10-SA-WP-01

Why do we need to understand how unexploited populations behave?

"To understand how populations will respond to exploitation, we need to appreciate how they will behave when unexploited"

Hilborn and Walters, 1992

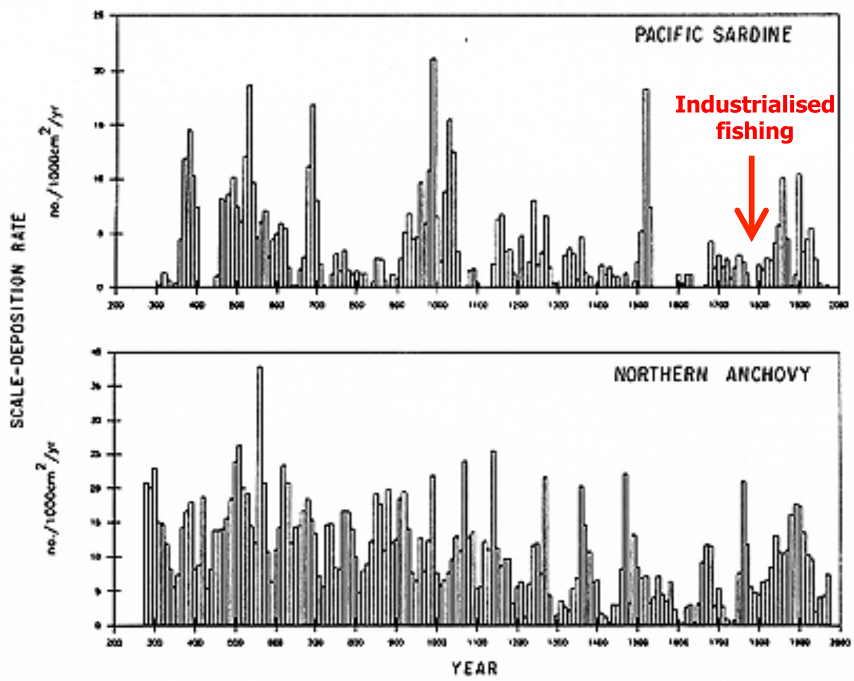
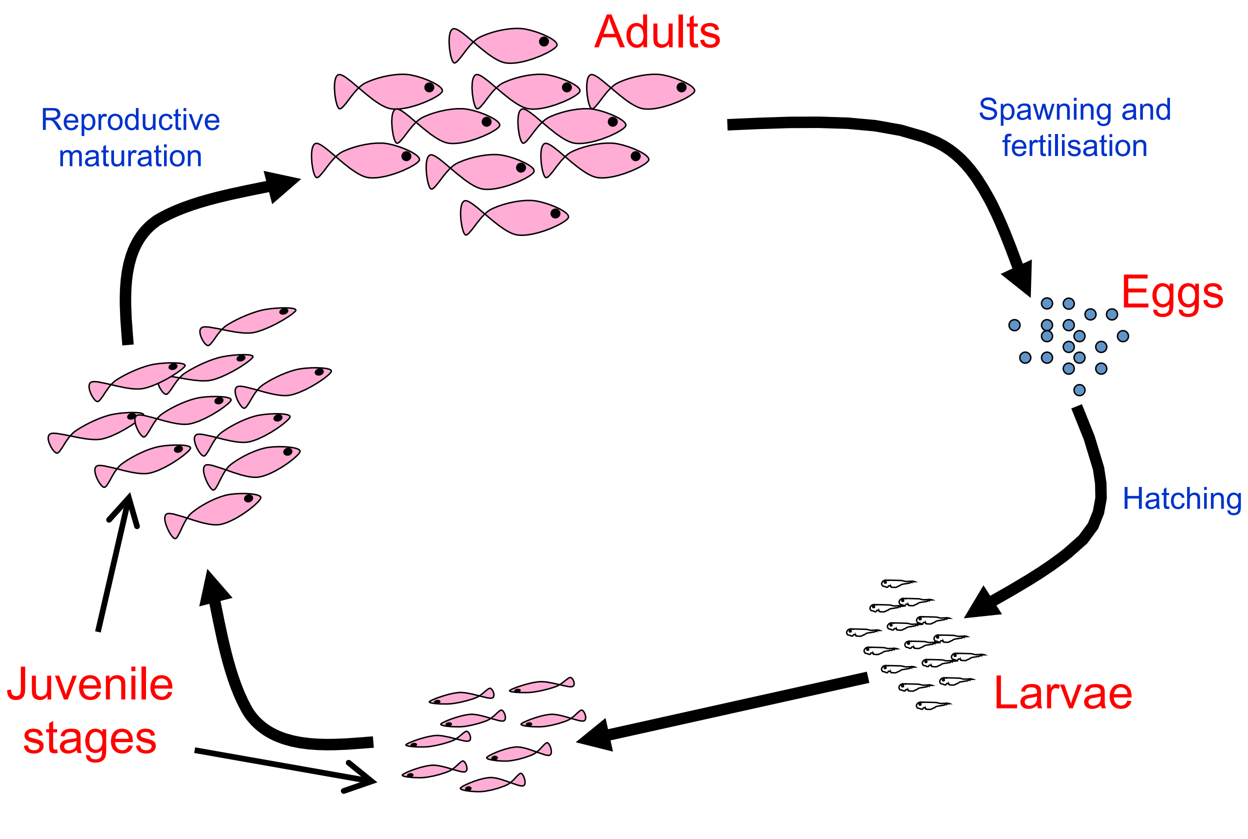


Figure 11. Time series of sardine and anchovy scale deposition rates. (from Baumgartner et al. 1992)

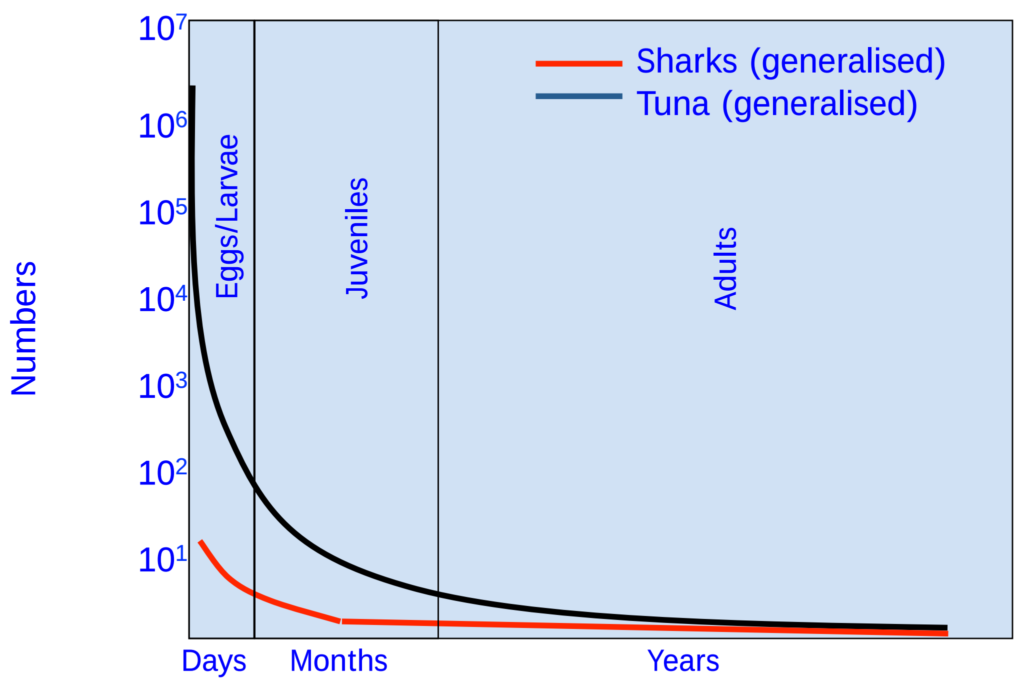
A generalised tuna life cycle



Variations in fish life cycles

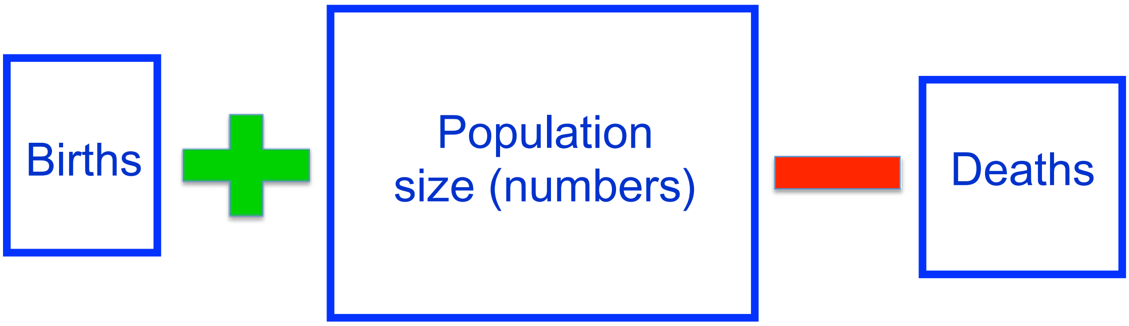
Within this basic strategy there is some variation, even across large pelagic species taken by tuna fisheries. Two well known species groups with very contrasting life histories are the tunas and sharks.

Big implications for population dynamics and for resilience to fishing.



Basic population dynamics

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



How do we explain what we will have next year?

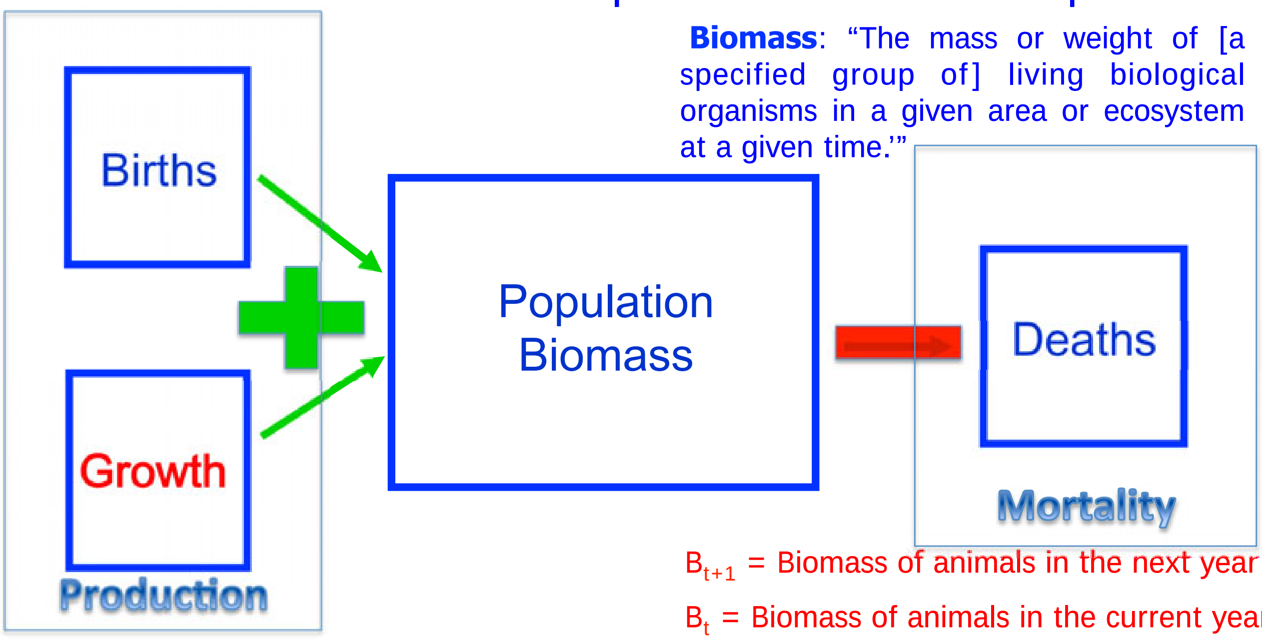
- Number of animals in the next year (N_{t+1})
- Number of animals in the current year (N_t)
- "Births" after one year (R)
- Natural deaths after one year (M)

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

Basic population dynamics

A biomass version of the previous model: conceptual

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



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

B_{t+1} = Biomass of animals in the next year

B_t = Biomass of animals in the current year

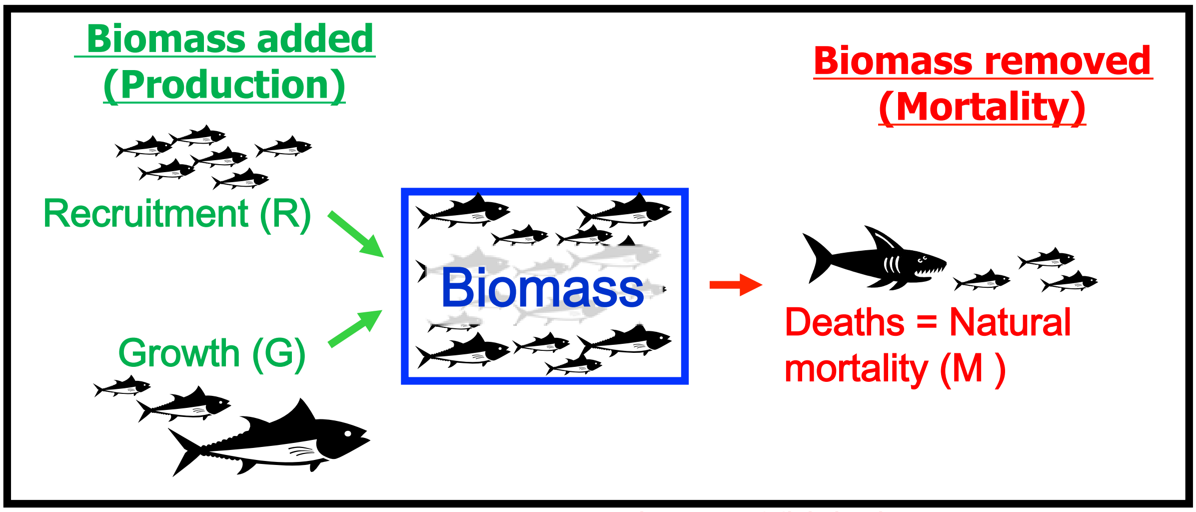
R = Biomass of newborns after one year

G = Growth (in mass) of age 2+ animals

M = Natural deaths after one year

Basic population dynamics

If we think of the biomass model for a tuna population it can be represented like this:



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

B_t+1 = Biomass of fish in the next year

B_t = Biomass of fish in the current year

R = Biomass of new recruits (e.g. in one years time)

G = Additional biomass due to growth of current fish

M = Biomass of fish from current population that died.

Basic population dynamics

A biomass version of the previous model: mathematical

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

Bt+1 = Biomass of fish in one year,

Bt = Current biomass;

R = Biomass of new recruits in one years time,

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).

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

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 and resultant larvae growing and surviving through each of the subsequent stages?

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

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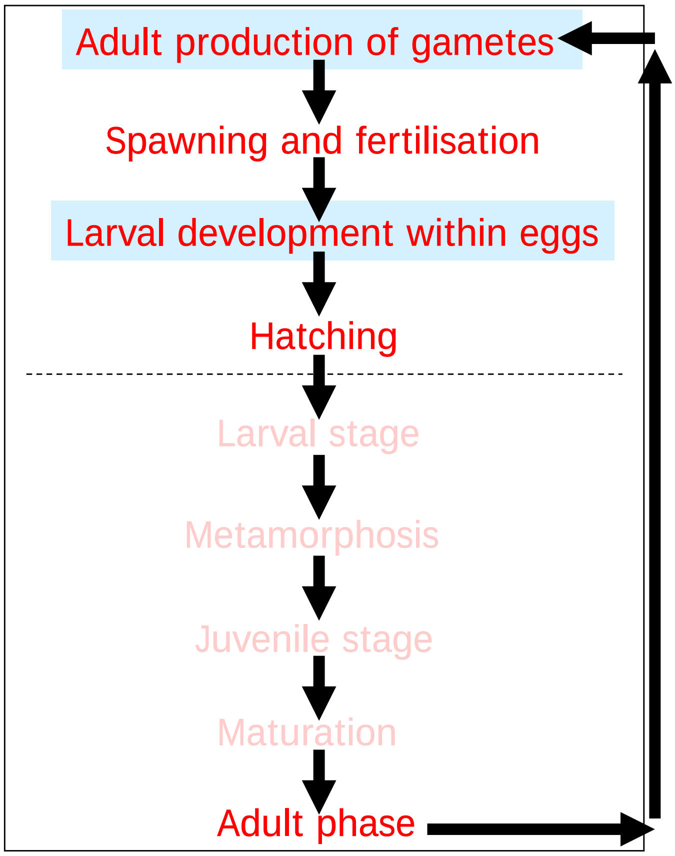
Recruitment (R)

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

Fecundity ("quantity")

Adult condition ("quality")

Environment ("good fortune")



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

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Recruitment (R)

Some processes that affect larval and juvenile survival

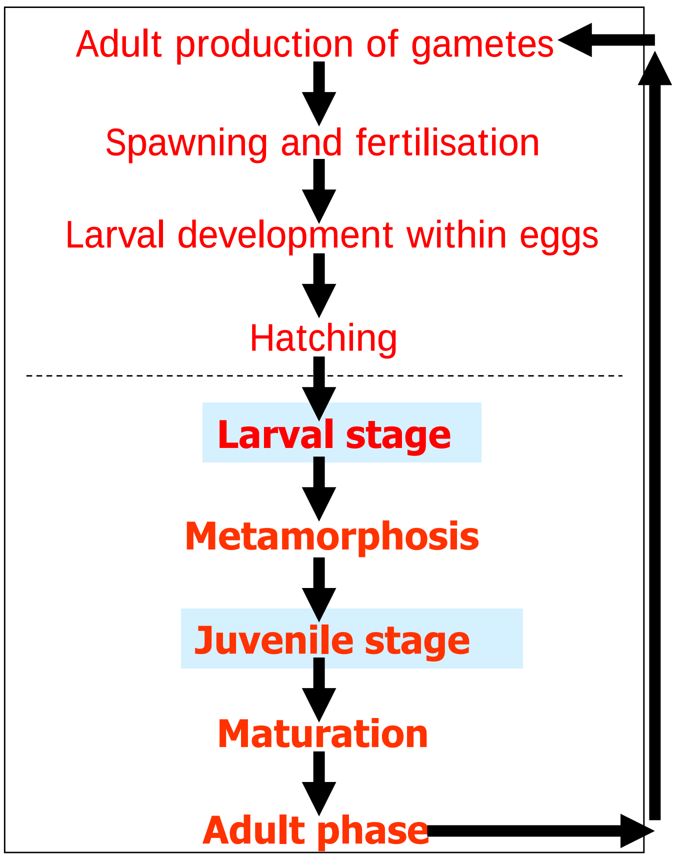
Biotic factors:

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)

SPC CPS

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 (this is the relationship between the number of spawning adults and the number of offspring they produce).**

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

Recruitment (R)

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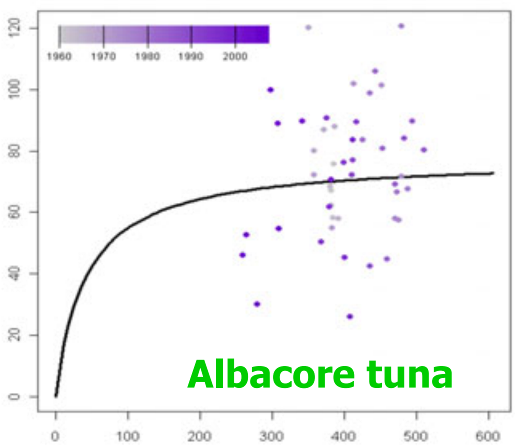
The stock-recruitment relationship

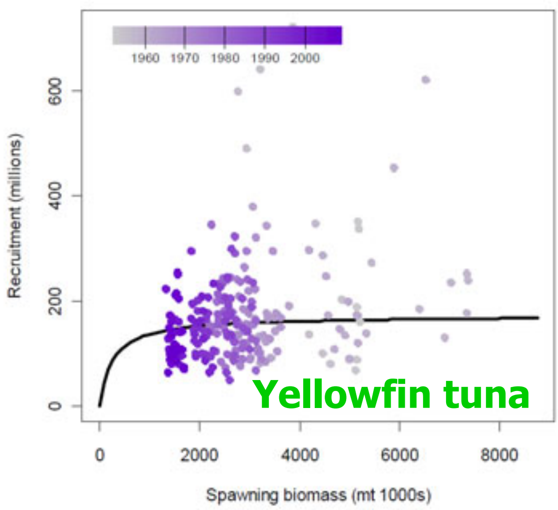
Two general theories:

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)





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

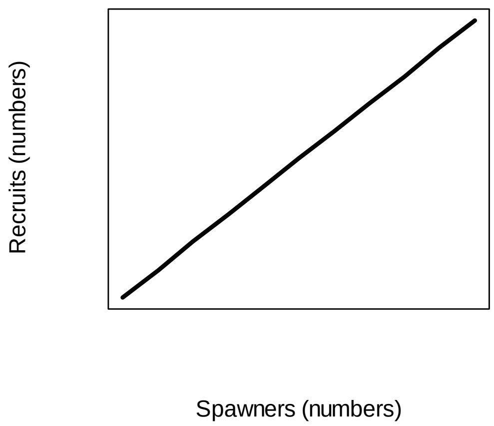
Recruitment (R)

The stock-recruitment relationship

Number of surviving offspring

Number of recruits per spawner

DI



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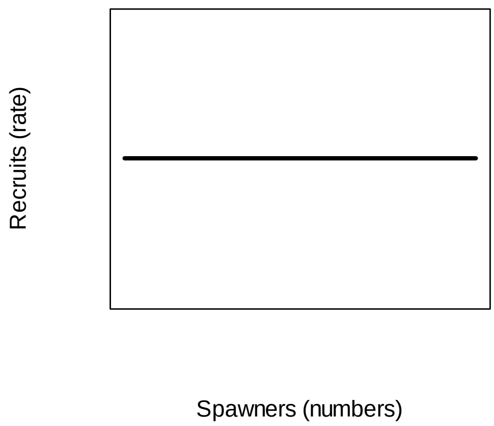

$B_{t+1}=B_t+R+G-M$

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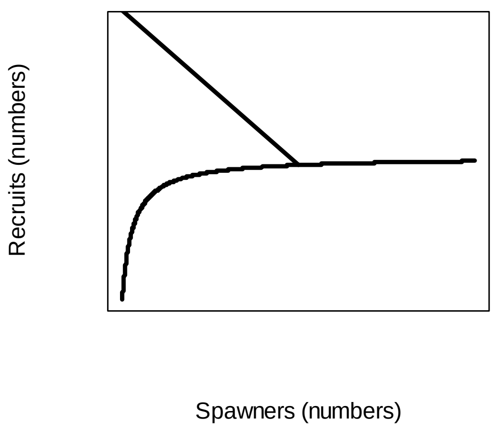
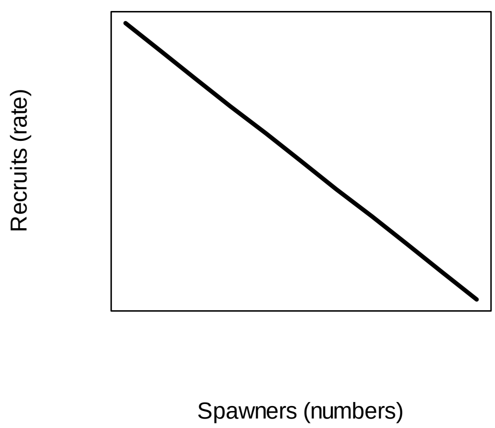


DD



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.

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

Natural mortality (M)

SPC CPS

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 that this typically refers to mortality **post-recruitment**
Mortality during pre-recruitment life-history stages is usually dealt with when assessing recruitment.

How do we express natural mortality?

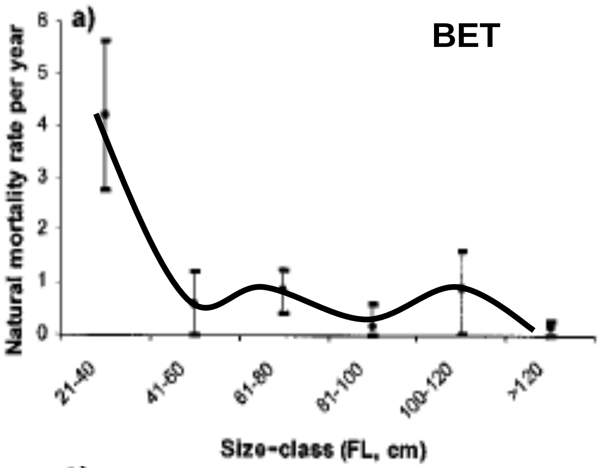
Natural mortality is usually expressed as an **instantaneous rate**. This is a relative change in the proportions of the size or age classes that suffer natural mortality during each time period.

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 provides clues to understanding the **"resilience"** of a stock to fishing.

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

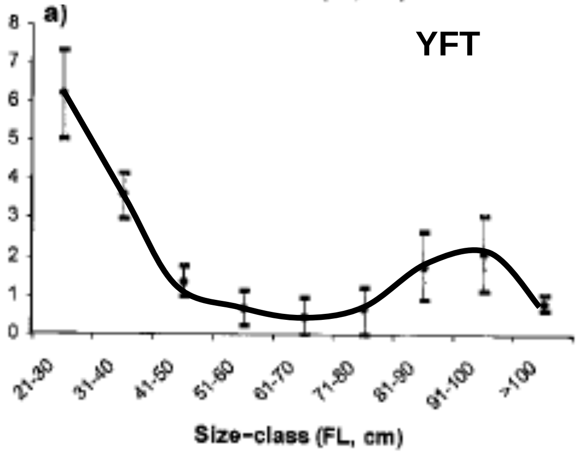
Natural mortality (M)

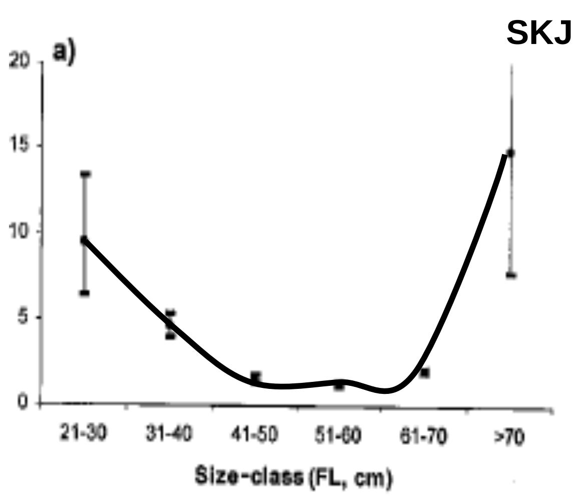
SPC CPS



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





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

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

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

Growth (G)

What is growth?

All fish grow. Growth is usually considered to mean a change in fish size in length or weight with age. Growth is an important process to understand as it:

- **Influences a range of population processes**
  E.g., natural mortality and 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. Note that we refer to the vulnerability to the fishing gear of fish of different size or age classes in the population as **"selectivity".**

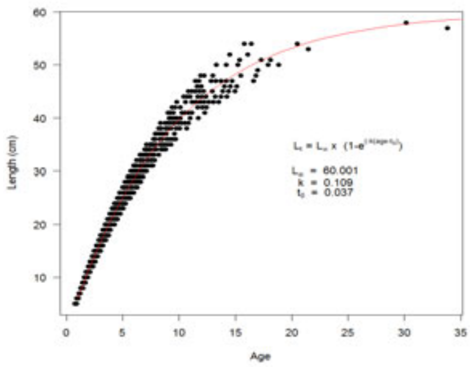
$B_{t+1}=B_t+R+G-M$

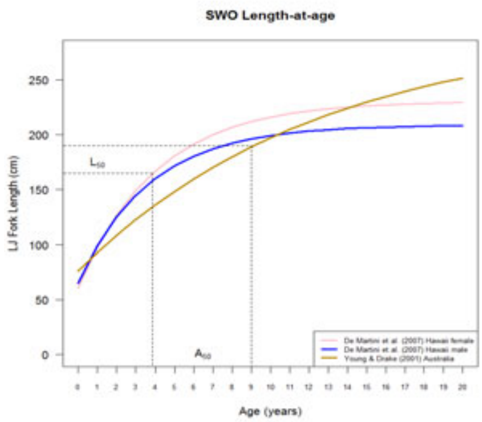
Growth (G)

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.



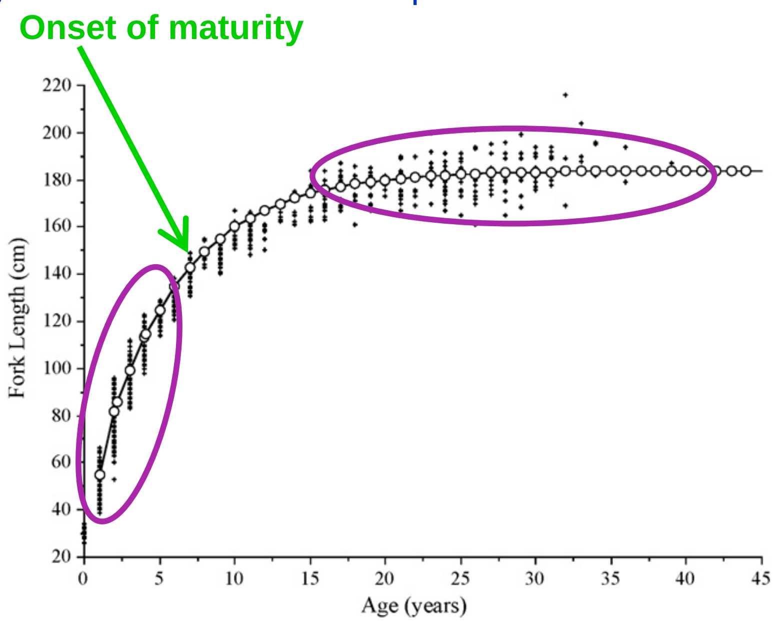


$B_{t+1}=B_t+R+G-M$

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

Movement—why might we bother?

As fish population dynamics requires us to know about changes in biomass in space and time, having a good understanding of fish movement is important.

Movement in fish population dynamics usually involves simply estimating the balance between immigration and emigration between stock areas or sub-areas in order to estimate biomass within a particular place.

We often assume that their is no net movement into or out of our stocks. However, a population model developed for a particular stock assessment may need to consider movement **within** the stock area. It may be necessary to look at the population by subareas and considering fish movement may be important to understand exchange between those parts.

In short, fish movement can affect the spatial distribution of fish biomass on a variety of spatial and temporal scales.

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**

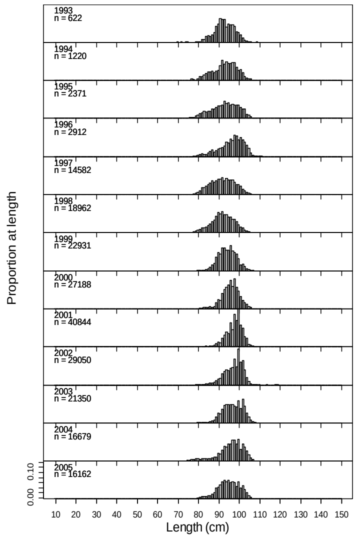
   Migrate to spawning areas (e.g. SBT), an ontogenetic change in preferred habitat (e.g. albacore), a response to seasonal (e.g. albacore) or long-term changes in prevailing environmental or oceanographic conditions (e.g. skipjack) , etc.

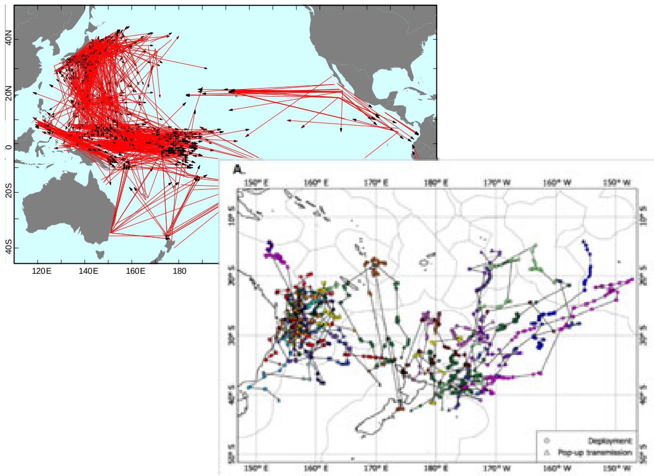
How is movement monitored?

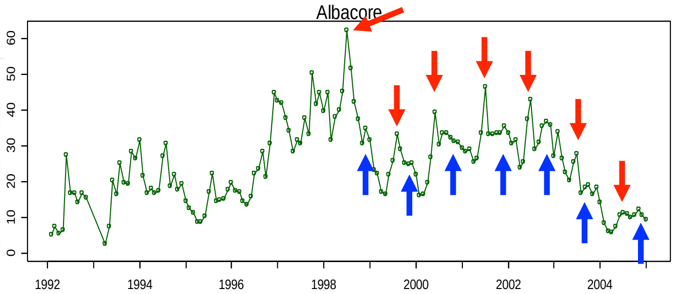
1. Size –frequency analyses

2. CPUE analyses

3. Tagging analyses

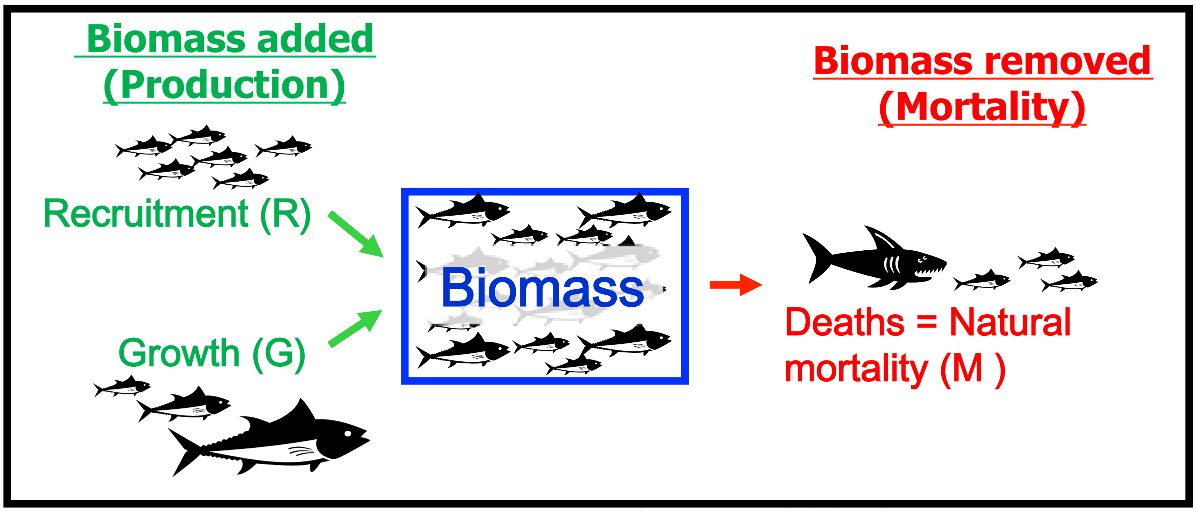






Fished Populations

Basic population dynamics model



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

B_t+1 = Biomass of fish in the next year

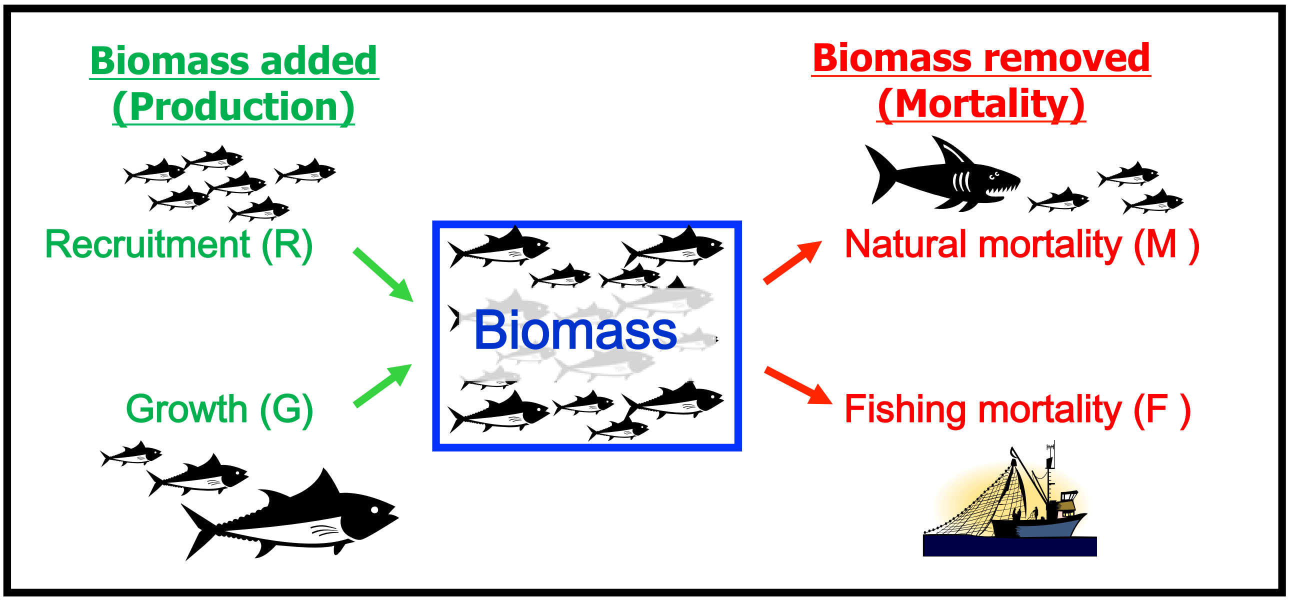
B_t = Biomass of fish in the current year

R = Biomass of new recruits (e.g. in one years time)

G = Additional biomass due to growth of current fish

M = Biomass of fish from current population that died.

Basic population dynamics model



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

Fishing and the "balance of nature"

The balance of nature

The idea that nature, that ecosystems and their living populations, are in balance, is a myth.

Nature is stochastic

Ecosystems and the interactions between their components are **variable** ("stochastic"), and the range of variability itself varies depending on the system and the component.

The degree of population variability depends on the time scale we are considering.

Fishing stochastic populations

Sardine and anchovy populations show natural fluctuations over 2000 years from the study of scale deposition in marine sediments

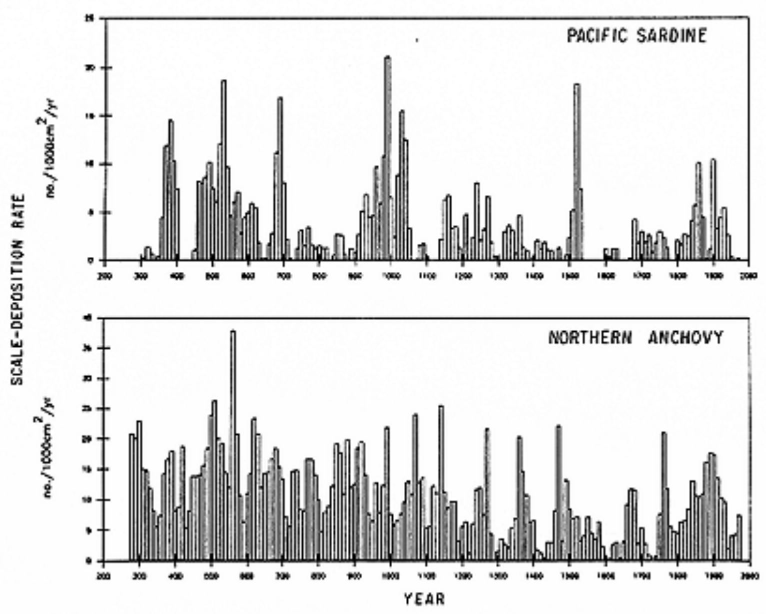
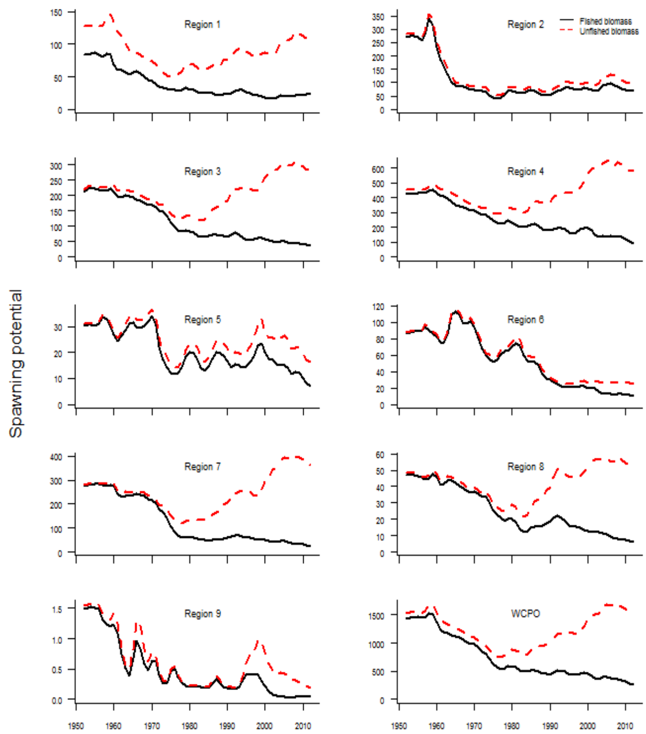


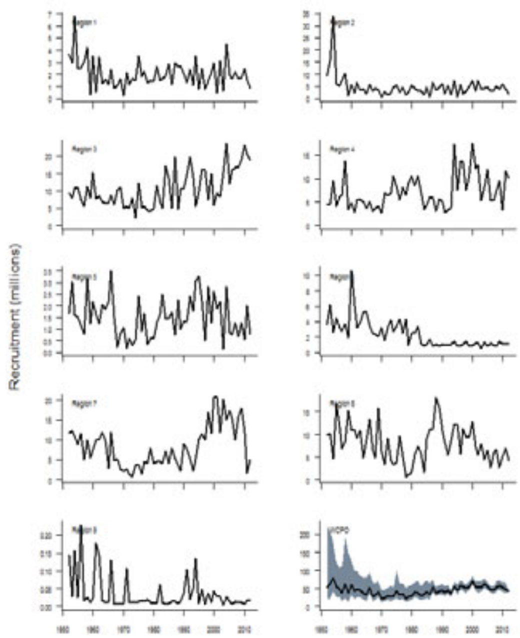
Figure 11. Time series of sardine and anchovy scale deposition rates. (from Baumgartner et al. 1992)

Fishing stochastic populations

Bigeye tuna – fishery impacts analyses of estimated biomass with and without the impacts of fishing (SC10-SA-WP-01, 2014)



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



Fishing impacts: nature vs humanity

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.

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

Fishing impacts: nature vs humanity

2. Observed change may not be due to natural causes

It is equally dangerous to assume that natural variability is causing the observed change. One might then miss an opportunity to implement changes to the fishery that might ensure sustainability of catch 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 influenced by both fishing and by environmental or other factors (e.g., eastern pacific sardine and anchovy)

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

Fishing impacts: nature vs humanity

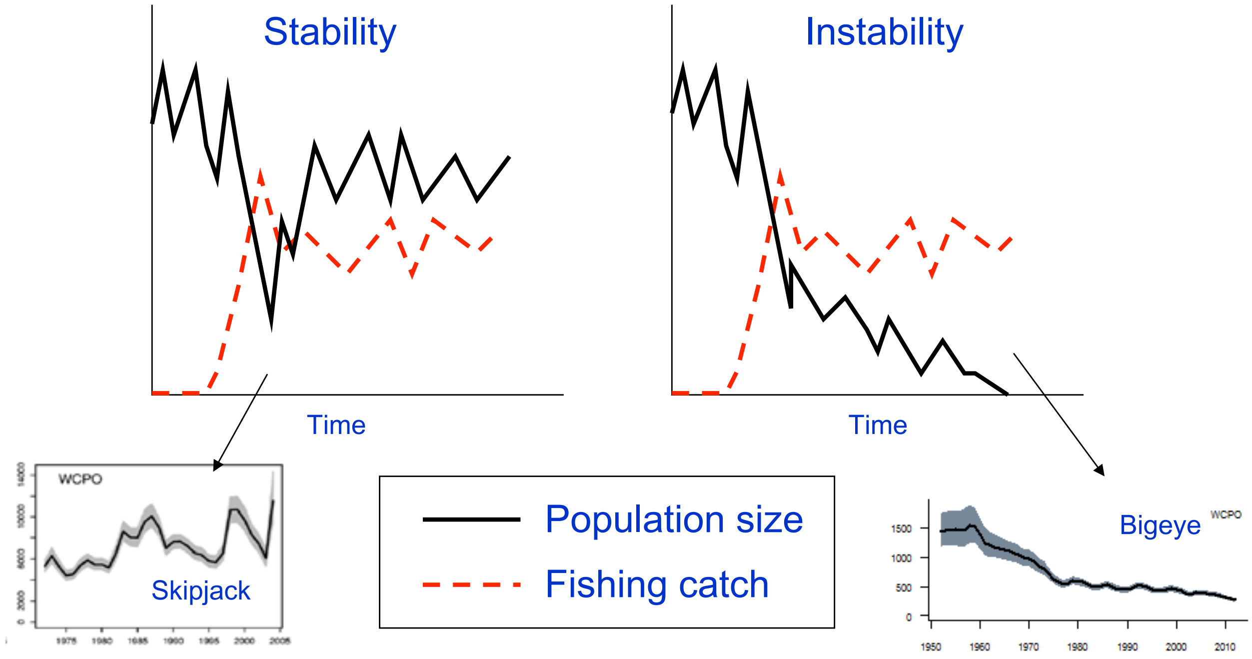
4. However, fishing can affect natural dynamics

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!

Population states

Stability versus instability of fished populations



= resilient to fishing pressure

= susceptible to overfishing

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 of depleting that population. 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....

....**How do we do this?**....

Lets compare and contrast the tropical tunas and sharks as an example

Stability and Resilience

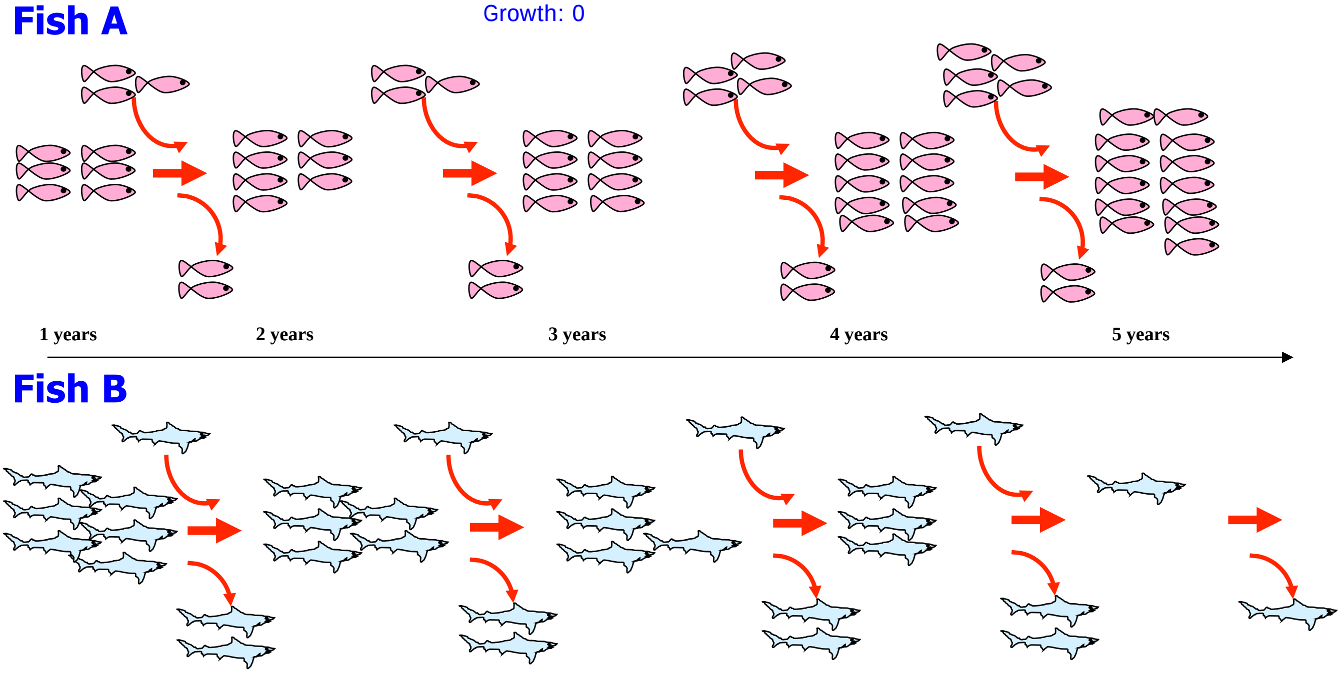
Examples:

	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 species
Life span	4-16 years	20-60 years

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

Resilience: the importance of biology

	Fish A	Fish B
Age to maturity:	1 years	1 years
Fishing Mortality: 2 per year (quota)		
Natural Mortality: 0		
Recruitment:	**3/6**	**1/6**
Growth: 0		



Variations among WCPO tuna

	Yellowfin	**Bigeye**
Spawning mode	Multiple (year round)	Multiple (year round)
Fecundity	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	Multiple (*but seasonal*)	Multiple (year round)
Fecundity	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	~15+yr	~4yr
Recruitment to fishery	~2yr(troll), 5+(LL)	0.5-1yr(PS)

Overfishing

OK, then, what is "sustainability"?

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

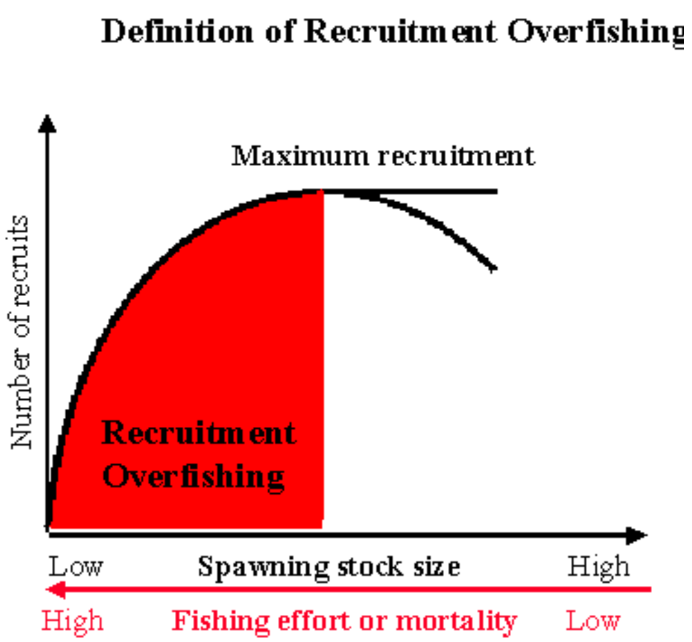
Overfishing

(i) Recruitment overfishing

A situation in which the rate of fishing is (or has been) high enough that annual recruitment to the exploitable stock has become significantly reduced.

The situation is characterized by a greatly reduced spawning stock, a decreasing proportion of older fish in the catch, and generally very low recruitment year after year.

If prolonged, recruitment overfishing can lead to stock collapse, particularly under unfavourable environmental conditions. (Restrepo 1999)



http://www.oceansatlas.com/

Overfishing

(ii) Growth overfishing

This occurs when too many small fish are caught, usually because of excessive effort and low gear selectivity (e.g. 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.

Key messages

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

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 biology of the population and its resilience. Eg. Does the species grow quickly or slowly, mature early or late, become vulnerable to the fishery when young or older, have a short or long lifespan etc.

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

4. Where catch levels lead to a drop in recruitment, catch is "unsustainable" and "overfishing" is occurring.**

Chapter 3

Key concepts of stock assessment modelling

Overview of key concepts

1. Fish stocks: What are they?
2. What is stock assessment?
3. What is a stock assessment model?
4. How does a stock assessment model “work”?
    1. Mathematical component (and a note about equations)
    2. Statistical component (and an introduction to abundance indices and model fitting)
5. Types of model
    1. WCPO tuna models
    2. Other models

Concept 1: The 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.

Definition of a "stock"

"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.

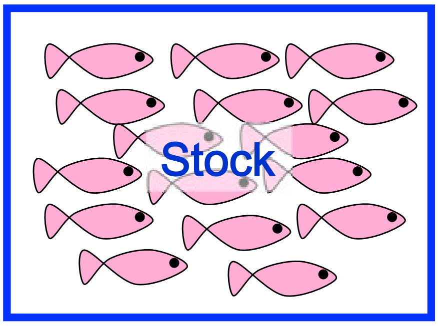
The unit should not be so large as to contain many genetically distinct races of subpopulations within it."

Hilborn and Walters (1991)

Concept 1: The fish stock

Why do we manage and assess fisheries at the level of a stock?

1. Little or no external influences, self contained
2. Scientifically meaningful
3. Management convenience



Concept 1: The fish stock

How do we identify a fish stock?

It's a very difficult task ………often little clear information. We can use:

- Genetics
- Tagging
- CPUE analyses
- Morphometrics

Often stock assessments are conducted on "stocks" where there is some uncertainty regarding the boundaries of the stock (e.g. WCPO v EPO bet/yft; SWPO v SPO v PO stm)

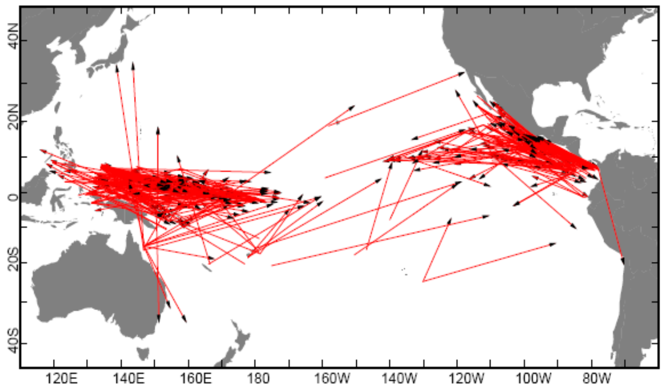
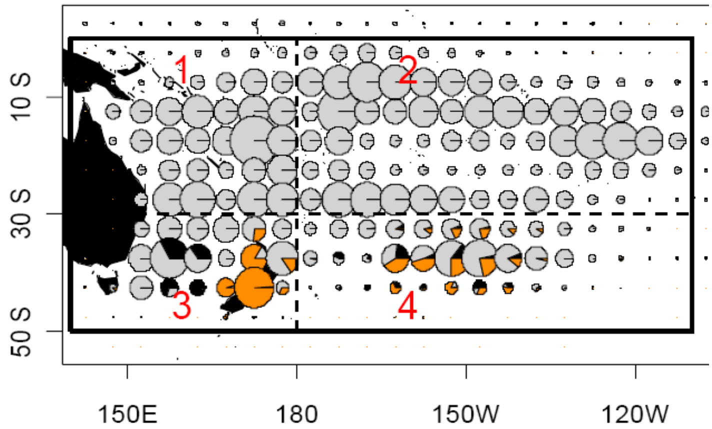


Figure 1. Long-distance (>1,000 nmi) movements of tagged yellowfin tuna.



Concept 1: The fish stock

Tuna stocks in the WCPO

Yellowfin tuna
Limited mixing and genetic variation found

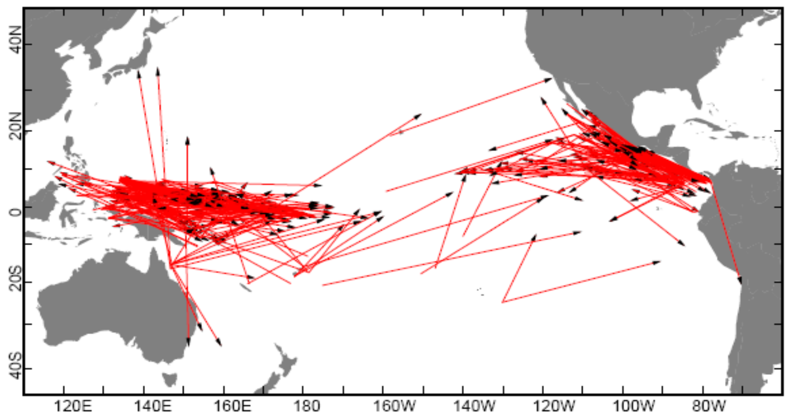
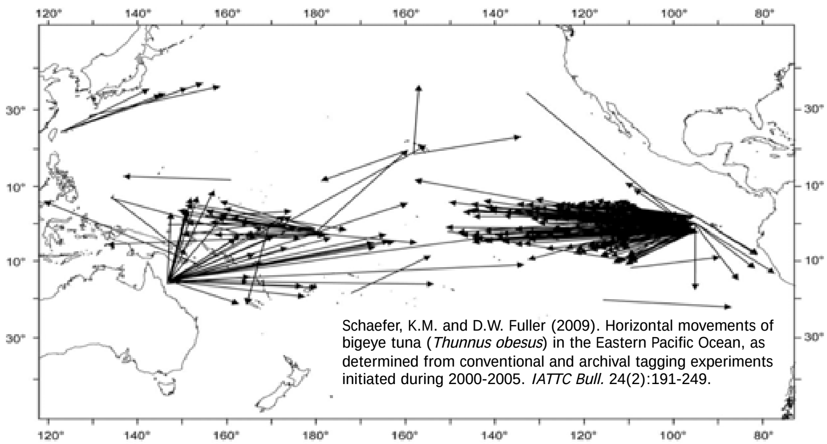


Figure 1. Long-distance (>1,000 nmi) movements of tagged yellowfin tuna.

Bigeye tuna
Mixing less limited and no genetic variation found



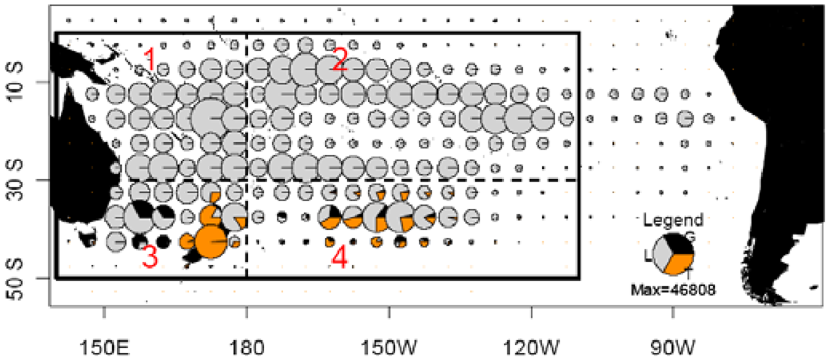
Schaefer, K.M. and D.W. Fuller (2009). Horizontal movements of bigeye tuna (*Thunnus obesus*) in the Eastern Pacific Ocean, as determined from conventional and archival tagging experiments initiated during 2000-2005. *IATTC Bull.* 24(2):191-249.

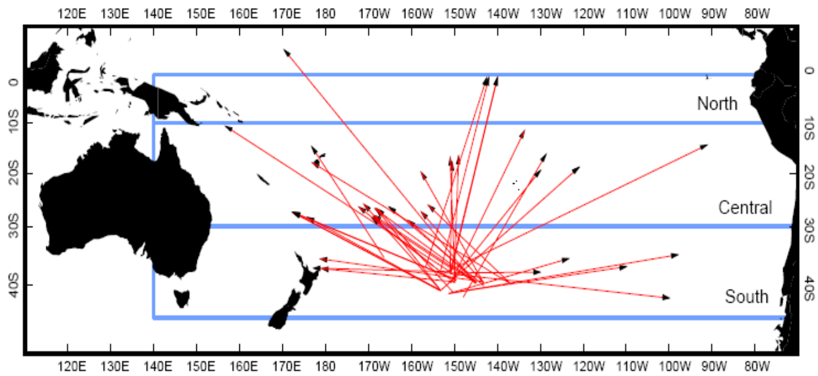
Concept 1: The fish stock

Tuna stocks in the WCPO

Albacore tuna

- Low catch and CPUE in equatorial waters suggests limited adult mixing
- No tag exchange betwee north and south PO tagged fish
- Discrete spawning areas (based on larval surveys) between North and south Pacific





Concept 1: The fish stock

Tuna stocks in the WCPO: Skipjack tuna

There is uncertainty regarding skipjack stock structure in the Pacific, but given a lack of evidence for trans basin movements and generally localised tag returns in general, mixing is thought to be limited within generations (short lived species) and in the medium term, meaning the WCPO “stock” is assessed as such for management purposes.

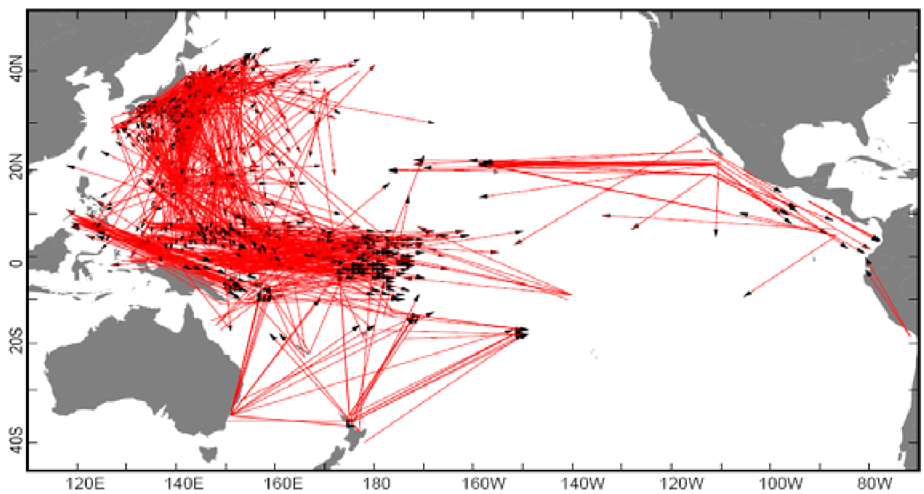
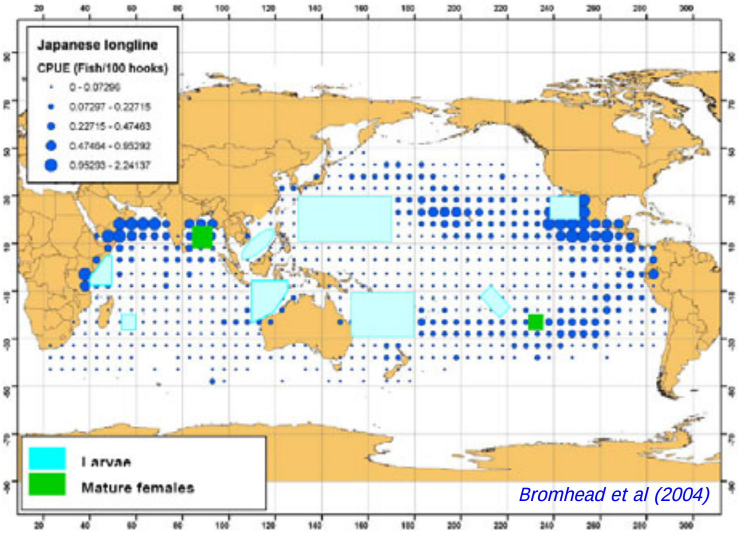


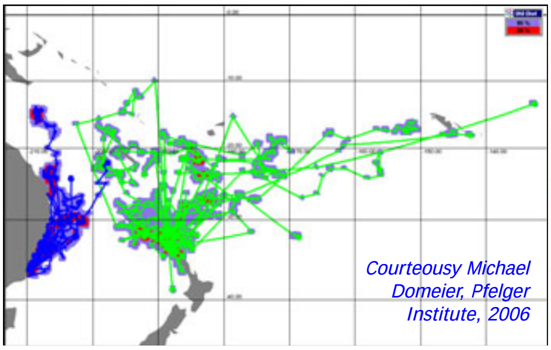
Figure 1. Long-distance (greater than 1,000 nmi) movements of tagged skipjack.

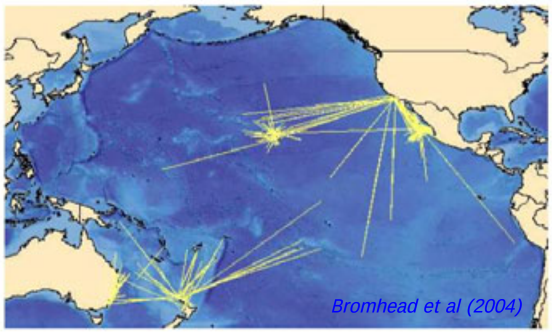
Concept 1: The fish stock

Striped marlin

Equatorial CPUEs low, genetic variation between SWPO and NEPO, discrete spawning areas?, no transbasin tag returns, no transbasin movement indicated by 50 PSAT tags, all indicate limited mixing and a potential southwest Pacific stock (for management purposes)







Concept 2: 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.

***Group discussion*

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

Concept 3:
The stock assessment model

A stock assessment model provides a mathematical simplification of a very complex system (fish and fishery), to help us estimate population changes over time in response to fishing

Concept 3:
The stock assessment model

Overview:

In explaining to you what a stock assessment model is, we are going to discuss the following:

1. What is an **equation**? (because stock assessment models comprise lots of them)
2. What is a [mathematical] **model**?
3. What is a **stock assessment model**?
4. How does a stock assessment model "work"?
    a. **Mathematical** component
    b. **Statistical** component (and an introduction to **abundance indices** and **model fitting**)
5. What are the different types of stock assessment model?

Concept 3:
The stock assessment model

1. Equations

An equation can be thought of as simply being a sentence, but the words have been replaced by symbols....for example:

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

If we know what the symbols mean, we can read the sentence!

"*Population biomass next year is equal to the biomass this year, plus biomass of new recruits in one years time, plus biomass of additional growth of this years fish, minus the biomass of fish that died of natural causes, minus the biomass of fish killed by fishing*".

Concept 3:
The stock assessment model

1. Equations

- Large stock assessment models can involve complex equations expressing mathematical and statistical functions which attempt to describe the interacting fishery and fish population processes.
- Interpreting those interlinking equations requires training in maths, statistics and computer programming...
- However, we don't need to have all that training to get a basic understanding of how stock assessment models work...

Concept 3: The stock assessment model

1. Equations

$$N_{t+1,a+1} = N_{t,a}e^{-(M_a + F_{t,a})}$$
$$F_{t,a} = q_t E_t s_a$$
$$C_{t,a} = N_{t,a}F_{t,a}w_a$$
$$R_t = (AS_t)/(b+S_t)$$
$$N_{t+1,1} = R_t$$
$$B_t = \Sigma N_{t,a}w_a$$
$$S_t = \Sigma N_{t,a}w_a o_a$$
$$VB_t = \Sigma N_{t,a}w_a s_a$$

We will focus on a very basic model of an exploited fish population during this workshop, which uses very simple equations to incorporate nearly all the major elements that typically comprise far more complex assessments, such as those conducted for tuna with MULTIFAN-CL in the Western and Central Pacific.

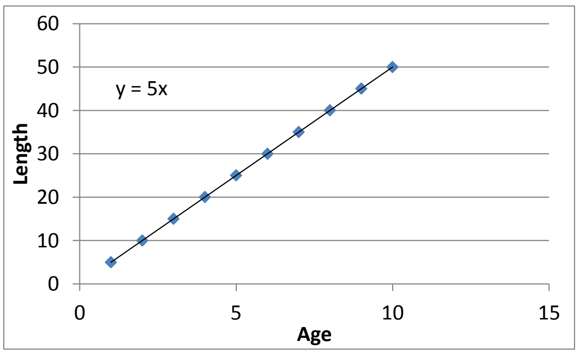
If you can gain an understanding of how our workshop model works, you will be a long way towards understanding the key principles and mechanics that underpin the Western and Central Pacific tuna assessment models.

Concept 3: The stock assessment model

2. What is a [mathematical] model?

A mathematical representation (or description) of a system or process that is used to help us understand the system and how the system works

Lets look at a really simple example of a model, in this case a model comprising only one equation:



This simple single equation model is a mathematical description of a biological process (growth!). It describes how quickly the animal gets bigger as it gets older. Easy!

(*NB: But a critical question we will address later is… how do we know if our model is "true" or realistic of the process it is trying to describe? ….we'll come back to this*)

Concept 3: The stock assessment model

3. What is a stock assessment model?

A stock assessment model provides a mathematical simplification of a very complex system (the fish population and fishery), to help us estimate population changes over time in response to fishing.

They serve as a tool to assist the provision of scientific advice to fisheries managers and policy makers in relation to the impact of fishing upon the status (health) of the stock (past, current, future), at the same time taking into consideration other factors influencing stock abundance (environmental impacts on recruitment etc).

Stock assessment models can be used to make predictions regarding the response of the stock to different **management actions**.

There are many different types of assessment model. In this workshop, we will concentrate on **age structured models**.

Concept 4: How does a stock assessment model work?

A stock assessment model can be considered to comprise two key components, these being:

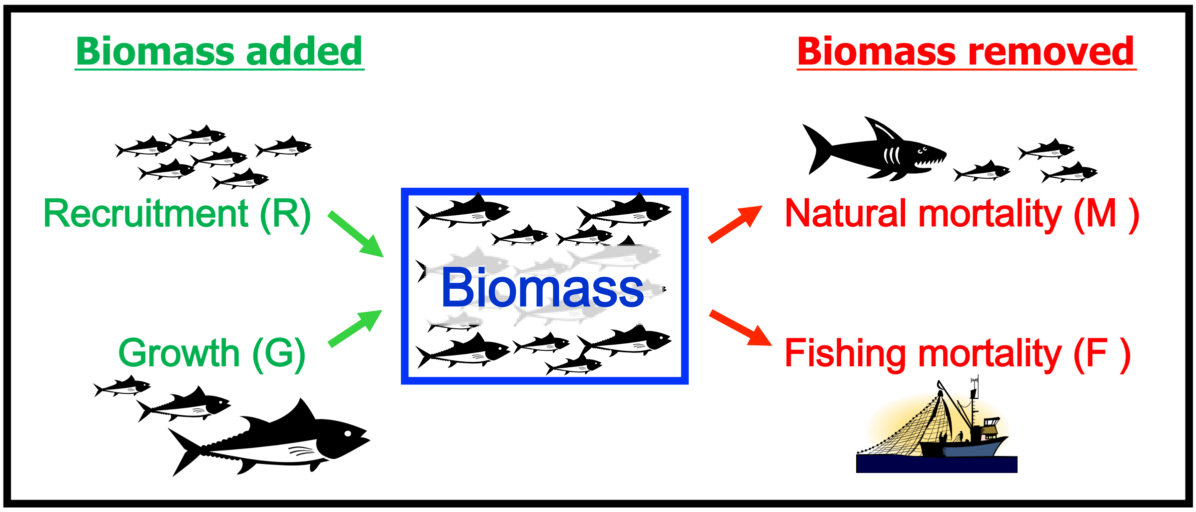
a. **A mathematical model** of population processes

b. **A statistical model** used to fit the mathematical model to data collected from the fishery

Concept 4a: Stock assessment mathematical model

1. Mathematical model of the exploited fish population dynamics: To estimate abundance (biomass) over time, the model must take into account (at the very least) four key processes: **Recruitment**, **Growth**, **Natural Mortality** and **Fishing Mortality,** conceptually expressed as:

$$\textbf{Biomass Model:}B_{t+1}=B_t+R+G-M-F$$



Concept 4a: Stock assessment mathematical model

Age Structured Model

$$N_{t+1,a+1} = N_{t,a}e^{-(M_a + F_{t,a})}$$

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

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

$$R_t = (AS_t)/(b+S_t)$$

$$N_{t+1,1} = R_t$$

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

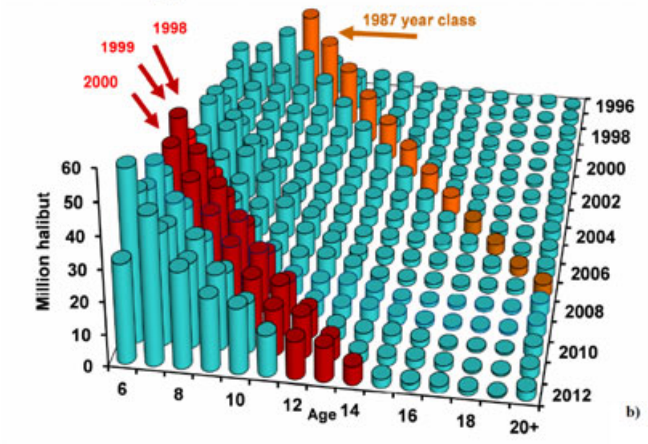
$$S_t = \Sigma N_{t,a}w_a o_a$$

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

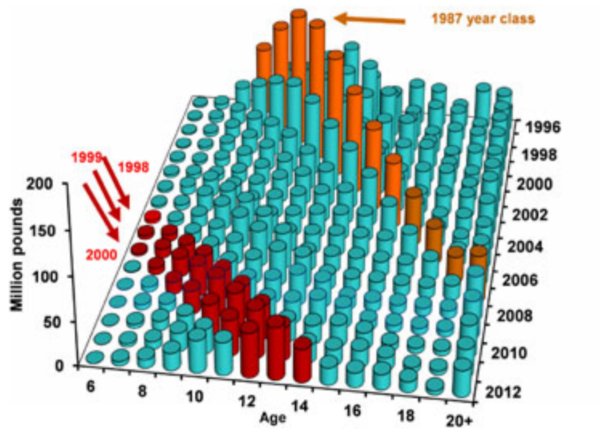
$N_{t+1,a+1}$ = Number of fish of age+1 at time +1
M_a = natural mortality rate at age *a*
F_a = fishing mortality rate at age *a*
q = catchability
E = fishing effort (units)
s = age specific vulnerability to the gear (selectivity of the gear)
$C_{t,a}$ = Catch at time t and age *a*
w_a = Mean weight at age *a* << *(Growth)*
R_t = Recruitment at time t
A = maximum recruitment
b = Stock size when recruitment is half the maximum recruitment
w_a = weight at age a
o_a = proportion mature at age a
B_t = population biomass at time t
S_t = spawning stock biomass at time t
VB = vulnerable biomass at time t

Illustration of age-structure

a) Total numbers in the population



b) Exploitable biomass in the population



Concept 4a: Stock assessment mathematical model

"Counting fish is just like counting trees...except we cant see them and they move!!"

Age Structured Model

$$N_{t+1,a+1} = N_{t,a}e^{-(M_a + F_{t,a})}$$

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

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

$$R_t = (AS_t)/(b+S_t)$$

$$N_{t+1,1} = R_t$$

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

$$S_t = \Sigma N_{t,a}w_a o_a$$

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

The **mathematical component** of the model comprises equations describing each of these processes and how they interact with each other to determine the population biomass (and other parameters) over time.

We build a model because we cant directly "count" the exact numbers of recruits and deaths nor measure the growth of each fish in the population ...

...instead of direct counts and measures, our model (via a series of equations) allows us to "estimate" these processes and the populations dynamics.

Concept 4a: Stock assessment mathematical model

Age Structured Model

$N_{t+1,a+1} = N_{t,a}e^{-(M_a + F_{t,a})}$

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

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

$R_t = (AS_t)/(b+S_t)$

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

$S_t = \Sigma N_{t,a} w_a o_a$

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

These equations are of little use unless we have data or information which can accurately inform the model of the value of most of the key parameters:

- How much fishing effort?
- How much catch?
- Whats the average weight of fish in each age class?
- What proportion of the fish in each age class are mature?

Etc, etc

We have to collect the data required to inform the model regarding the value of of these parameters

Concept 4a: Stock assessment mathematical model

Age Structured Model

$N_{t+1,a+1} = N_{t,a}e^{-(M_a + F_{t,a})}$

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

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

$S_t = \Sigma N_{t,a} w_a o_a$

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

However, the reality is that we have variable levels of information or data pertaining to the different parameters:

Some parameters we have very good estimates for (e.g. maybe catch, average size at age) derived from biological research or fishery data collection

Some parameters we have limited data for and some uncertainty

Some parameters we have no data for and high uncertainty (unknown parameter values)

Concept 4a: Stock assessment mathematical model

Age Structured Model

$N_{t+1,a+1} = N_{t,a}e^{-(M_a + F_{t,a})}$

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

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$S_t = \Sigma N_{t,a} w_a o_a$

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Given that we have moderate or large uncertainty regarding the value of some parameters, **how do we determine their value in an assessment model?**

How do we determine that the model overall can accurately predict the population dynamics and status of the fish population? (i.e. is an accurate model of "reality")

We do this by a process called **"fitting" the model to fishery data using the second component of the model, the statistical component.**

How does this work?

Concept 4b: Stock assessment statistical model fitting

How does model fitting work?

1. We need an index of abundance

To make sure our model can accurately predict how the population size changes over time, we need to collect and provide the model with data from the fishery itself which acts as an indicator of those changes in population size:

i.e; data which can act as an **index of abundance** (or an index of relative population size) over time.

Typically the index used is **catch rate** or **catch per unit effort (CPUE)** data, generally using data collected from fishers logsheets:

CPUE = catch/effort (e.g. 6 fish/1000 hooks; 2mt/set)

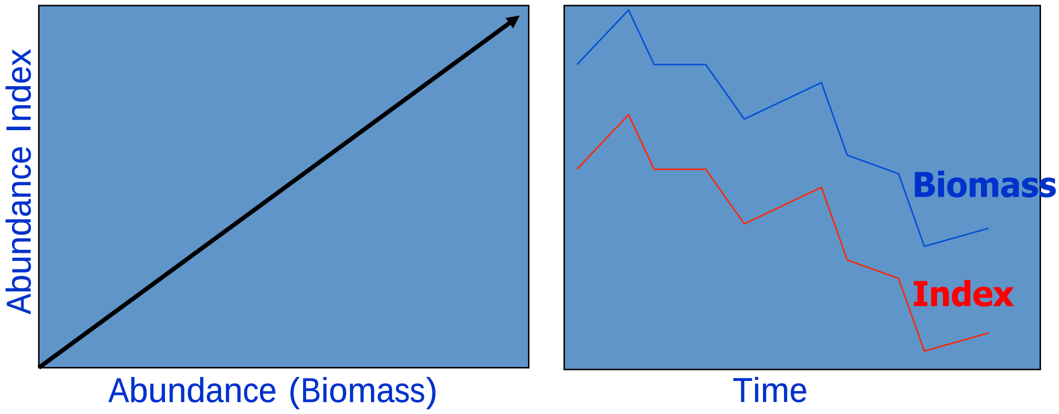
Concept 4b: Stock assessment statistical model fitting

How does model fitting work?

2. How is CPUE data an "index of abundance"?

The use of CPUE relies on the assumption that the relationship between the index (CPUE) and abundance is linear (proportional), so if CPUE goes up, the population has gotten bigger; if it goes down, it has gotten smaller. In this way CPUE is assumed to be an accurate **index** of population change over time.

*(**In fact, this is not always true, but we will discuss this further later)*



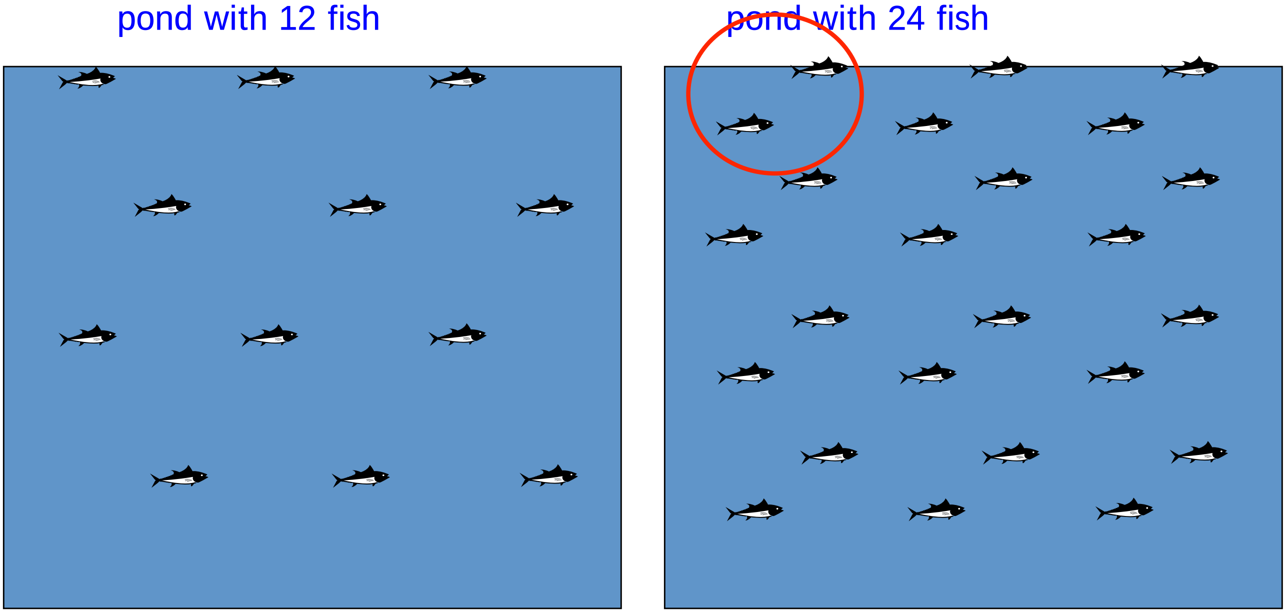
Concept 4b: Stock assessment statistical model fitting

How does model fitting work?

2. How is CPUE data an "index of abundance"?

pond with 12 fish

pond with 24 fish



Mean CPUE ~ 1.2/set

Mean CPUE ~ 2.4/set

Concept 4b: Stock assessment statistical model fitting

How does "model fitting" work?

- So we have our **observed CPUE** series
- Our model also has an equation to **predict CPUE**.
- We can now employ the statistical component of the model to search for and select the "best" combination of parameter values (for the "unknown" parameters) which maximises the models ability to accurately **predict** the **observed** CPUE data (i.e.; pick the values which maximise the fit of the model predictions to the observed data).
- Note that the tuna assessments also fit to other data types:
    - **Tagging data** (to ensure realistic modelling of movement)
    - **Size data** (to ensure realistic modelling of population structure)

Concept 4b: Stock assessment statistical model fitting

What are the different approaches to model fitting?

There are (at least) three general approaches to how we might go about doing this that you should be aware of (or at least know exist!):

- **Least-squares estimation**
- **Maximum likelihood estimation**
- **Bayesian estimation**

We use maximum-likelihood estimation (MLE)

In our tropical tuna assessments, method (ii) (MLE) is most commonly used to fit our assessment models to our data, with that data typically being the CPUE data (an index of population size), the size data (an index of population structure) and the tagging data (an index of population movement)

Concept 4b: Stock assessment statistical model fitting

There are two methods we will discuss today by which stock assessment scientists fit models to observation data are:

1. **Least squares (LS) approach**

Basically, this approach asks "What combination of values result in there being the smallest difference (degree of error) between the model estimated CPUE series and the real CPUE series?"

2. **Maximum likelihood (ML) approach**

This approach asks "What combination of values for all of these parameters would most likely result in the observed CPUE values occuring?"

LS and ML serve as criterion by which to judge the quality of the fit

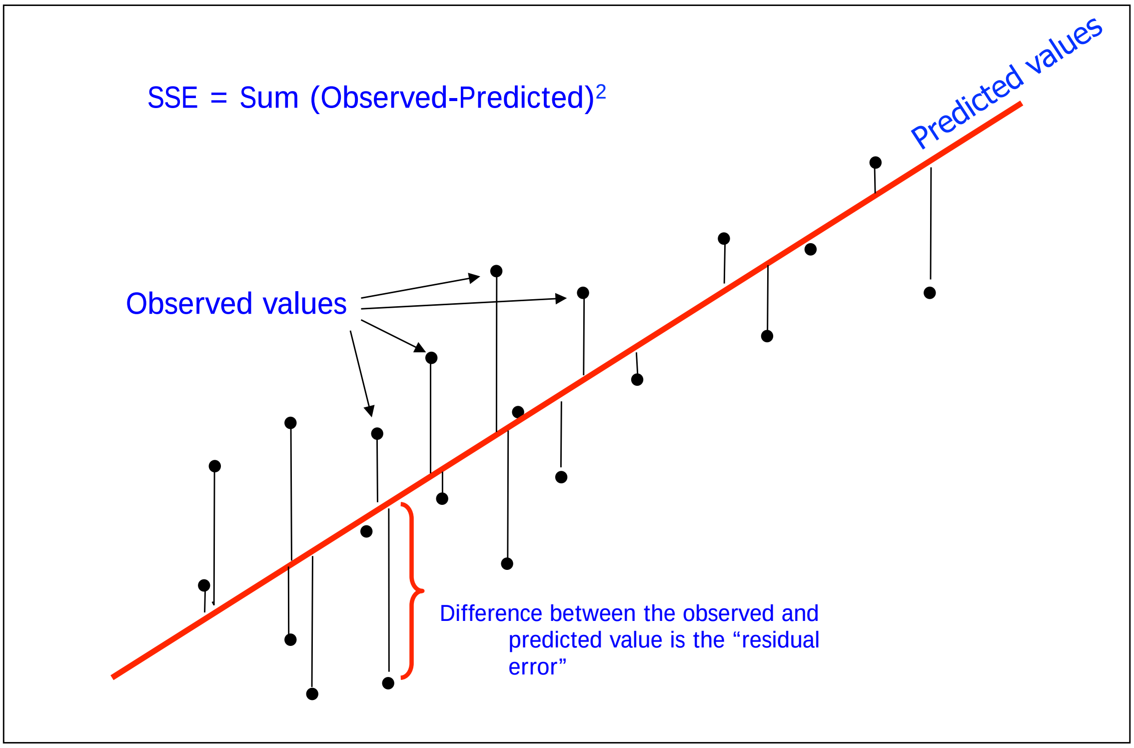
Model fitting: LS approach

1. Minimisation of Sums of Squares of Errors

- This approach involves a search for the parameter values which minimize the sums of squared differences (i.e., produces the "least squares" value) between the observed data and the data as predicted by the model and parameters.
- It is almost impossible in any slightly complex system to create a model that exactly fits the real data....there is always some error. The objective of the LS approach is to find parameter values that minimise the total error.

Model fitting: LS approach

Models used to deduce relationship and find best fit



Model fitting: ML approach

2. The Maximum Likelihood Method

Parameters are selected which maximise the probability or likelihood that the observed values (the data) would have occurred given the particular model and the set of parameters selected (the hypothesis being tested). The set of parameter values which generate the largest likelihood are the maximum likelihood estimates:

So..

Likelihood = P{data|hypothesis}

Which means "the probability of the data (the observed values) given the hypothesis (the model plus the parameter values selected)".

E.g. Think of the flip of a coin. Whats the probability of getting heads? Of getting tails? Stock assessment models can use fairly complex statistics to determine the probability of, for example, the observed CPUE series occuring, given a particular model.

Model fitting: ML approach

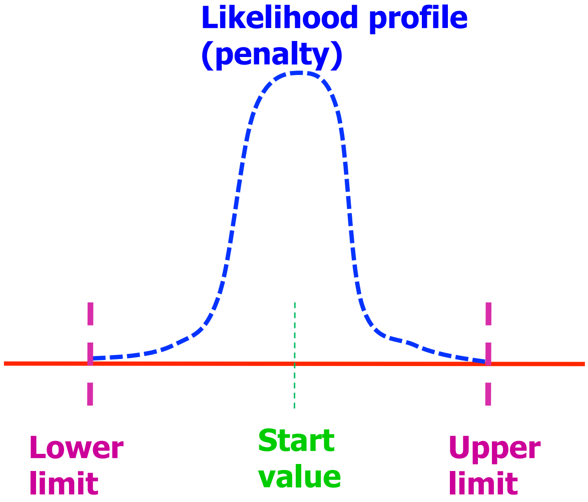
A note on parameter estimation

2. However, we don't just allow the model to pick ANY value for the uncertain or unknown parameters however! Typically, we provide the model:

a. A **start value** (from which it begins its search)

b. Some boundary or **limit values** (to which it must constrain its search within)

c. A **likelihood distribution (penalty)** which specifies to the model which values within the range specified will be more likely.



Model fitting: Summary

1. We use our knowledge of population processes to build a **mathematical model** of the population that has **equations** to describe all the processes, how they link together, and how they influence population size over time.

2. Each equation will be made up of different components (or **parameters**)

3. Some of the parameter values we will know already (e.g from biological research, from fisheries catch effort data collection, etc). Some of the parameters will have **unknown values**.

4. We use a **statistical model** (and computer) to go through all the different combinations of possible values for those unknown parameters, until it finds a combination that allows the model to accurately **predict** the observed CPUE. In other words, produce a CPUE time series that **fits** or matches (i.e. differs very little from..) the real CPUE time series,which we believe is an accurate index of changes in population size over time.

** This description describes *some* of the core principles only

Model fitting: Summary

Model fitting….

Age Structured Model

$$N_{t+1,a+1} = N_{t,a}e^{-(M_a + F_{t,a})}$$

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

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

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

$$S_t = \Sigma N_{t,a} w_a o_a$$

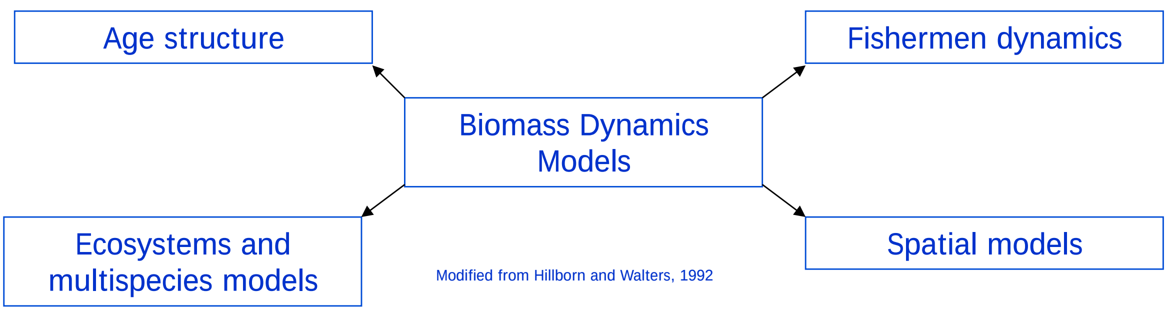
$$VB_t = \Sigma N_{t,a} w_a s_a$$

- Here are the equations that described the population processes….we believe these are correct based on past research etc.
- And we have data collected from the fishery or science research for many of the parameters.
- But we don't have any data for some parameters.
- Model fitting is the process by which our computer programme searches amongst all the possible "unknown" parameter values until it finds and selects the "best" combination of parameter values which maximise the fit of the model predictions to the observed data (e.g. CPUE).
- In other words it selects values for the unknown parameters which maximise the models ability to accurately predict the observed CPUE (in this example) data.

Model types and selection

There are many different types of fish stock assessment model that can be used and selecting an appropriate model is dependant on the management question being asked and the data that is available.

What are the various types of stock assessment model? How do they differ?



Modified from Hillborn and Walters, 1992

WE ARE GOING TO FOCUS ON **AGE STRUCTURED** MODELS IN THIS WORKSHOP

Key messages

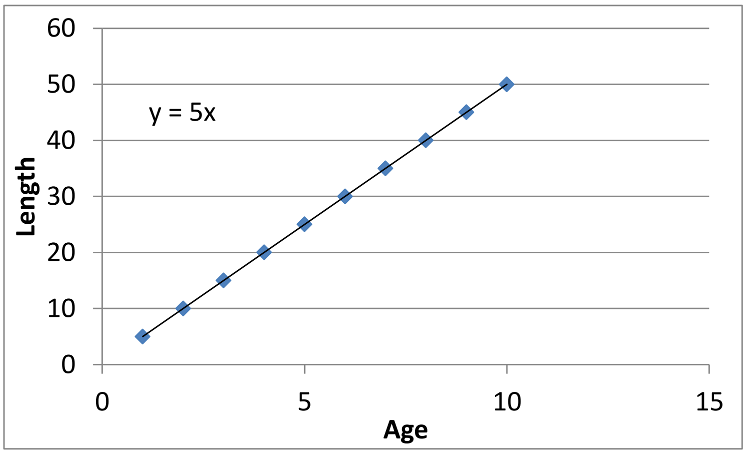
1. We must identify/define the stock we wish to assess
2. We model the population dynamics of the stock using a model (mathematical equations) governing the processes of recruitment, growth, natural mortality and fishing mortality
3. We estimate the parameters of the model by statistically fitting to data, using methods such as least squares or maximum likelihood
4. Stock assessment modelling can get very complicated very quickly, and requires extreme familiarity with the data to "get it right"

Additional useful information – To be covered in subsequent presentations

1. Examples of equations in stock assessment
2. Difference vs differential equations
3. Model fitting by least squares
4. Model fitting by maximum likelihood

Examples of equations in stock assessment

Remember this equation?



Hypothetically it might be used in an assessment model to describe how the fish grow in size as they get older. This is really all any of the equations in the model are doing, describing processes in the population...the population dynamics including its interation with the fishery

(*NB: But again....a critical question we will address later is... how do we know if our model is "true" or realistic of the process it is trying to describe? ....we'll come back to this*)

Examples of equations in stock assessment

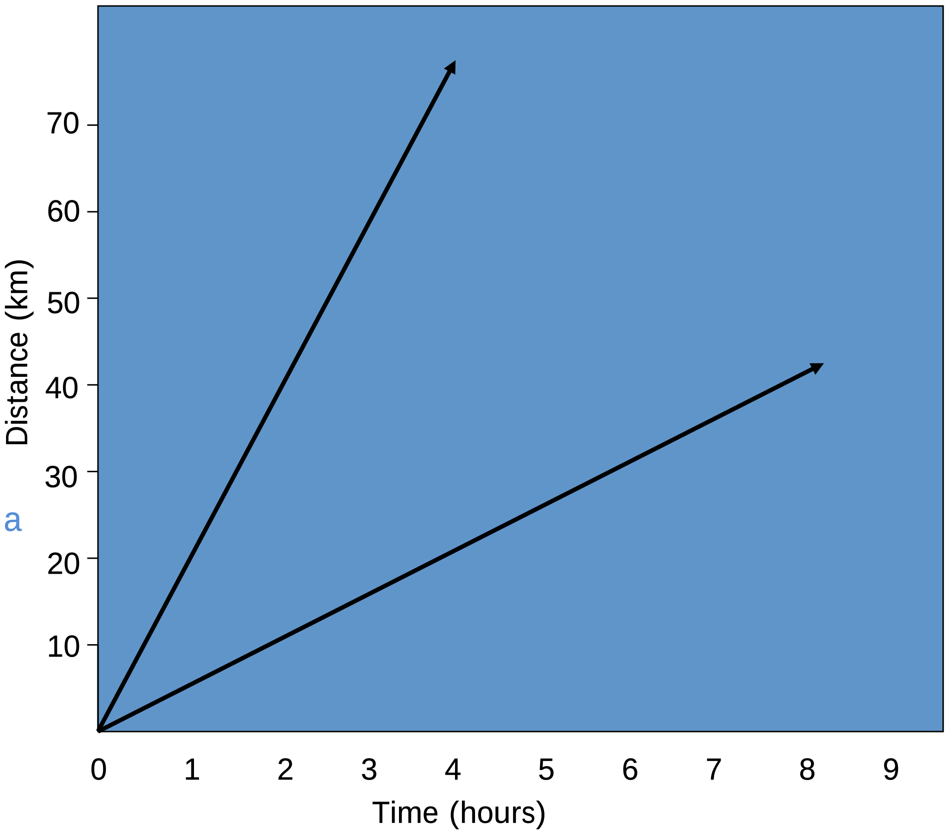
Calculating rates (of change)

..we do it every day..

Car speed (km/hour)
Interest rates
Weight loss (kg/week)
Typing (words/minute)

What is a rate?

It is the extent to which a change in one quantity affects a change in another related quantity. This is called a *rate of change*.



Examples of equations in stock assessment

Example

Two cars, A and B

Car A travels 80km after 4 hours

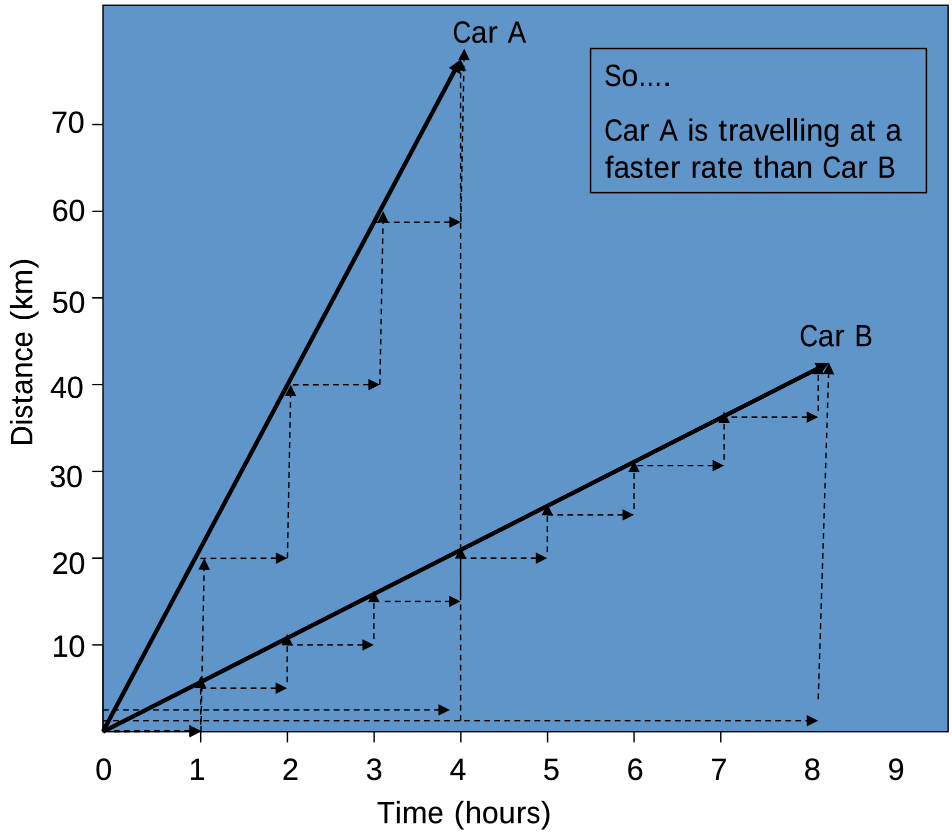
Car B travels 40km after 8 hours

How do we calculate the rate of travel?

Rate = change in y
change in x

Car A: Rate = 80/4
= 20km/hour

Car B: Rate = 40/8
= 5km/hour



Examples of equations in stock assessment

Relevance to stock assessment?

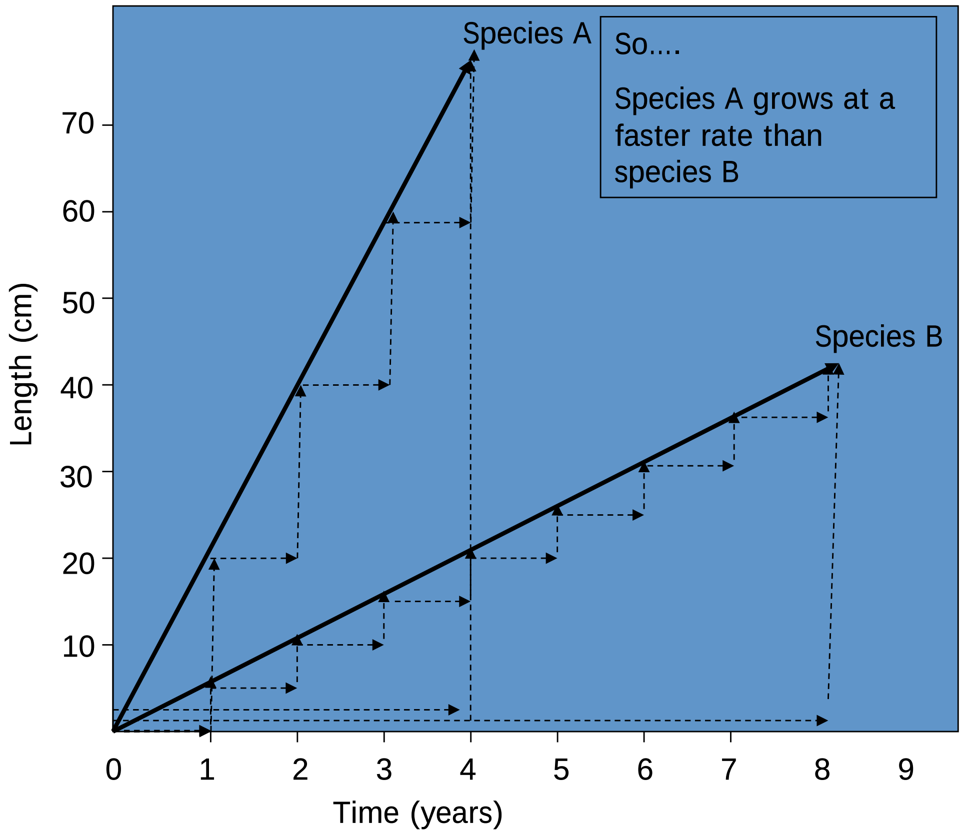
e.g. fish growth rates

Growth rate impacts population size

1. Natural mortality
2. Size at maturity
3. Biomass increase in existing pop

Therefore estimating growth rates is important in predicting population change over time

This is just one example of how rates may be used in stock assessment



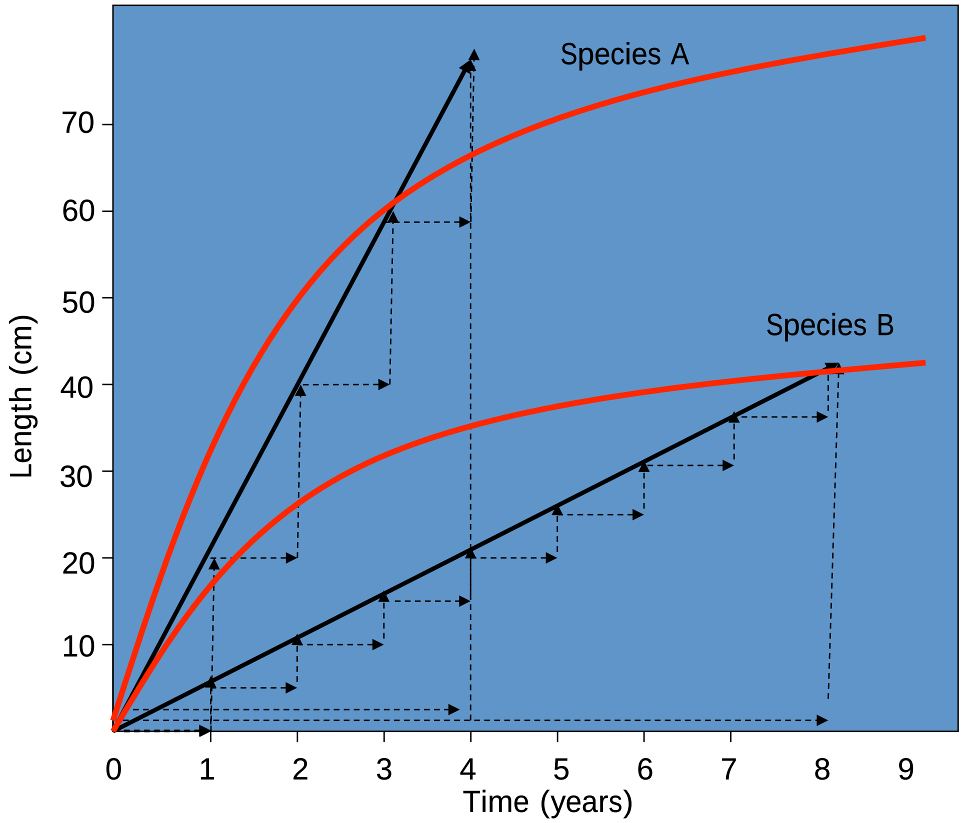
Examples of equations in stock assessment

Relevance to stock assessment?

Often the rates are not constant as in this example

e.g. fish growth rates (in length) rates slow as the fish get older

e.g. fish survival rates may increase as fish get older and then decrease when very old.



Examples of equations in stock assessment

Difference Equations

Predicting values at fixed points in time.

Example: Two populations, A and B. **Population A** grows at 20000 fish per year. **Population B** grows at 5000 fish per year.

How do we calculate the population size 4 years into the future?

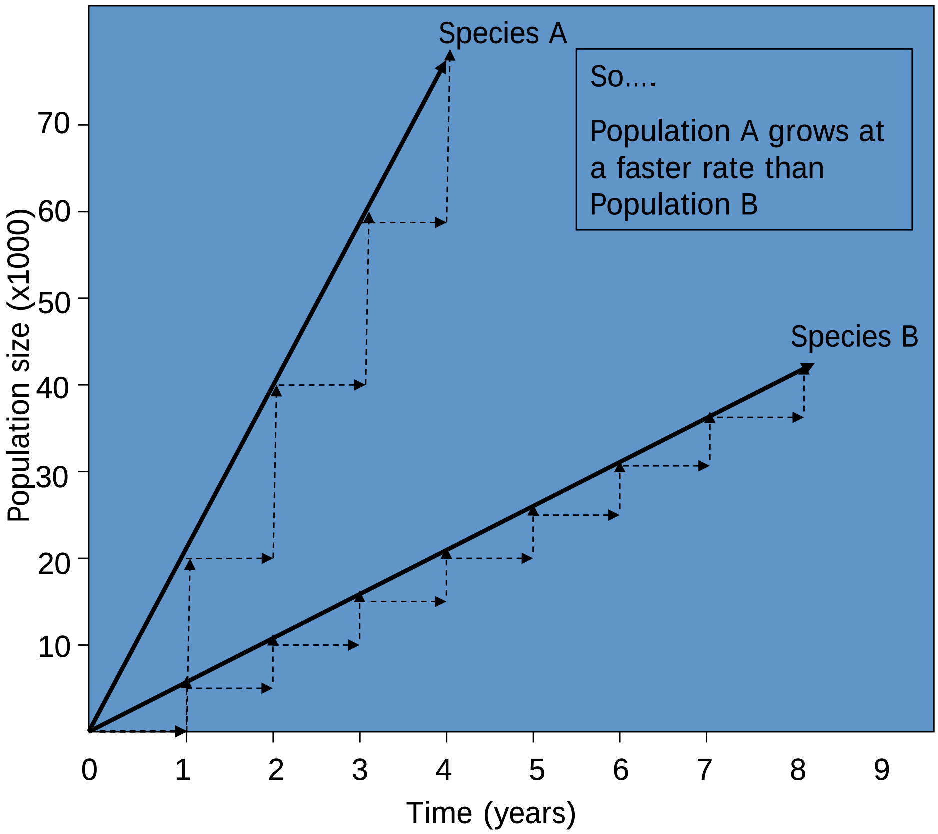
Rate =

change in y/change in x

But we want to know y!

Species A
20000=y/4
4*20000=y
80000=y

Species B
5000=y/4
4*5000=y
20000=y



Difference vs differential equations

Two of the key types of equation used in stock assessment models are:

1. **Differential equations – measure rates of change**
2. **Difference equations – predict values at fixed point in time**

....the key point is that the estimation of each of the 4 key processes requires equations, and the full suite of equations together make up the assessment model...

Difference vs differential equations

Equations which estimate a value at a fixed point (e.g. in time) are called difference equations

We already know one very well!

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

Many stock assessments these days are based on difference equations....they are easier to understand and more intuitively logical

However, each of the components of such an equation may require estimation by another equation, and often these equations can involve the calculation of rates (ie. Use of differential equations)

Difference vs differential equations

For example, a basic logistic growth model

We can write it to calculate change in biomass over time:

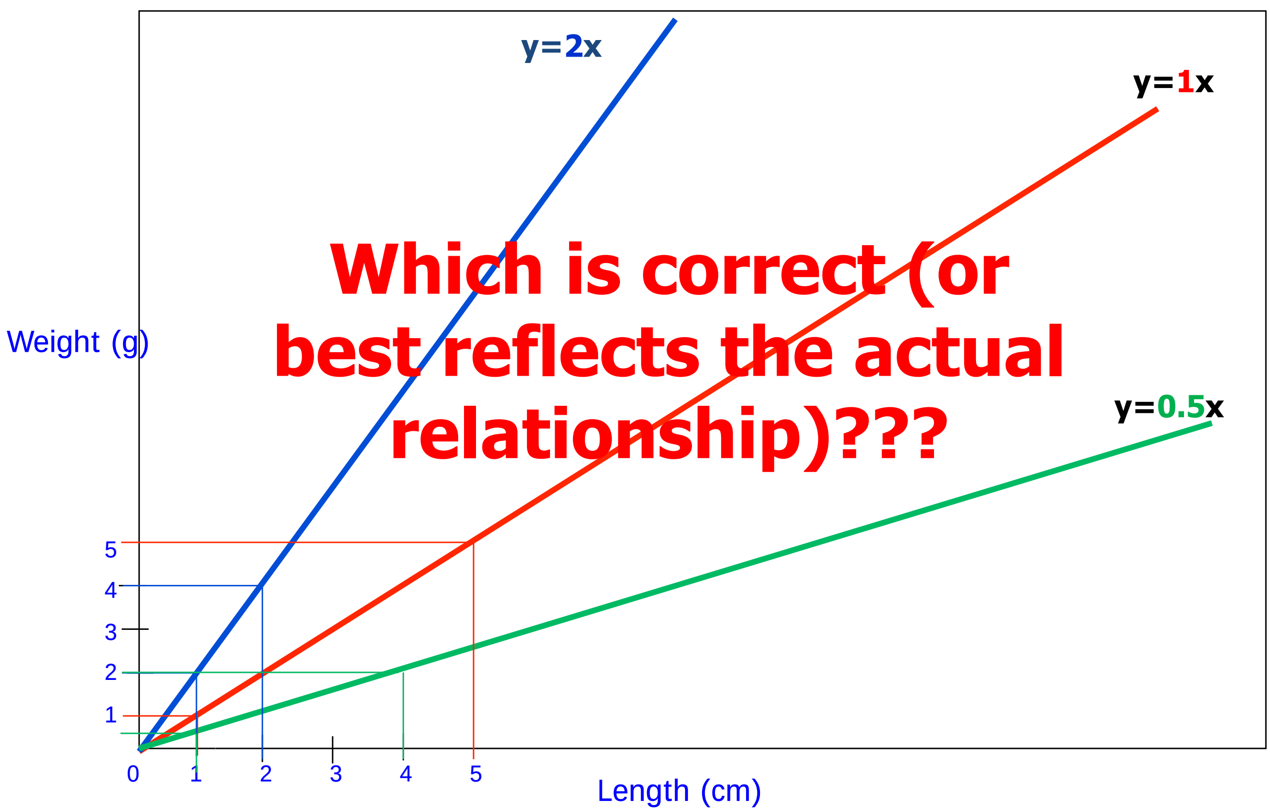
$$dB/dt = rB(1-B_t/k)-C$$

Or we can write it to predict biomass at some time in the future

$$B_{t+1} = B_t + rB(1-B_t/k)-C_t$$

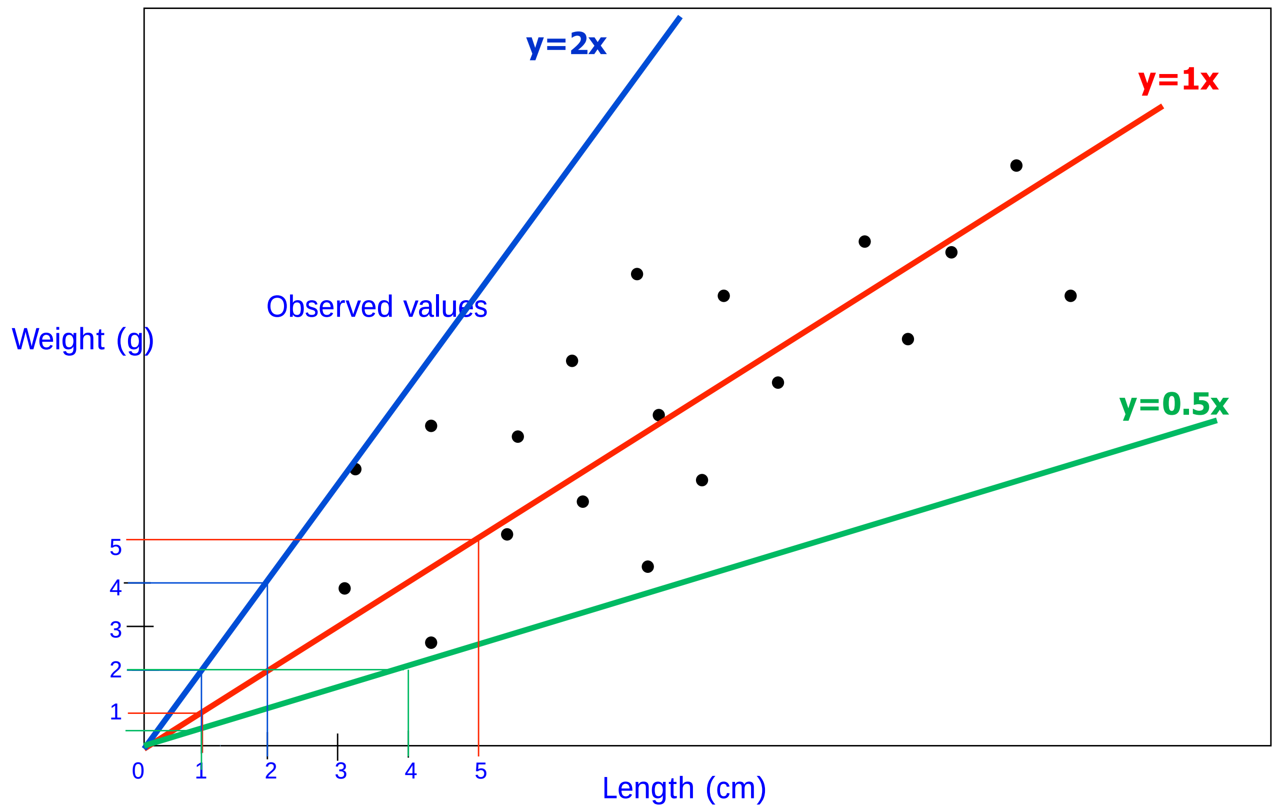
Model fitting by least squares

An example using fish length and weight: **y=mx**



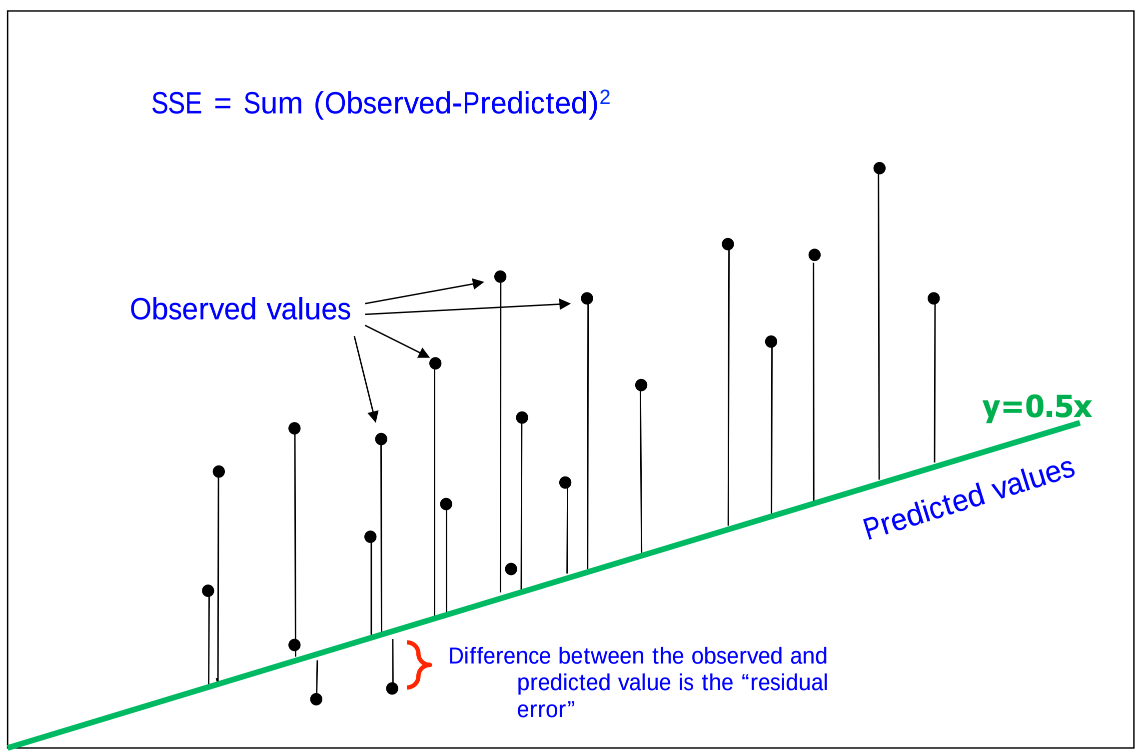
Model fitting by least squares

An example using fish length and weight: **y=mx**



Model fitting by least squares

Models used to deduce relationship and find best fit



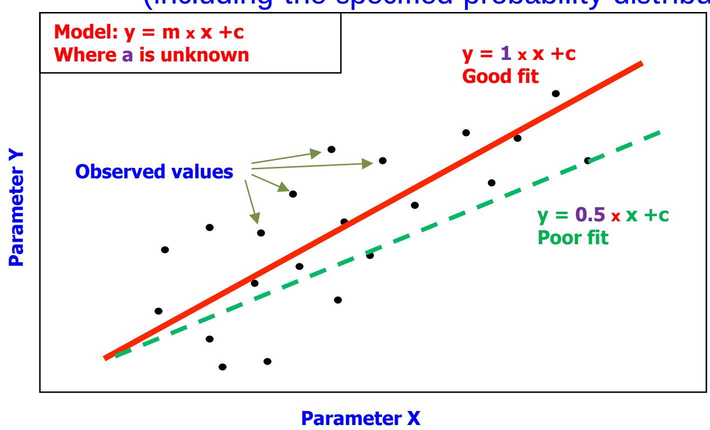
Maximum likelihood (old method of presenting the subject) may not be presented in this session. However, for the curious the slides are included. Session 12 is when this will be covered.

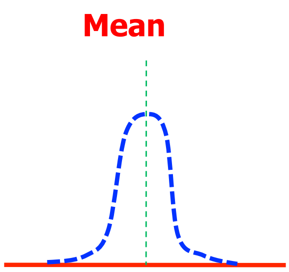
Model fitting by maximum likelihood

Maximum Likelihood: An example

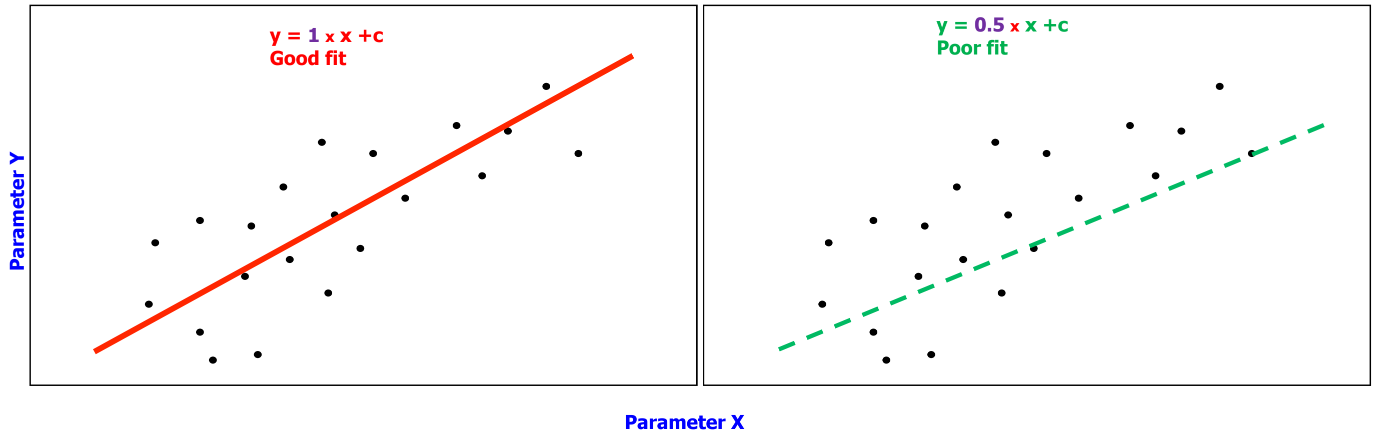
Lets look at our previous example used to describe SSE approach but this time apply a Maximum likelihood approach.

1. We have a model for the relationship between two parameters, y=mx+c
2. **x** and **c** are known, **m** is not
3. We can specify a starting mean value and probability distribution around the mean which provides the model an indication of the most likely value but some freedom to estimate alternate values if they provide a better fit.
4. The model searches through all possible values of **m** until it finds a value which maximises the likelihood of the observed data, given the model specified (including the specified probability distribution)

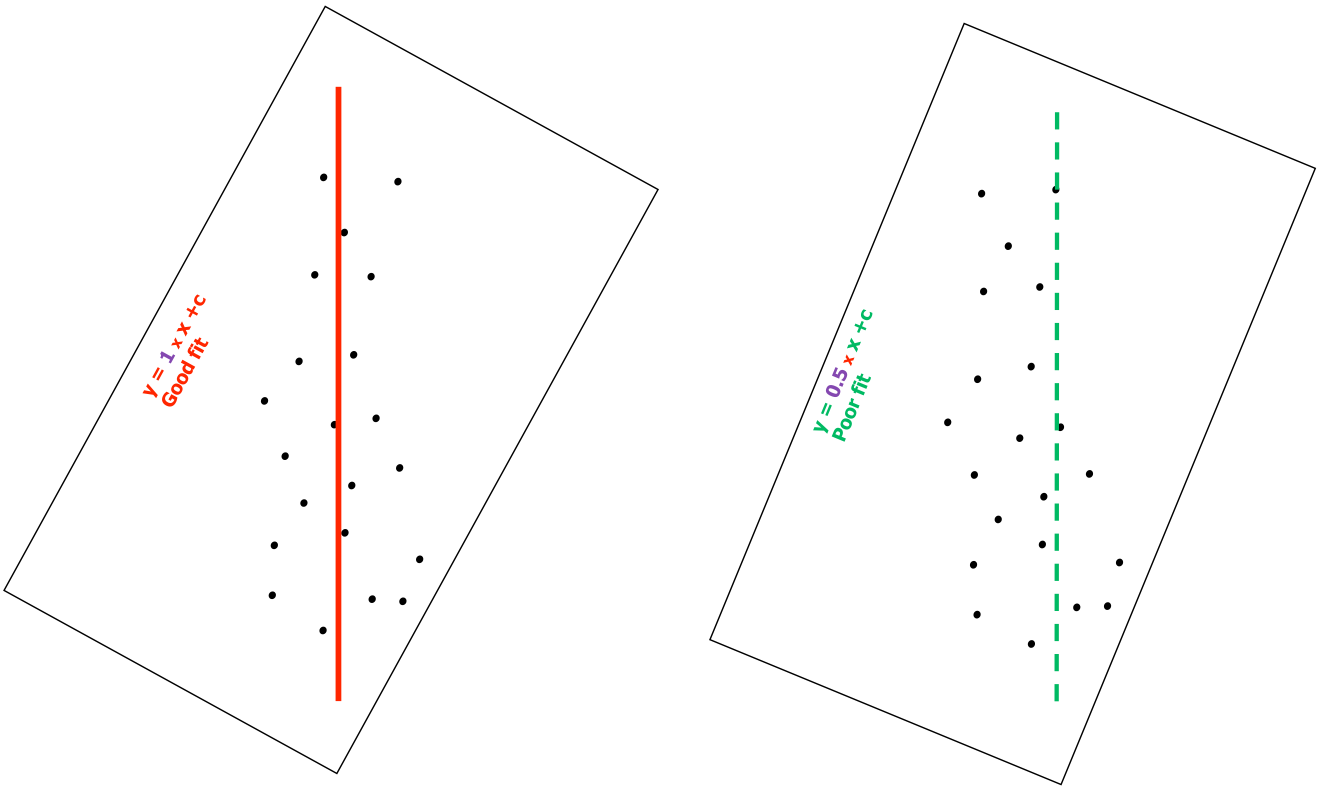




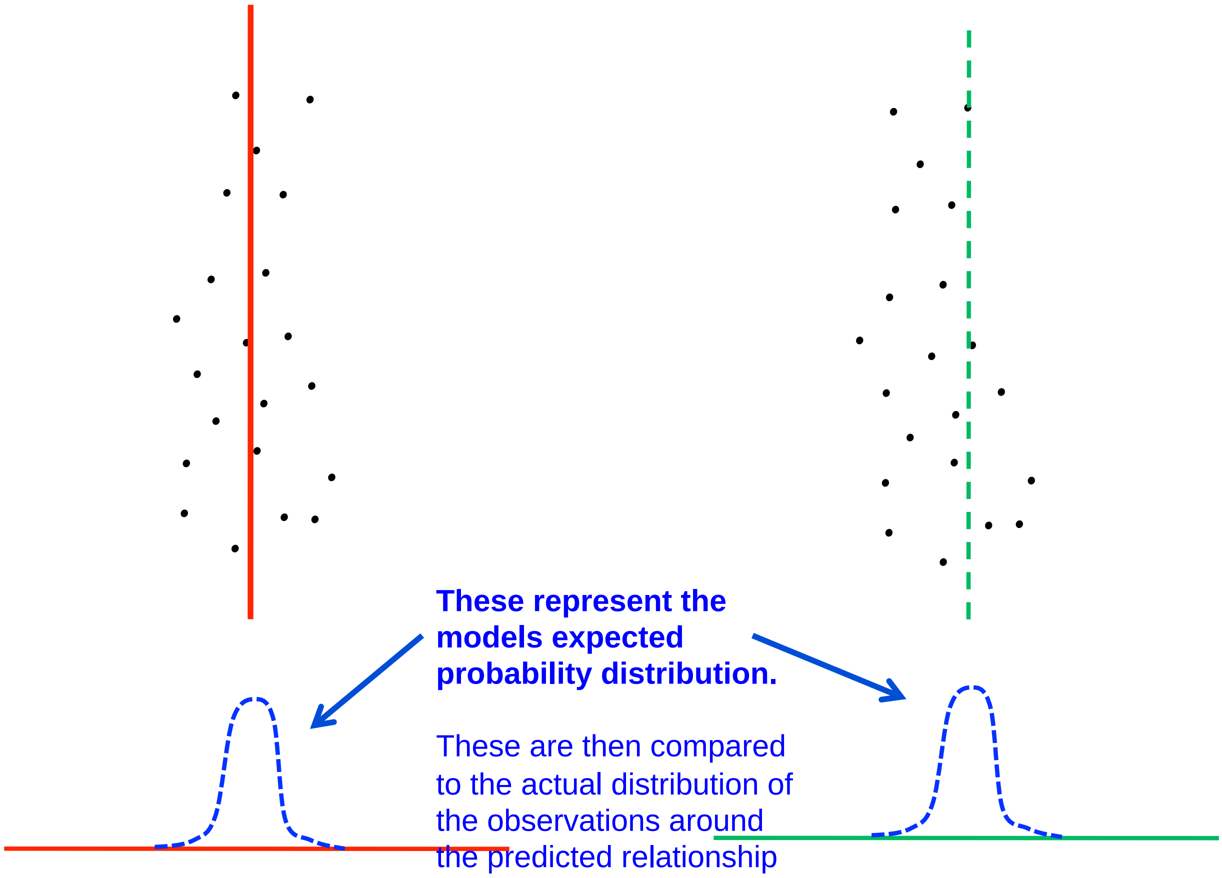
Model fitting by maximum likelihood



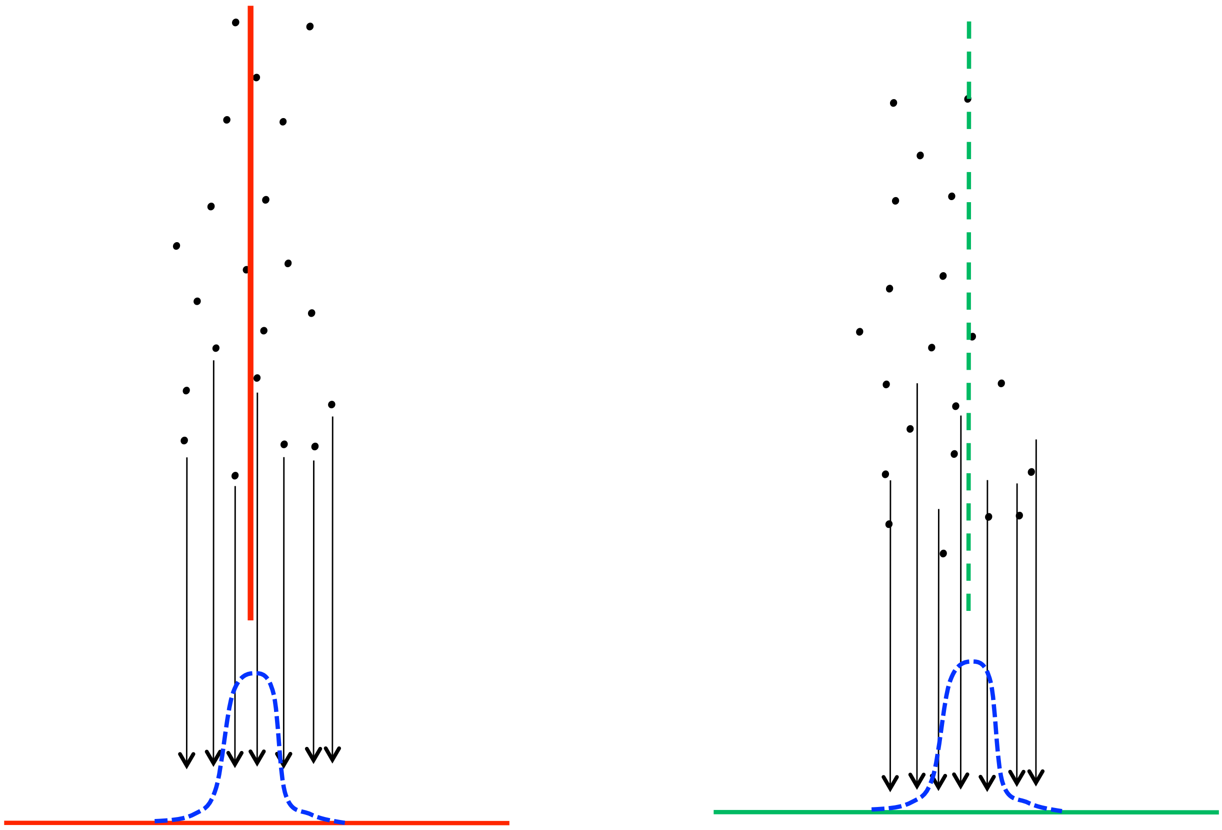
Model fitting by maximum likelihood



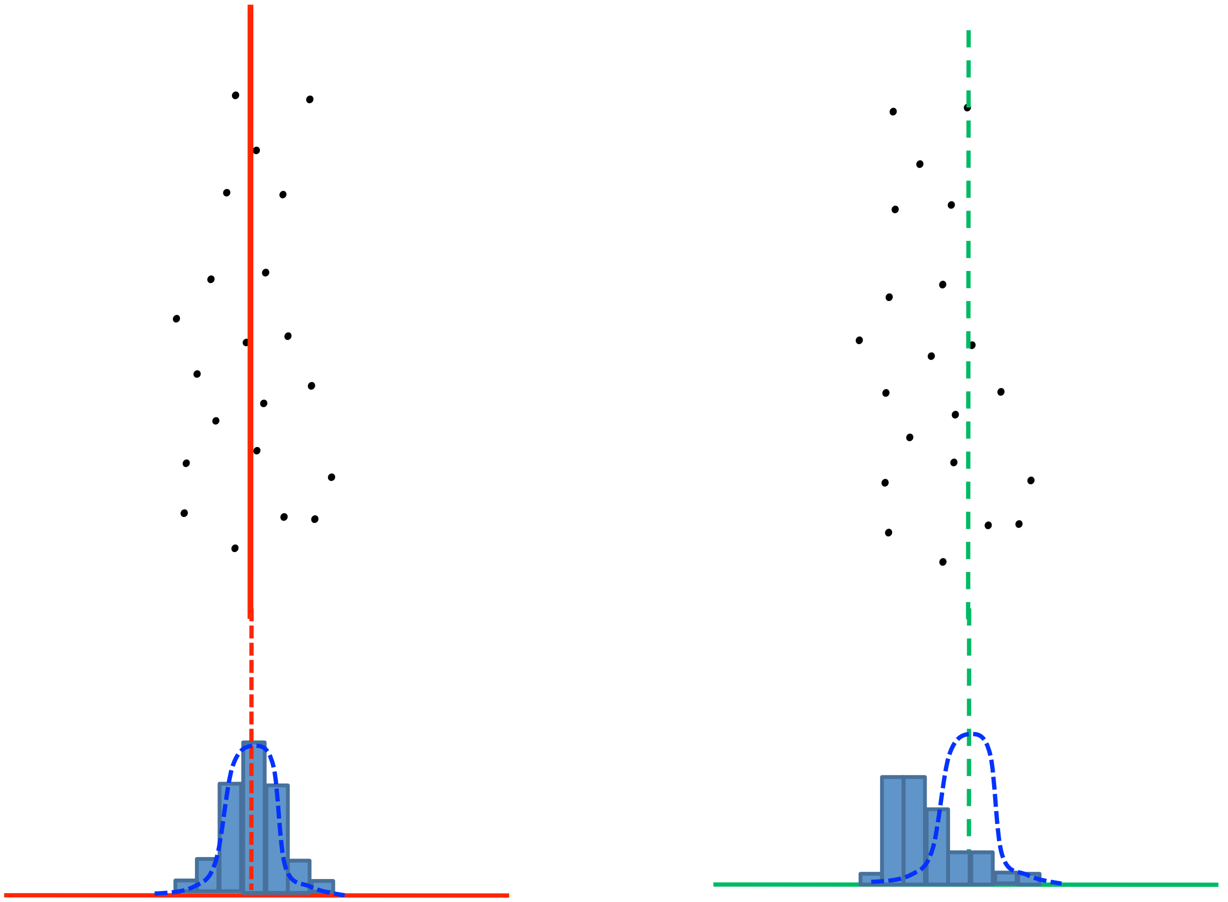
Model fitting by maximum likelihood



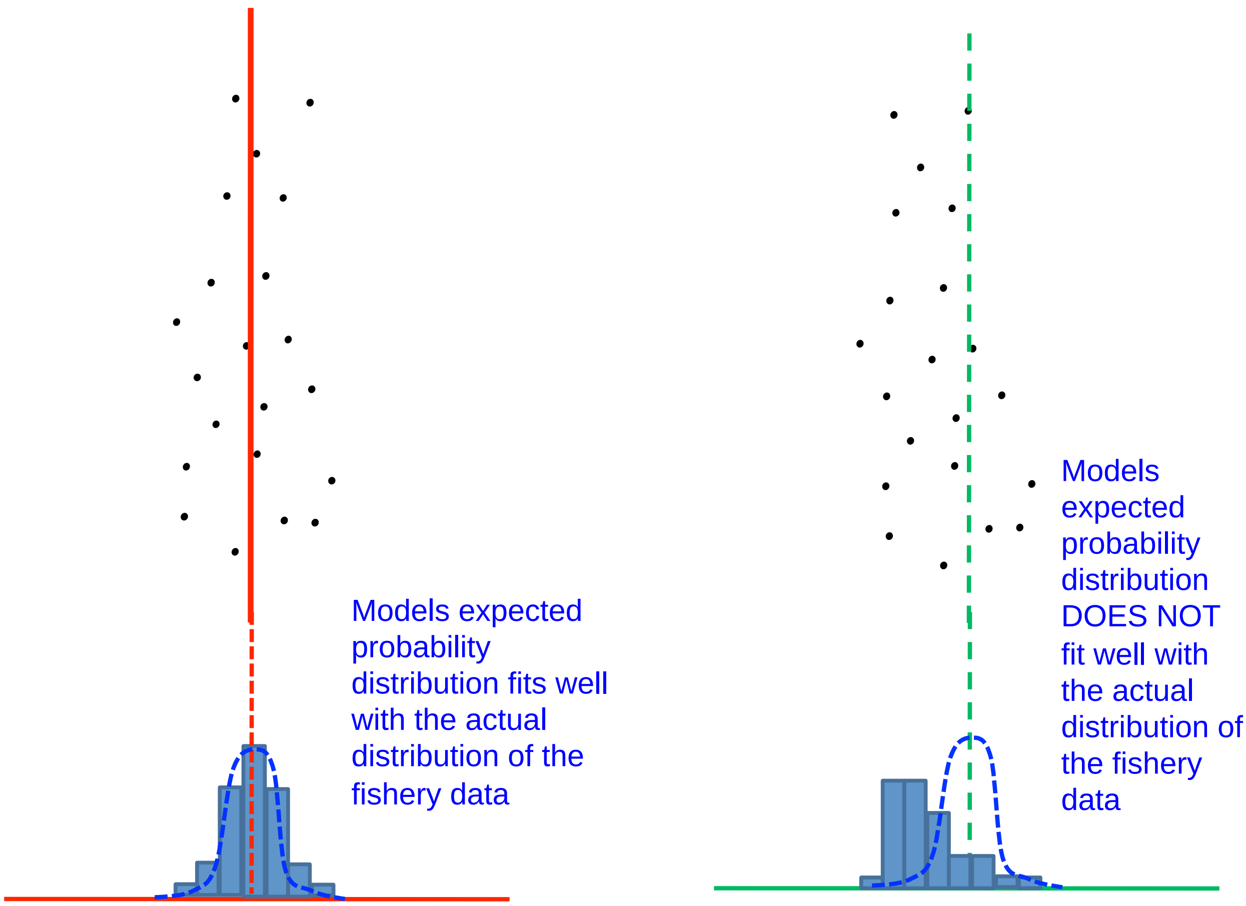
Model fitting by maximum likelihood



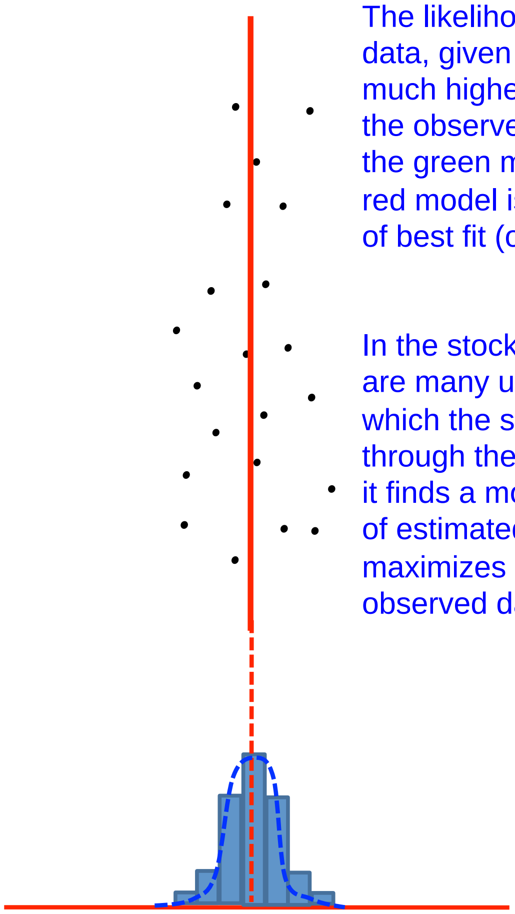
Model fitting by maximum likelihood



Model fitting by maximum likelihood

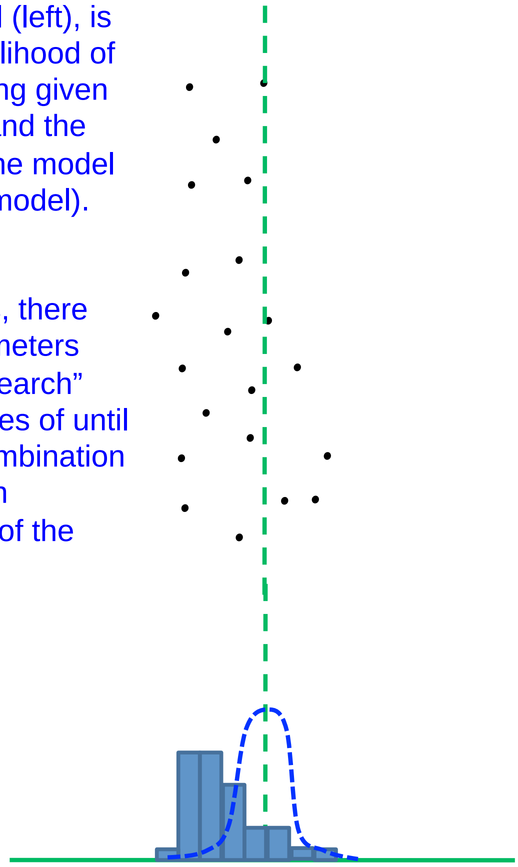


Model fitting by maximum likelihood



The likelihood of the observed data, given the red model (left), is much higher than the likelihood of the observed data occuring given the green model (right), and the red model is chosen as the model of best fit (or most likely model).

In the stock assessments, there are many unknown parameters which the software will "search" through the possible values of until it finds a model with a combination of estimated values which maximizes the likelihood of the observed data occurring



Model fitting by maximum likelihood

Note!

- Typically, to find the MLEs we actually search for parameter values that minimise the model's negative log-likelihood function, logL,
- So, in an assessment using MLE, to determine the model with the best fit, find the model with the lowest negative log-likelihood score. A table is usually produced which provides the negative log-likelihood estimates for each data set offered to the model (e.g., catch, size, tagging data) and the combined total for all of these.

Table 1. Details of objective function components for the base-case model and three of the sensitivity analyses.

Objective function component	**base-case**	**ID-low-catch**	**ID-high-catch**	**region3-growth**
Total catch log-likelihood	598.80	595.90	600.18	638.50
Length frequency log-likelihood	-349,920.62	-349,876.45	-349,936.53	-350,030.85
Weight frequency log-likelihood	-760,710.15	-760,709.29	-760,713.94	-759,670.09
Tag log-likelihood	2,618.91	2,606.04	2,632.90	3,118.94
Penalties	7,152.87	7,148.73	7,157.87	7,331.48
Total function value	-1,100,260.19	-1,100,235.07	-1,100,259.52	-1,098,612.02

Chapter 4

Fisheries data collection for stock assessment

Overview

Five key bits to this session:

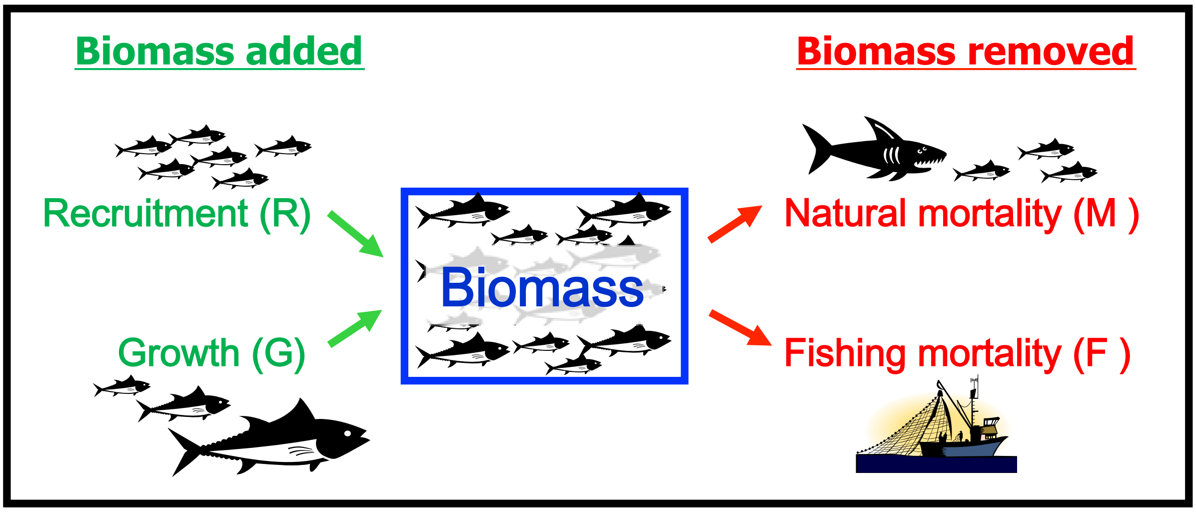
1. An overview of fisheries data collection generally
2. An overview of MULTIFAN-CL's data requirements
3. Fisheries data collection programmes in the WCPO

   a. **Fishery-dependant** data collection programmes in the WCPO: (i) logbook data; (ii) regional at-sea observer programmes; and (iii) port or market sampling programmes

   b. **Scientific data collection** programmes in the WCPO: (i) mark-recapture data; (ii) age and growth research; (iii) reproductive, feeding, and other biological data; and (iv) environmental data

Our conceptual model of a fish population

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



Fisheries data collection

Overview

Stock assessment models need data! Specifically, data that describes or relates to the fish population, its size, key processes, size structure, movement and interaction with the fishery, and how all of these change over time.

Without all of these data, we ***can not***:

a. Determine if our *model* of the fish population is an realistic one (via the model fitting process described earlier).
b. Confidently use our model to make predictions about stock status and the future effectiveness of different management strategies.

Fishery-dependant and fishery-independant data - Fisheries data are usually divided into two general types.

"Fishery-dependant" data are collected directly from the fishery or about the fishing process.

"Fishery-independent" data are collected independently of the fishing process.

Fisheries data collection

Overview

Some common types of fisheries data used in stock assessments are:

- **Fishery catch**
  Fishery dependant by definition.
- **Fishery-dependant *relative* biomass estimates (abundance indices)**
  E.g., standardised commercial catch-per-unit-effort series
- **Fishery-dependant stock composition estimates**
  E.g., tuna length or weight data collected either by regional at-sea observer or port sampling programmes
- ***Fishery-independent relative and absolute biomass estimates**
  Unfortunately, because of the spatial scale of our stocks, collecting traditional fishery-independent relative (e.g., trawl surveys) and absolute biomass (e.g., acoustic or egg-production surveys) estimates are impractical for the WCPO tropical tuna stocks.

Fisheries data collection*

Overview

Some other aspects of fisheries data to be aware of at this point:

- **The compromise between information content and expense**
  As the information content of different fisheries data sources grows (i.e., the ability of a given data source to tell you about true stock size) linearly, expense seems to grow multiplicatively!
- **Many data types have multiple uses**
  Many different data types can be used for purposes other than the primary purpose for which they are collected. This can help to reduce the different marginal costs of the results produced (e.g. catch and effort data used in fisheries economic efficiency analyses etc).

Fisheries data collection

Overview

Two other important issues to consider when evaluating fisheries data:

- **Every sampling project needs to have clearly-stated objectives**
  Every data collection programme should have a clearly stated set of objectives. What exactly is the sampling programme trying to achieve ("who, what, where, when, why, and how")?

  Do you know why you collect the data that you do collect?

- **Data accuracy and precision can be difficult to achieve but should always be tested**
  We should also expect to see an appropriate consideration of the accuracy and precision of the sample data (NB: "sample representativeness").

  e.g. is the size data collected representative of the size composition of the overall catch?

MULTIFAN-CL

What are MULTIFAN-CL's data requirements?

MULTIFAN-CL (MFCL) is often described as a "**length-based, age-structured, statistical population dynamics model"** developed for assessment of the WCPO tropical tunas (ALB, BET, SKJ, and YFT). Particular data sets are collected throughout the WCPO to allow particular model process parameters to be estimated during each model run.

(i) Recruitment
Length-frequency data, environmental predictors where these exist

(ii) Growth
Otoliths, length- and weight-frequency data, mark-recapture ("tagging") data

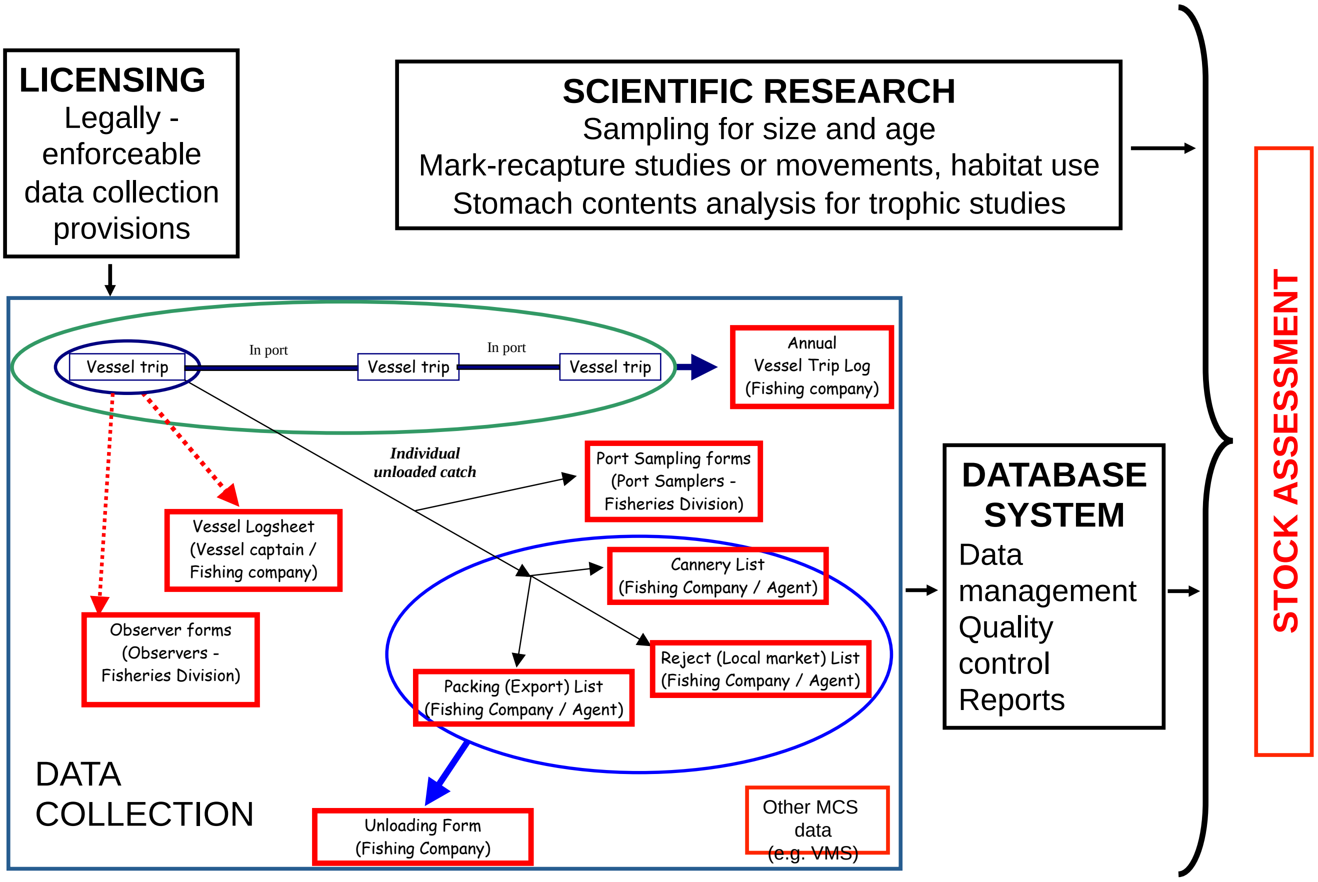
(iii) Fishing mortality
Logsheets and landings data → standardised catch-per-unit-effort (CPUE) abundance indices

(iv) Natural mortality
Mark-recapture data

(v) Movement
Mark-recapture data

All these data are critical to successfully completing each assessment

WCPO assessment data flow*

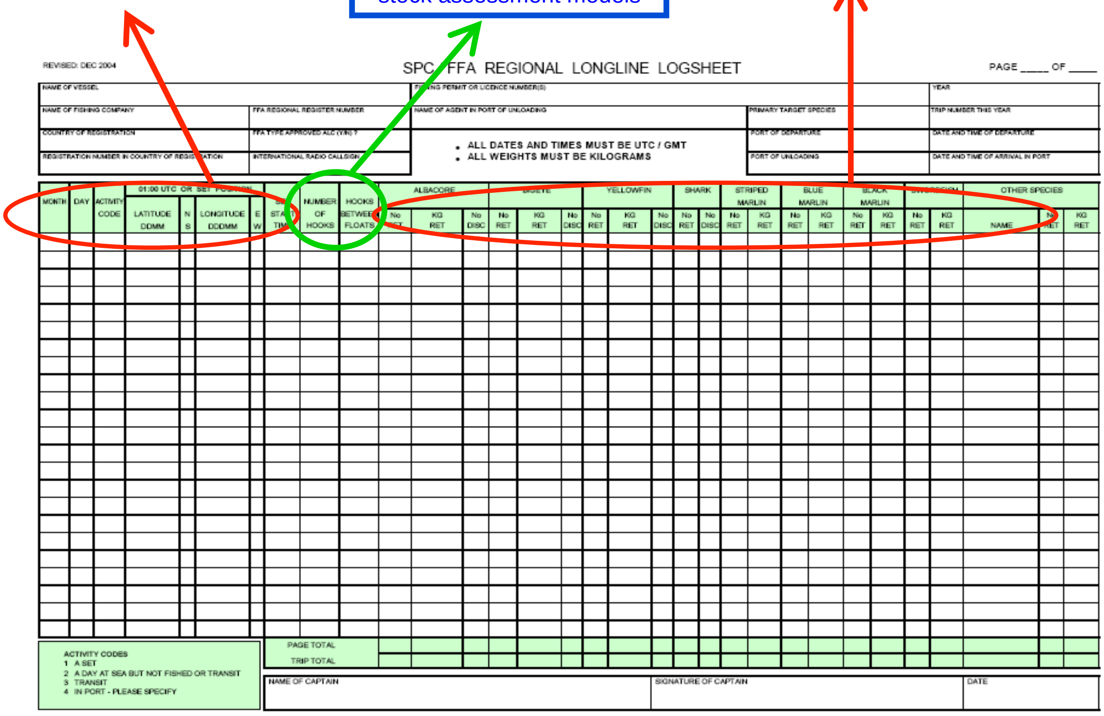


Catch-effort log data

Used to allow spatial and temporal stratification of data within model and for standardising catch rates

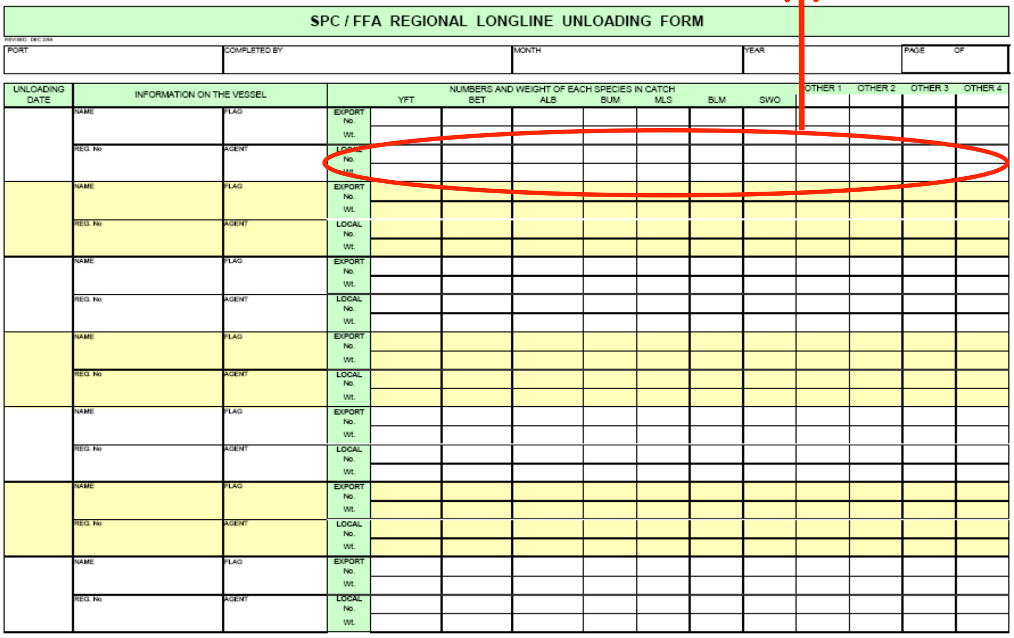
Gear and method data are used to help standardise fishing effort within the stock assessment models

Catch data to estimate fishing mortality and CPUE data for model fitting



Landings or unloadings data

Unloadings data are used to validate the logbook data used in the assessments

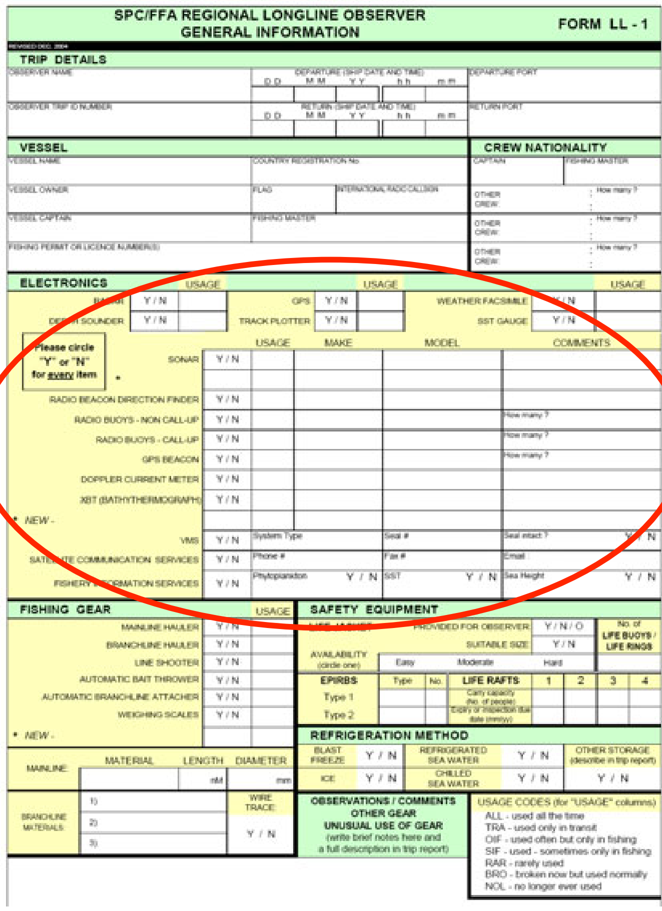


Observer data: catch-effort data

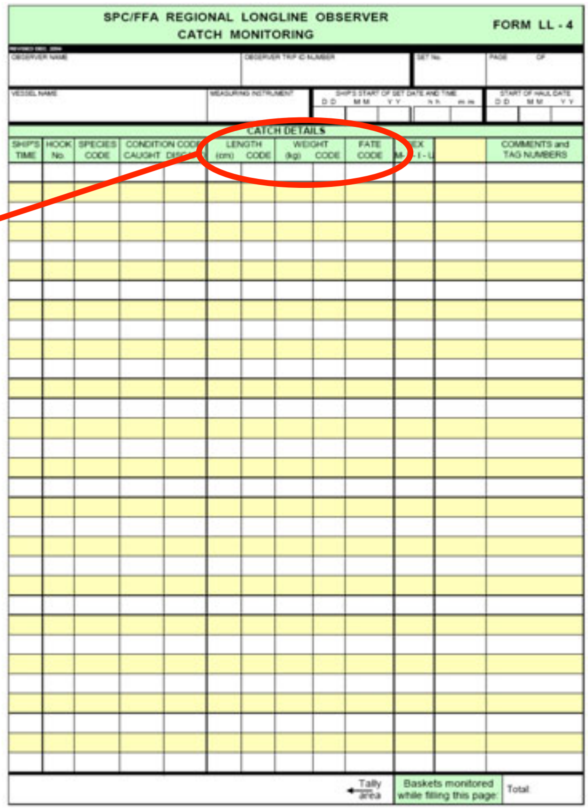
**Gear and method data are can be used to standardise fishing effort (or CPUE) to feed these data into the stock assessment models.

Effort data are critical to the accurate estimation of the catch

Observer data have not been used a lot for this purpose in the past but are likely to be in future, in particular for assessments of bycatch species like sharks



Observer data: catch composition



Size and other catch-composition data are critical for estimating growth and mortality and for separating age classes within the catch, and population size structure, all of which are needed within an age-structured stock assessment model

Observer data: biological sampling

For collection of biological samples by observers, scientists provide separate sampling forms to fill in, but which are linked to the standard observer forms

Often, scientific observers programmes are the only practical way to collect certain kinds of data from the catch

Port sampling data

Overview

1. Port-sampling data: data collected by port sampling staff at points (ports) of unloading

2. Data collected: (i) cover a broad area of fishing; (ii) catch by species for the entire trip; and (iii) the composition of the target species catch (length-frequency and other data)

3. Requires liaison with locally-based fishing companies and agencies and government departments (e.g., Customs Dpts). Coverage of unloadings data by vessel is not complete—there are problems covering all ports.

4. DWFNs (Government Departments and companies) also compile their own data (mainly from unloadings) and provide annual catch estimates to the OFP.

Port sampling data

Overview

5. The data contain more than 16 million length measurements collected from a variety of sources since 1960s.

6. The data are used to (among other things):

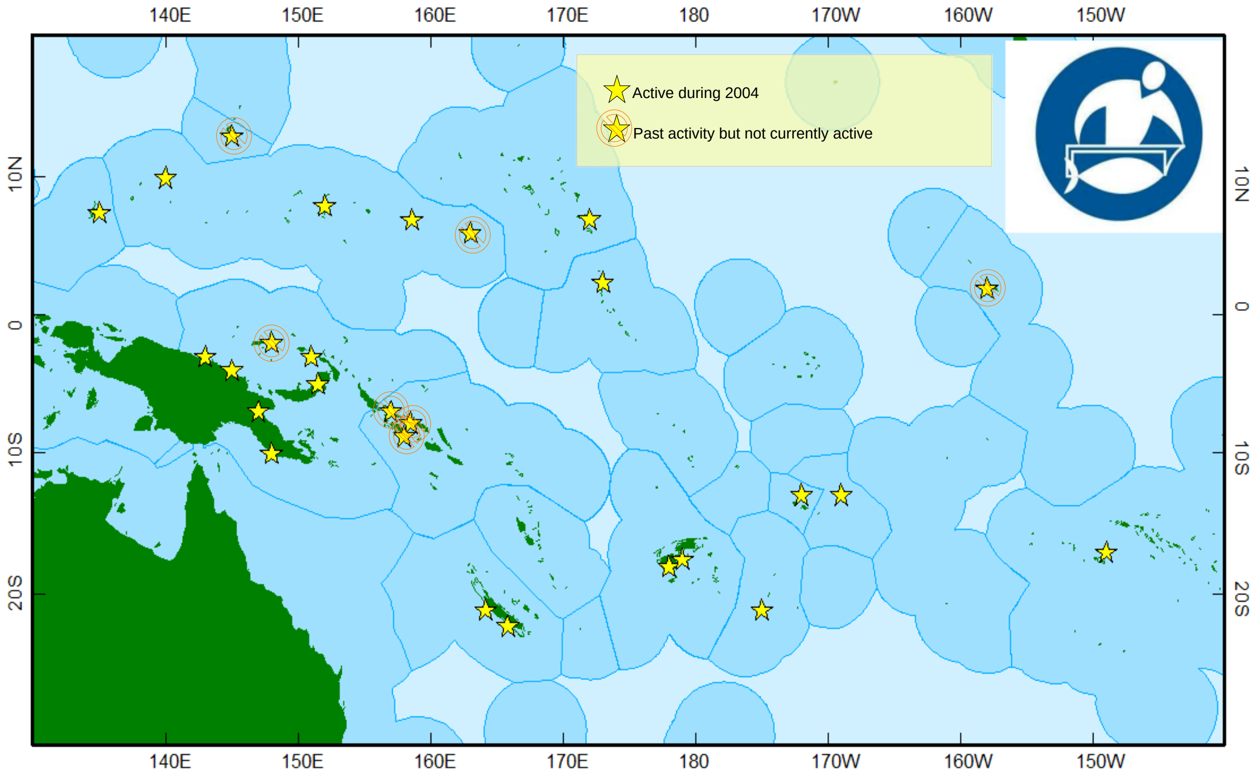
- **Validate logsheet data**
  (E.g., unloaded weights by species)

- **Quantify or characterise fishery trends**
  (E.g., length frequency data)

- **Stock assessment model inputs**
  (E.g., from which other different but related quantities such as the catch age composition may be estimated)

Port sampling data

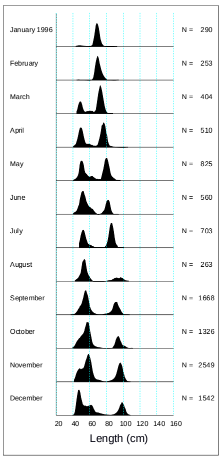
**Ports in the WCPO where length measurement and species composition sampling are undertaken



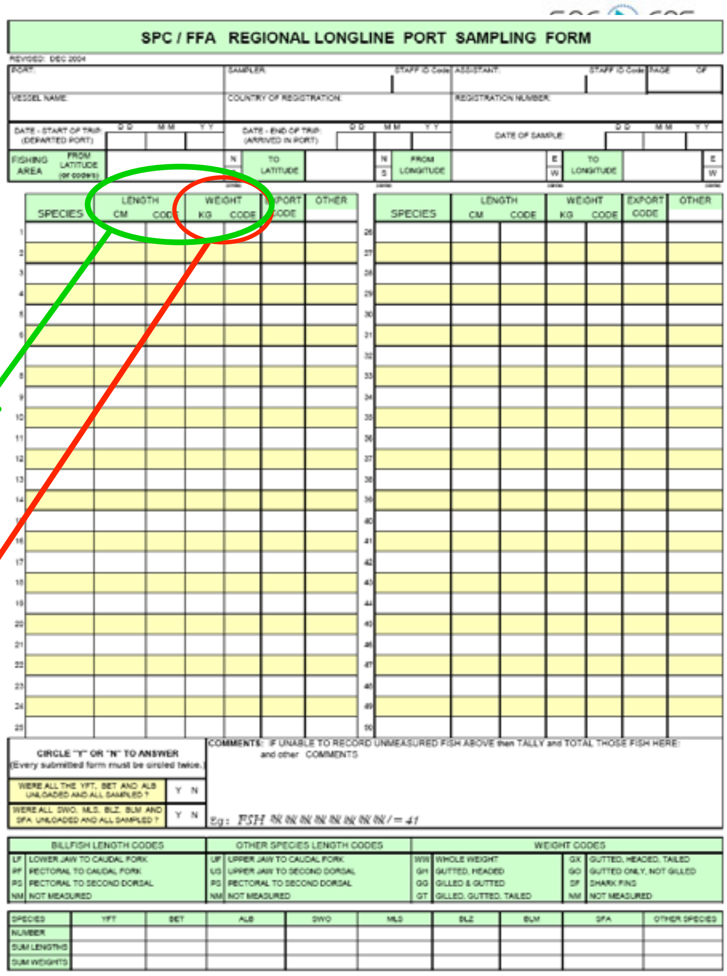
Port sampling data

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

Size data are critical to estimation of growth and mortality, and for separating age classes, in age structured models



Weight data for validating logbook catch estimates outside of assessment model



SPC / FFA REGIONAL LONGLINE PORT SAMPLING FORM

REVISED: DEC 2004

PORT: | SAMPLER | STAFF ID Code | ASSISTANT | STAFF ID Code | PAGE | OF

VESSEL NAME | COUNTRY OF REGISTRATION | REGISTRATION NUMBER

DATE - START OF TRIP (DEPARTED PORT) DD MM YY | DATE - END OF TRIP (ARRIVED IN PORT) DD MM YY | DATE OF SAMPLE DD MM YY

FISHING AREA | FROM LATITUDE | N S | TO LATITUDE | N S | FROM LONGITUDE | E W | TO LONGITUDE | E W

SPECIES | LENGTH CM CODE | WEIGHT KG CODE | EXPORT CODE | OTHER

CIRCLE "Y" OR "N" TO ANSWER (Every submitted form must be circled twice.)

WERE ALL THE YFT, BET AND ALB UNLOADED AND ALL SAMPLED ? Y N

WERE ALL SWO, MLS, BLZ, BUM AND SFA UNLOADED AND ALL SAMPLED ? Y N

COMMENTS: IF UNABLE TO RECORD UNMEASURED FISH ABOVE then TALLY and TOTAL THOSE FISH HERE and other COMMENTS

BILLFISH LENGTH CODES | OTHER SPECIES LENGTH CODES | WEIGHT CODES

LF LOWER JAW TO CAUDAL FORK | UF UPPER JAW TO CAUDAL FORK | WW WHOLE WEIGHT | GX GUTTED, HEADED, TAILED

PF PECTORAL TO CAUDAL FORK | US UPPER JAW TO SECOND DORSAL | GH GUTTED, HEADED | GO GUTTED ONLY, NOT GILLED

PS PECTORAL TO SECOND DORSAL | PS PECTORAL TO SECOND DORSAL | GG GILLED & GUTTED | SF SHARK FINS

NM NOT MEASURED | NM NOT MEASURED | GT GILLED, GUTTED, TAILED | NM NOT MEASURED

SPECIES | YFT | BET | ALB | SWO | MLS | BLZ | BUM | SFA | OTHER SPECIES

NUMBER

SUM LENGTHS

SUM WEIGHTS

Mark-recapture (Tagging*) data

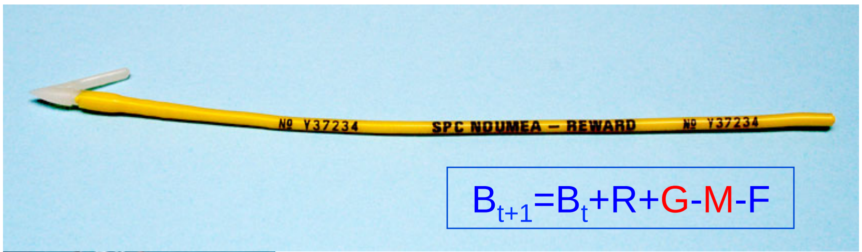
Overview

1. Mark-recapture or "tagging" experiments can potentially produce a variety of information for stock assessments:

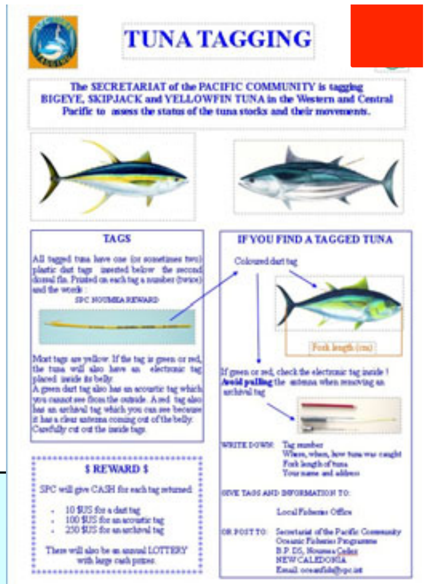
- **Movement**
- **Natural mortality**
- **Growth**
- **Exploitation rates (total and fishing mortality)**

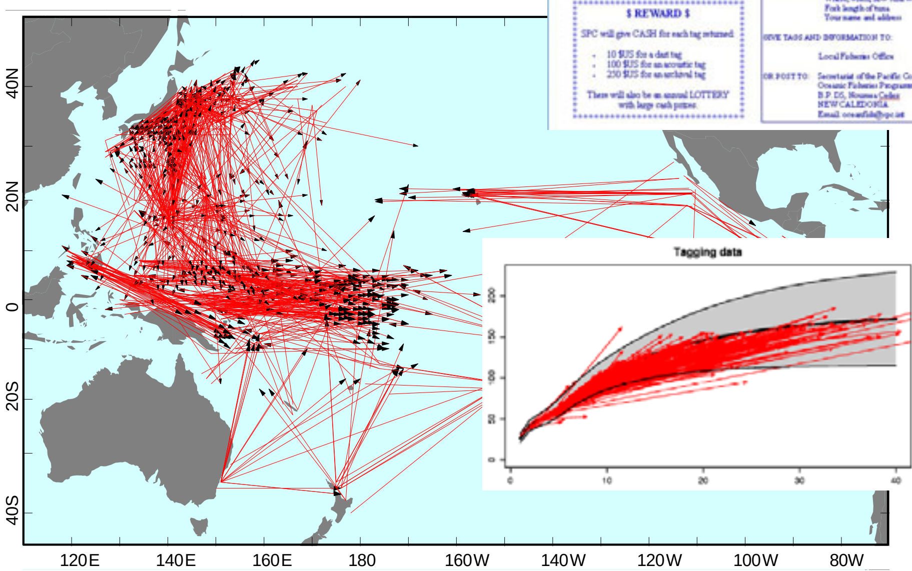
2. Different kinds of tags have different uses: c.f., "conventional" tags and modern, electronic tags (e.g., PSAT, SPOT, acoustic). However, the latter are ***much*** more expensive. (Why is this a problem? What are the implications of this?)

Conventional tags



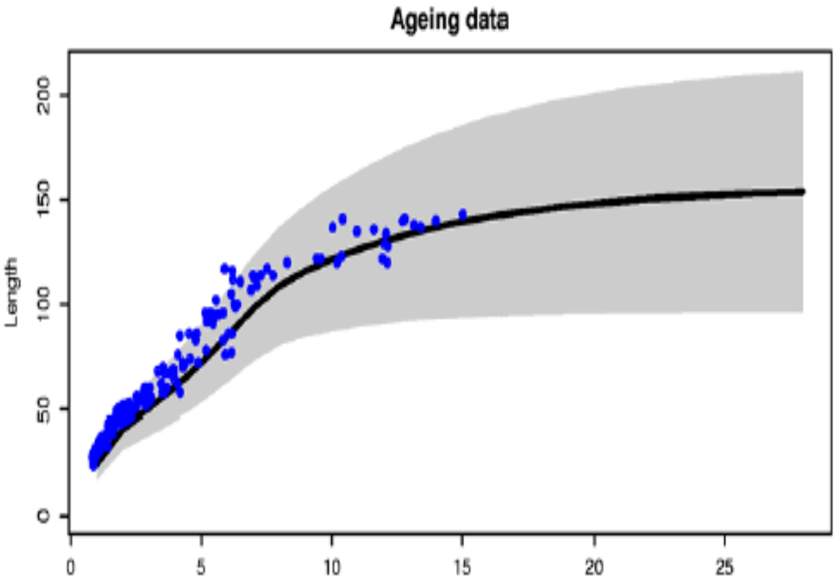
$$B_{t+1}=B_t+R+G-M-F$$

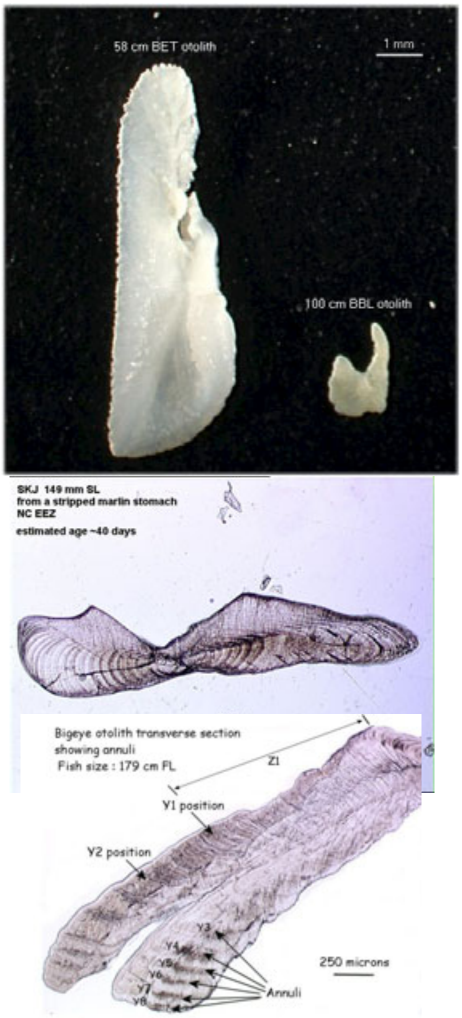




Age and growth data

In an age-structured model, the collection of age data is critical to estimation of all parameters. Fish age is estimated through analyses of seasonal growth rings (annuli) in hard body parts (e.g., otoliths or ear stones in tuna and fin spines in marlin), with these being collected by observers, port samplers or directly by scientists. (What structures might we use in sharks?)





Reproductive data

Understanding fecundity and, in particular, size and age at maturity is critical to the estimation of adult spawning biomass (which is used to estimate recruitment) within an age-structured model.

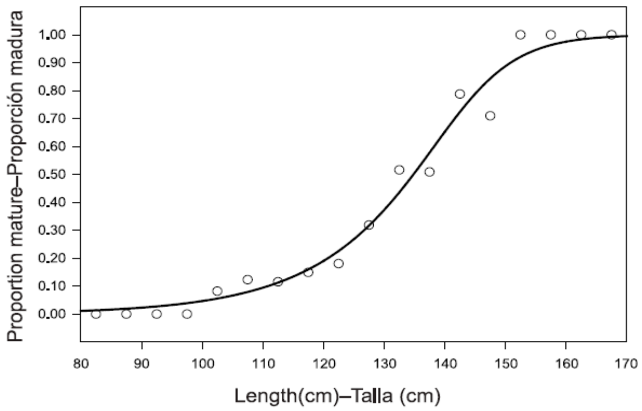
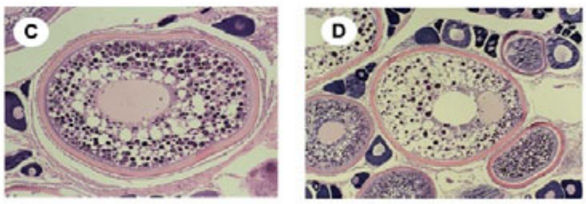


FIGURE 6. Relationship between proportion of female bigeye tuna mature and length. The circles represent the observed value in each 5-cm length interval. The curve is for the Richards

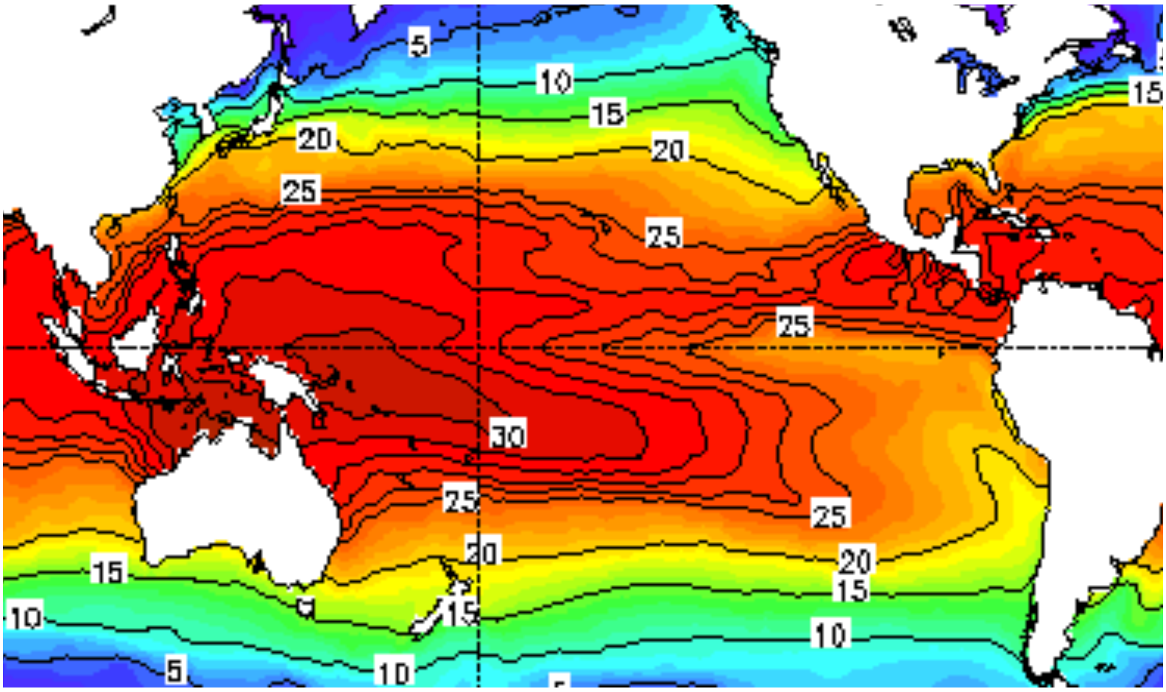


Schaefer et al. (2005)

REPRODUCTIVE BIOLOGY OF BIGEYE TUNA (THUNNUS OBESUS) IN THE EASTERN AND CENTRAL PACIFIC OCEAN. INTER-AMERICAN TROPICAL TUNA COMMISSION BULLETIN VOL 23, No. 1.

Environmental data

E.g., sea surface temperature (SST) fields



Modern remote sensing (satellite) technology allows environmental data to be gathered on an ocean-basin or global scale in near to real time cost-effectively. However, such data are not (yet) used directly in the WCPO tuna assessments.

Summary

1. Many types of data are collected for use in WCPO tropical tuna stock assessments. Most data are produced by or are associated with the fishing process ("fishery-dependant")

2. Data types collected include catch-effort and landings logsheets, fishing method data, fish size and other biological data, and environmental and oceanographic data.

3. The ongoing collection of such data **is vital** for future assessments of the tropical tuna stocks in the WCPO. **Data series length and continuity is everything.**

4. However, data quality is just as important as data quantity or coverage. There is a need to compromise between data information content and collection expense.

Summary

5. Every data collection programme should have clearly-stated objectives. Data accuracy and precision can be difficult to achieve but should always be tested.

6. The data collected in the WCPO permit WCPO tuna scientists to undertake comprehensive tuna stock assessments to provide information regarding the status of the target tuna stocks, information which is critical to the management of the tuna resources in the region

7. However, there is a particular need for more mark-recapture ("tagging") data to assist with understanding stock structure, likely present and future fishing and natural mortality levels, fish movement and growth. Hence the ongoing tuna tagging programme being run by SPC.

Discussion Exercise*

a. What is your role back home in fisheries
b. How is your job related to data collection (if at all)
c. What data are you responsible for either directly collecting or supervising/managing the collection and storage of?
d. Based on information presented in this session or your own knowledge, explain why that data is important to stock assessment (if at all).
e. Specifically, which parameters or key processes within an assessment model is the data you collect used for estimating?

Chapter 5

Fish growth

Overview

We will address five key questions during this session:

1. What is fish growth?

2. Why is proper consideration of fish growth important in age-structured stock assessment models?

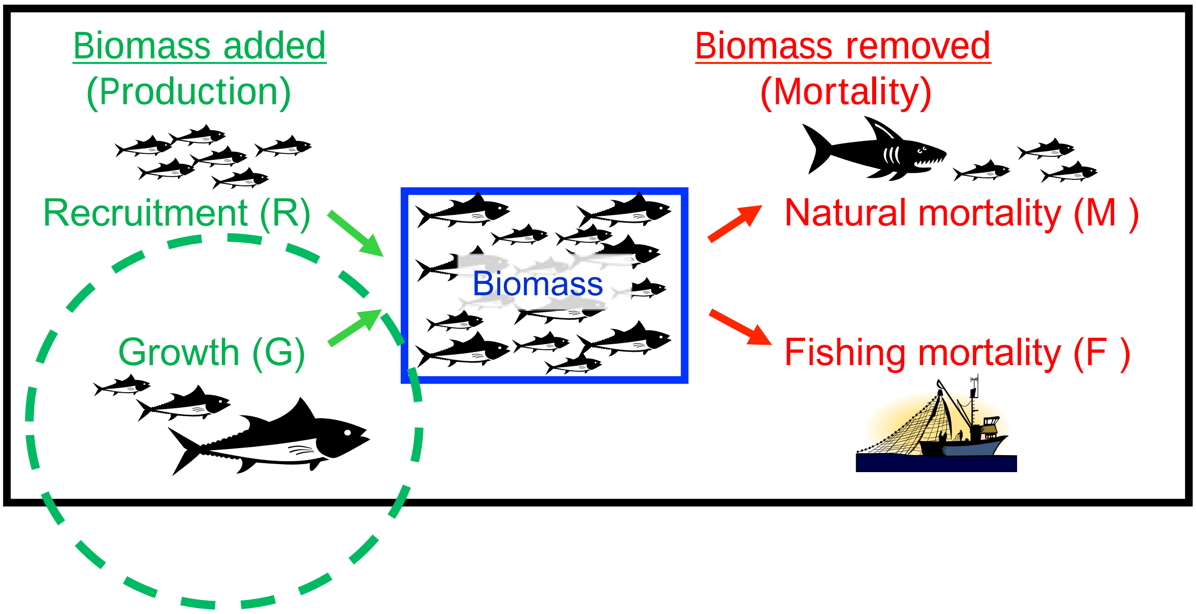
3. How do we measure and estimate growth **outside** a stock assessment model?

4. How do we use growth data **within** a stock assessment model (in particular, within MULTIFAN-CL)?

5. What particular problems are associated with using growth data in a stock assessment?

Our conceptual model of a fish population

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



What is fish growth?

Growth in fisheries science is usually defined as a change in fish size (length or weight) with age.

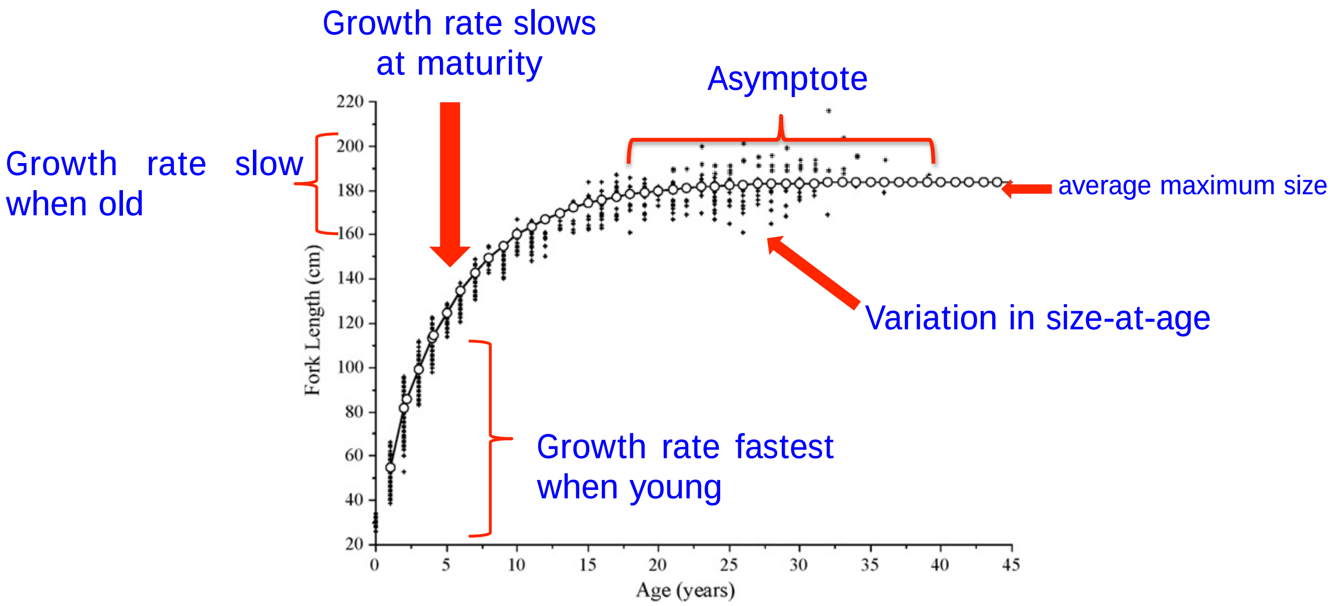
Growth is usually described in terms of average growth, as the growth of individuals can be highly variable.

Growth is an important process to understand as it:

- **Influences related population processes**
  e.g. natural mortality and maturity rates.
- **Influences the rate at which a cohort gains biomass**
  Growth is the process by which a size or age group (cohort) moving through the population increases in size and hence in biomass.
- **Influences fish vulnerability to the fishing gear**
  The vulnerability (**selectivity**) of individual fish to fishing gear often changes as fish change in size or age.

Describing Growth

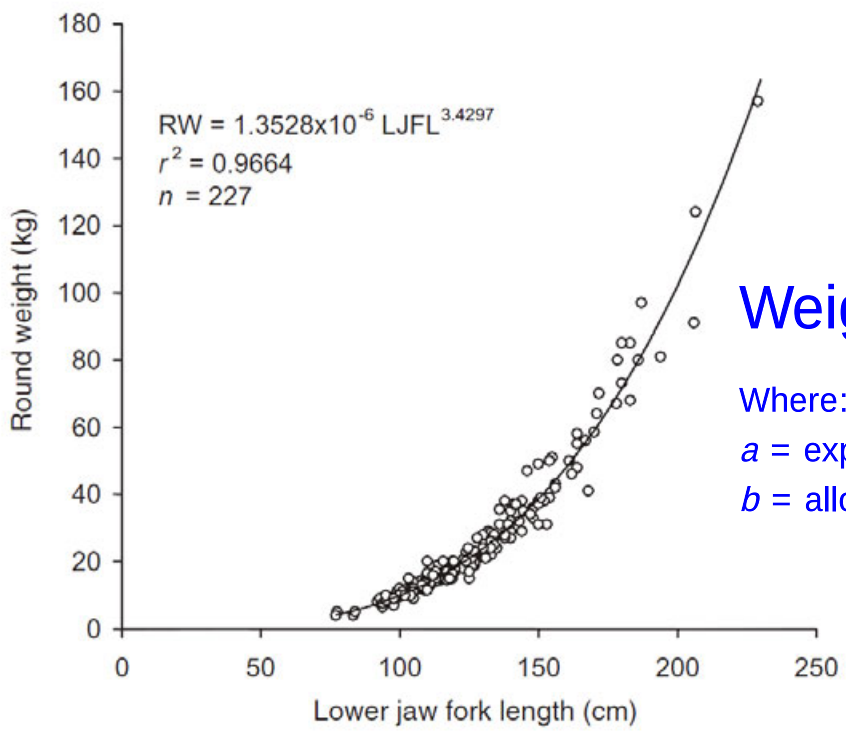
- Typically, the average growth pattern for fish is **asymptotic**,
  - Rate of growth slows down with age.
  - Growth curve reaches a species-specific maximum size or weight (asymptote).
  - **Note that not all individuals will follow the average growth trend for the species or stock – variation in size-at-age.**



Gunn et al. (2008). Southern Bluefin tuna

Length-weight relationship

Describes the rate at which a fish gains weight



Sun et al. (2003). Swordfish (Taiwan)

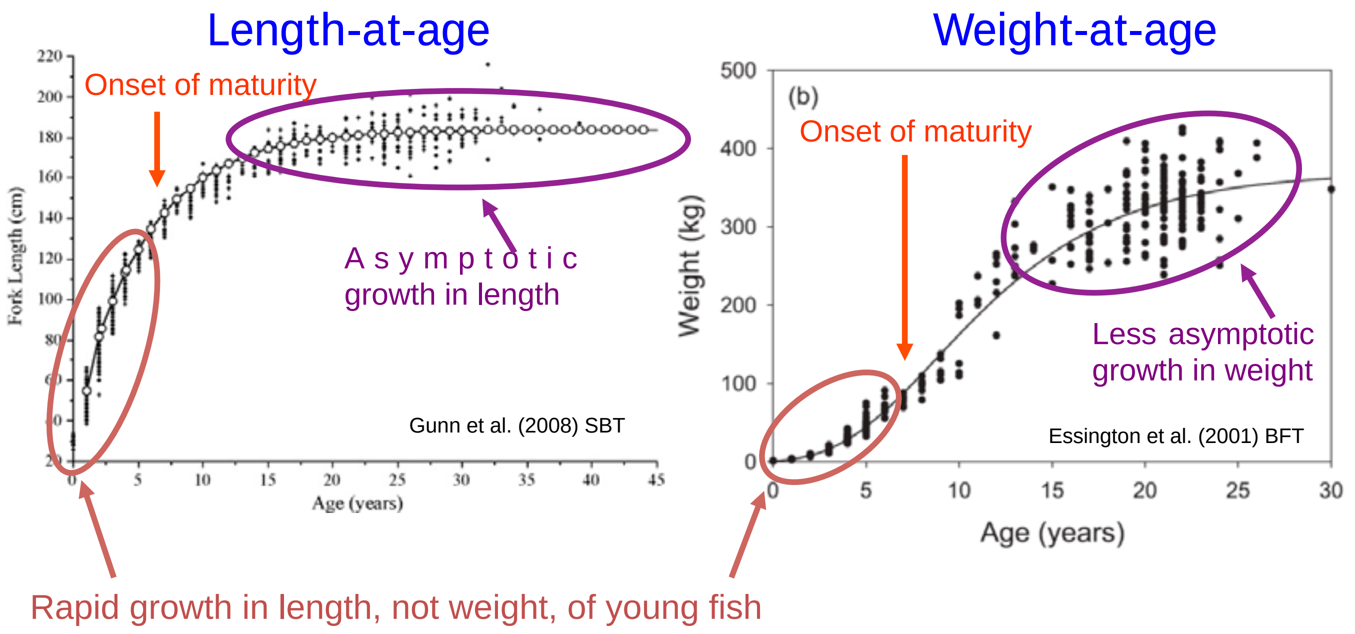
Weight = a x length^b

Where:

a = exp(intercept) from ln(W) ~ ln(L)

b = allometric growth parameter

Growth in length vs. weight

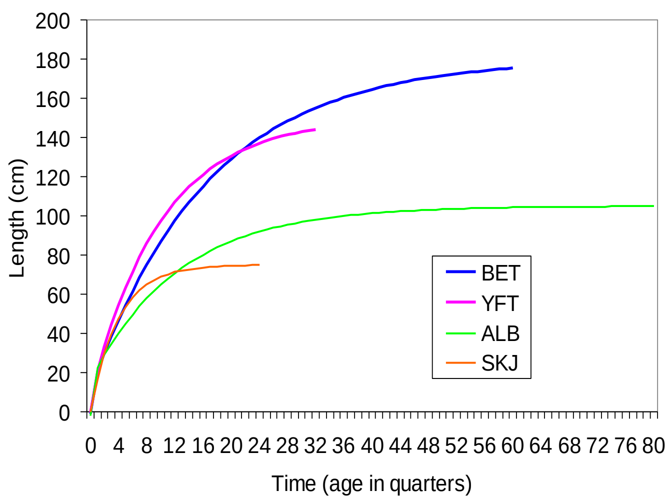


Species-specific growth

Different species grow at different rates, and to different sizes.

Accurately estimating growth rates and maximum size is critical in stock assessment as it affects estimates of:

- biomass-at-age
- vulnerability-at-age,
- maturity, mortality etc.



Growth is a crude indicator of stock productivity:

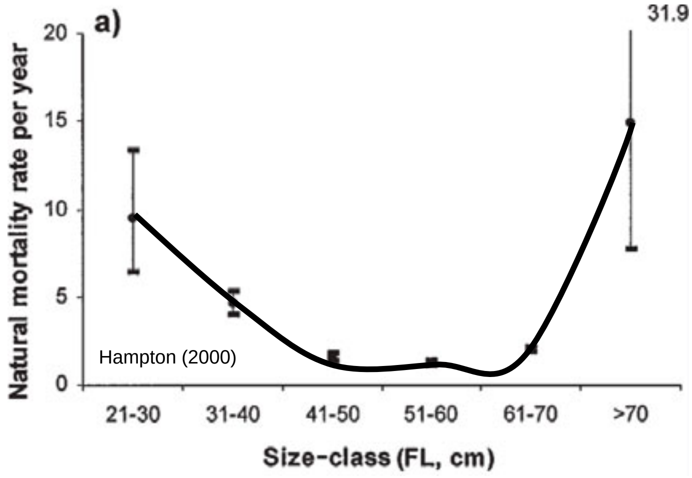
Short-lived, fast growing = **high productivity**

Long-lived, slow growing = **low productivity**

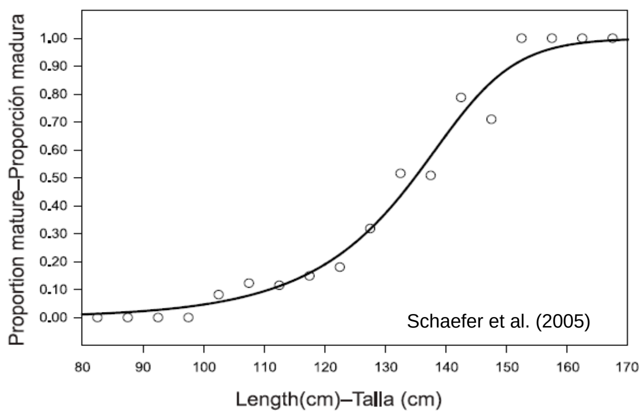
Why is growth important in stock assessment models?

1. Growth influences natural mortality and maturity

Natural Mortality - Skipjack



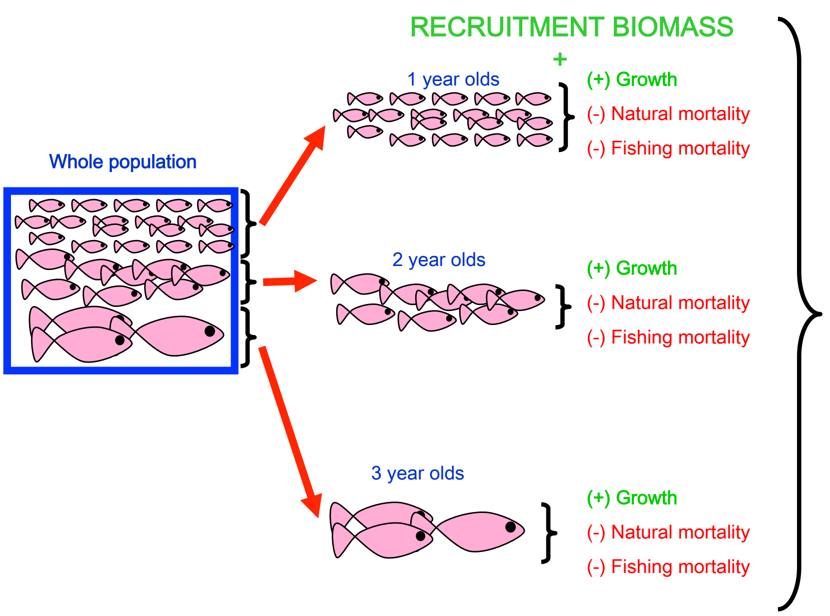
Maturity curve - Bigeye

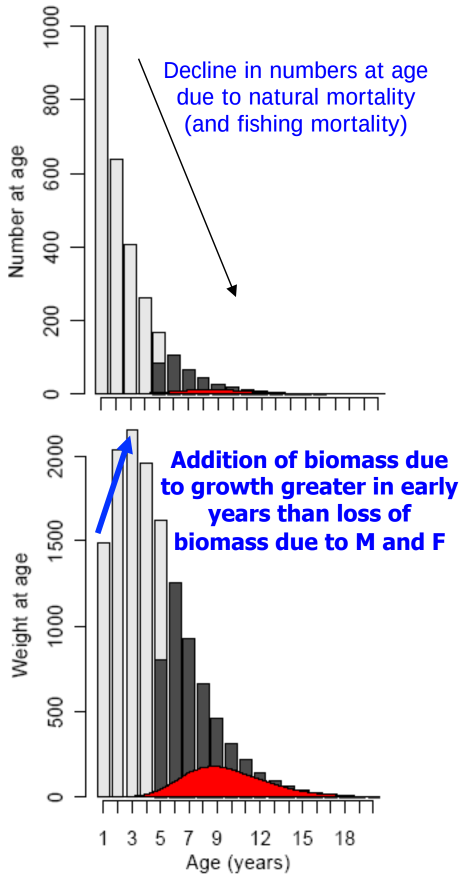


Understanding the maturity schedule of a stock is critical as it influences future recruitment

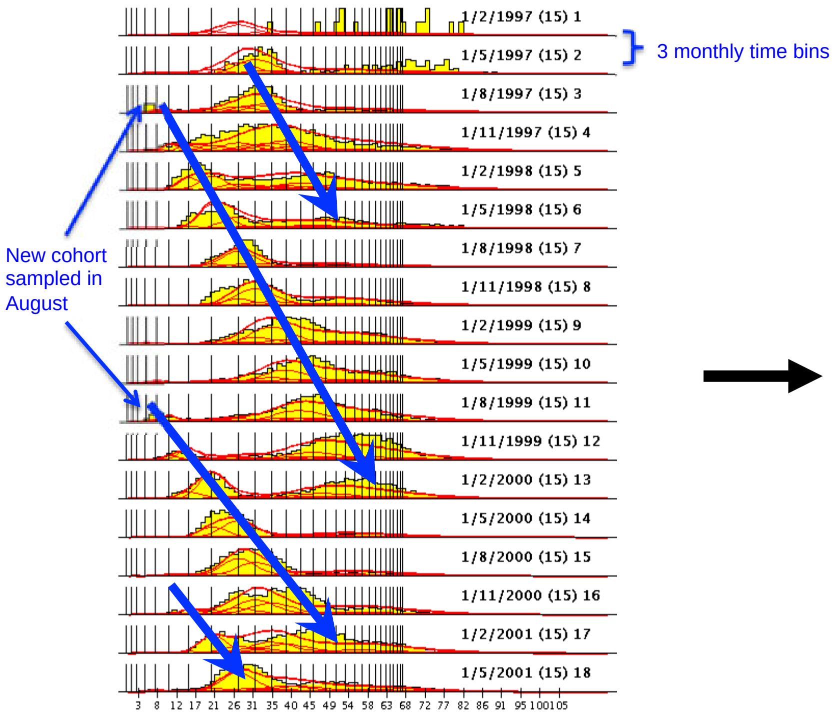
Why is growth important in stock assessment models?

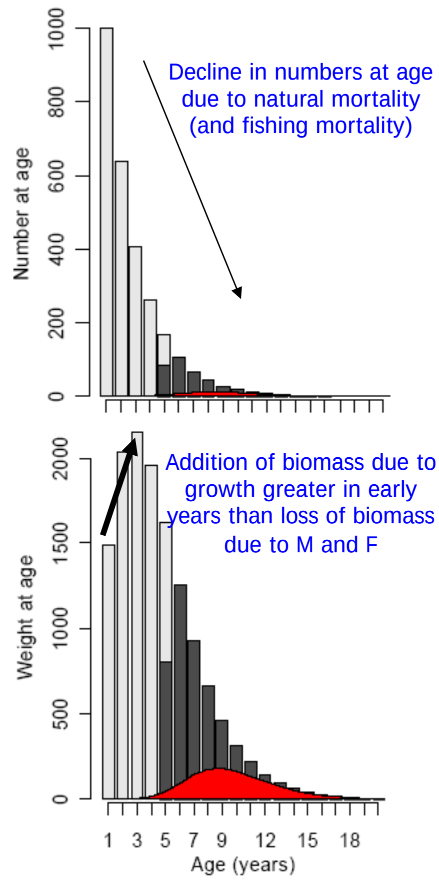
2. Increases cohort biomass





Why is growth important in stock assessment models?

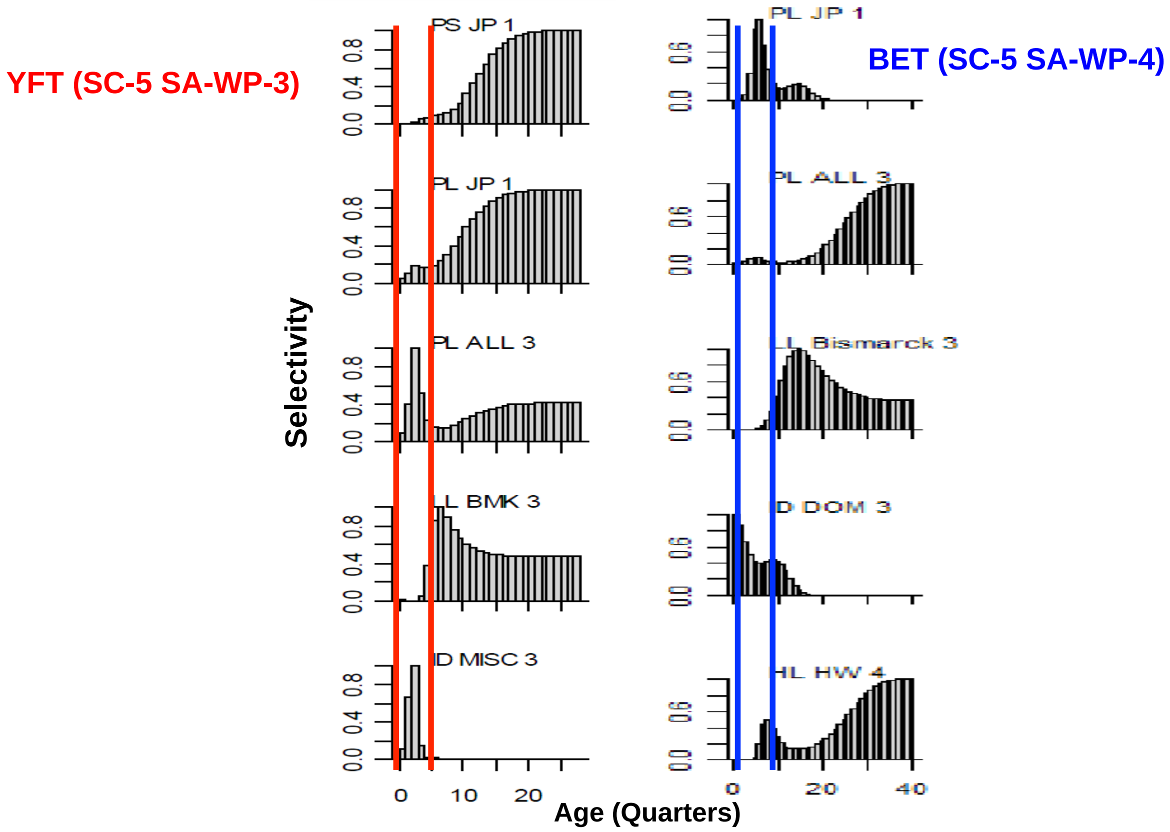




Age structured models need information regarding the growth rate of fish in different age classes, so that the model can identify age classes (cohorts) from the size data provided to the model, track them through time, and apply appropriate age-specific natural and fishing mortality factors to each age class.

Why is growth important in stock assessment models?

3. Influences cohort average vulnerability to the fishing gear (**selectivity**)

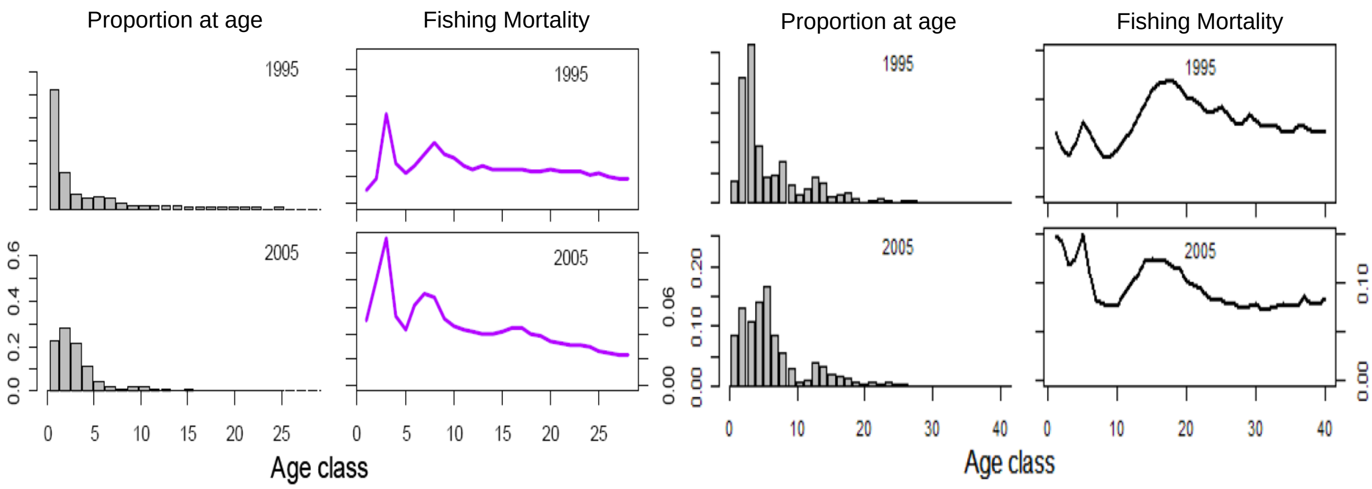


Why is growth important in stock assessment models?

3. Influences cohort average vulnerability to the fishing gear

YFT - (SC-5 SA-WP-3)

BET - (SC-5 SA-WP-4)



How is fish growth estimated?

Estimated by a model or measured

Various data sources and methods can be used. WCPFC stock assessments typically incorporate a combination of sources :

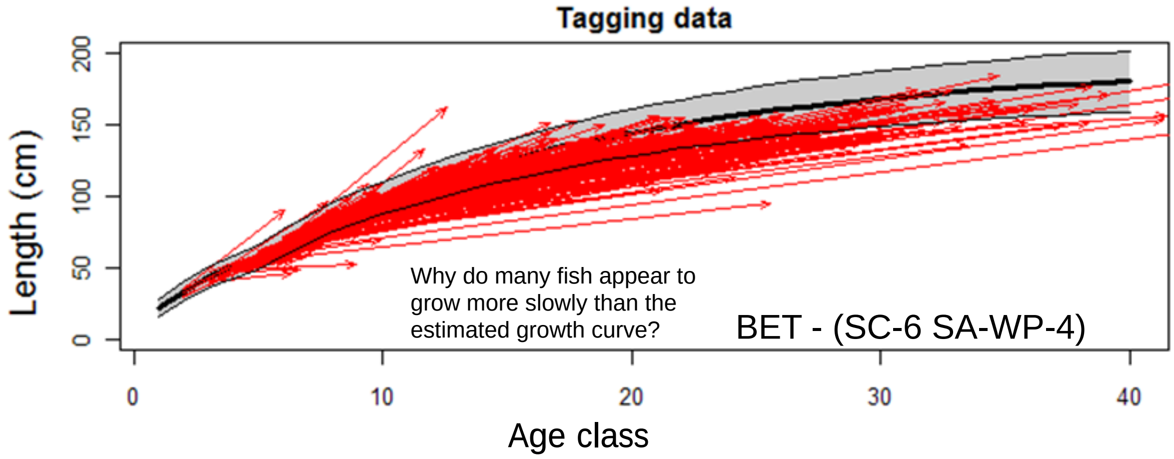
- **Mark-recapture (tagging) studies**
  Compare the relationship between **size-at-release**, **size-at-recapture**, and the time at liberty. (How much did the fish grow between release and recapture).

- **Length frequency modal progression**
  Length frequency data collected from a fishery can be split into the individual length frequency modes that correspond to each age class. (NB: **this is what is done inside MFCL**.)

- **Analysis of hard (calcified) body parts**
  Calcified body parts such as otoliths (ear bones), vertebrae, or scales often have visible (at least under a microscope) growth rings. Counting the number of growth rings provides an estimate of age for an individual fish. A growth model can then be fitted to the length and age data.

How is fish growth estimated?

1. Mark-recapture data



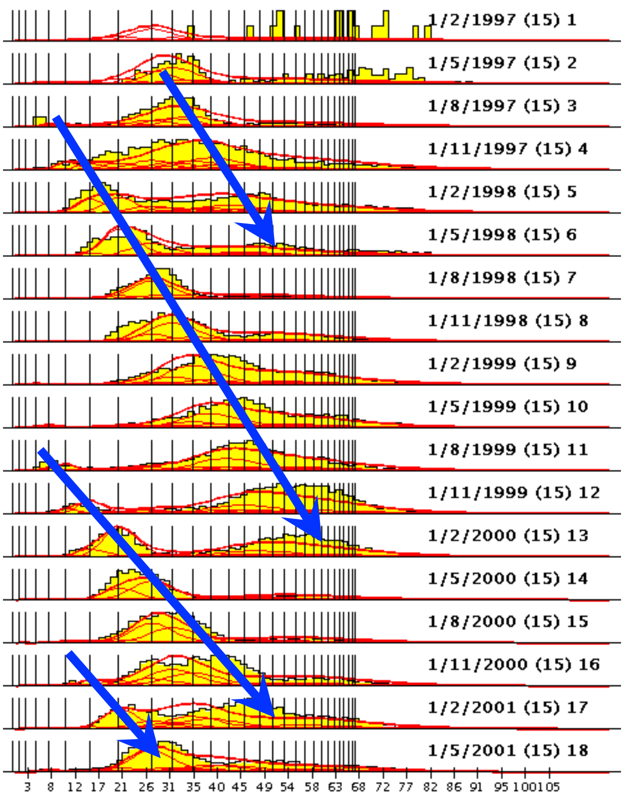
Tagging data can be very valuable for estimating growth, assuming that:

1. there are no tag effects on growth.
2. tagging is conducted in a manner that is representative of the fish population as a whole and over time.
3. Recapture information (length and date) are accurately reported.

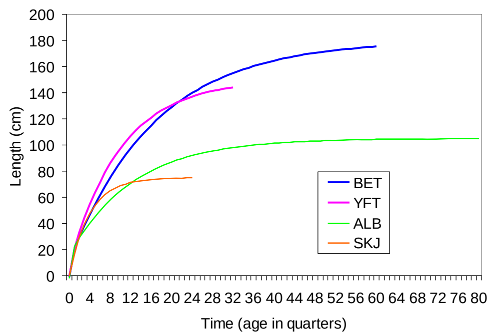
Mark-recapture studies are typically expensive, and need to be well planned to produce data that is representative of the stock.

How is fish growth estimated?

2. Modal progression analysis

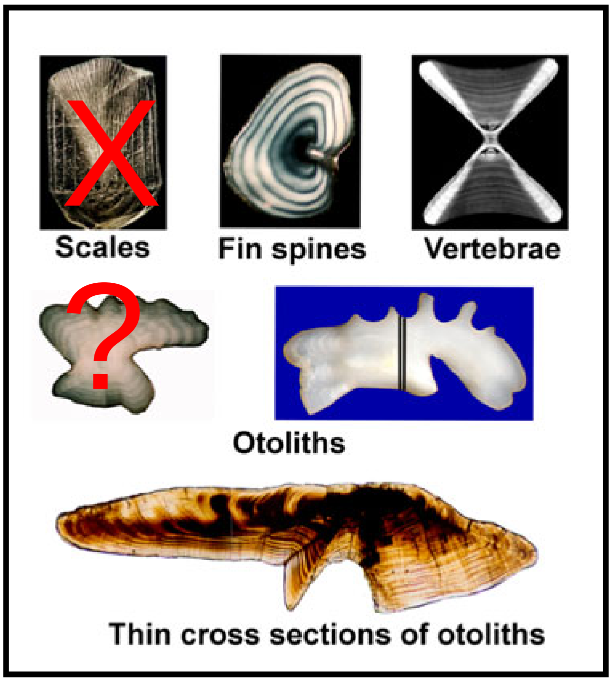


- Size frequency data can be used to identify and track fish cohorts (age classes) through time, providing an estimate of growth.
- Merging of length or size modes of fish in older age classes can make it more difficult to apply this method correctly (e.g. Albacore)



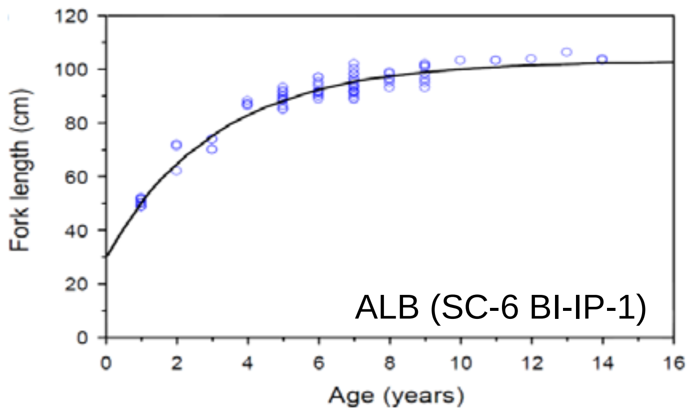
How is fish growth estimated?

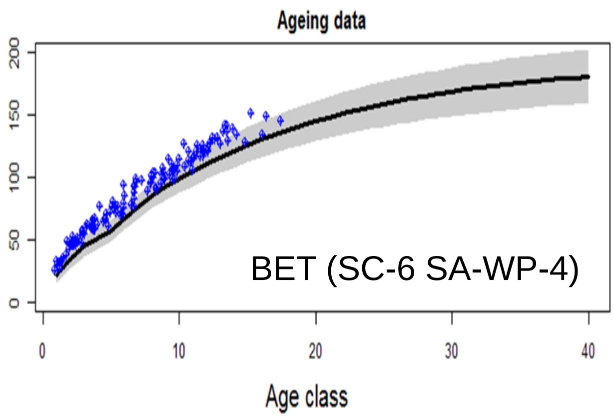
3. Analysis of hard body parts such as otoliths

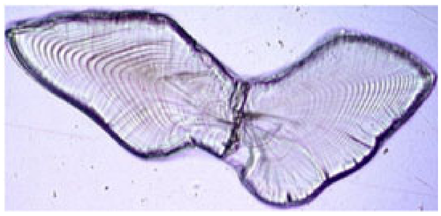


How is fish growth estimated?

3. Analysis of hard body parts such as otoliths







- Counts of growth increments in otoliths provides a direct estimate of age
- We can plot size against age for a sample from the population to estimate average growth curve
- But why do otolith data indicate that fish grow faster (than the estimated growth curve from size-frequency and tagging data)?

How is fish growth estimated?

3. Analysis of hard body parts such as otoliths

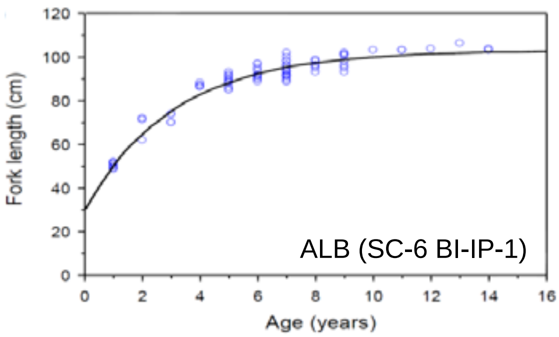
$ $

Growth estimates from hard parts can be extremely valuable, but…

- Hard body-part studies can be expensive, and data collected need to be representative of the stock.
- Otolith reader accuracy must be tested and monitored on an ongoing basis to prevent unconscious shifts in reader interpretation from occurring.
- The periodicity of growth increments must be ***validated***, e.g. via tetracycline marking.

Fish growth models

1. A range of models (curves) have been developed to describe fish growth.
2. The choice of model to use depends on the question, i.e.
   - To predict age from size data - Choose model that best fits the data (usually the approach taken for stock assessments)
   - To understand the growth process – Choose model with (biologically) meaningful parameters
3. Growth models typically provide an estimate of mean growth rate and mean maximum size (in length or weight).



Fish growth models

The von Bertalanffy (VBGF) growth model

For better or for worse, the von Bertalanffy growth function (VBGF) is the most commonly used to describe the length-age relationship in fish.

$$L_t = L_\infty\left[1 - e^{-K(t-t_0)}\right]$$

L_t = fish length at time t

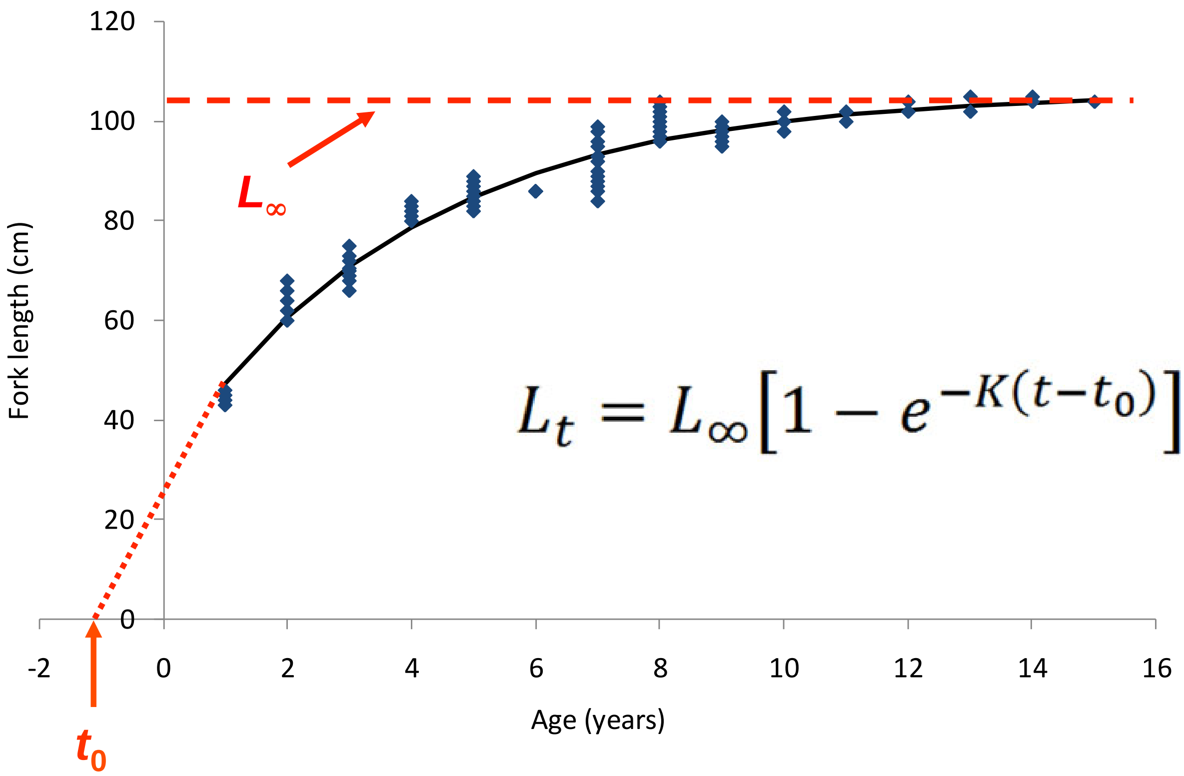
L_∞ = average maximum length for the population

K = the rate at which a fish will approach L_∞.
K is **not** the growth rate. The units of K are in time^{-1} rather than change in size per unit of time.

t_0 = theoretical age at length 0

K and t_0 have little biological meaning

Fish growth models



Fish growth models

The von Bertalanffy growth model for weight at age

Combining the VBGF with a length-weight relationship gives

$$W_t = W_\infty \left[1 - e^{-K(t-t_0)}\right]^b$$

W_t = fish weight at time *t*

W_∞ = average maximum weight for the population

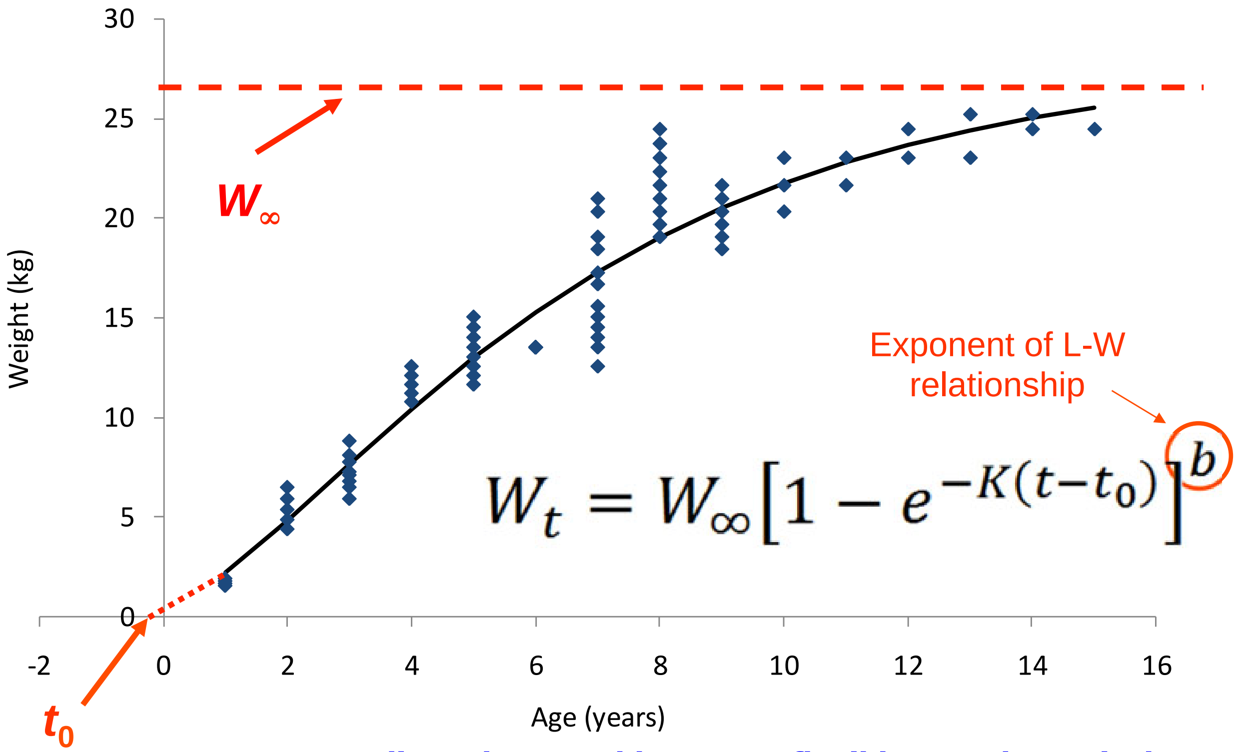
e = the base of the natural logarithm

***K* =** the exponential rate of approach to the asymptotic size (W_∞)

b = the allometric growth parameter

t_0 = theoretical age at weight 0

Fish growth models



Many, more complicated, arguably more flexible, mathematical growth models do exist (e.g., Schnute 1981)…

Fish growth models

Typical effects of varying the VBGF parameters:

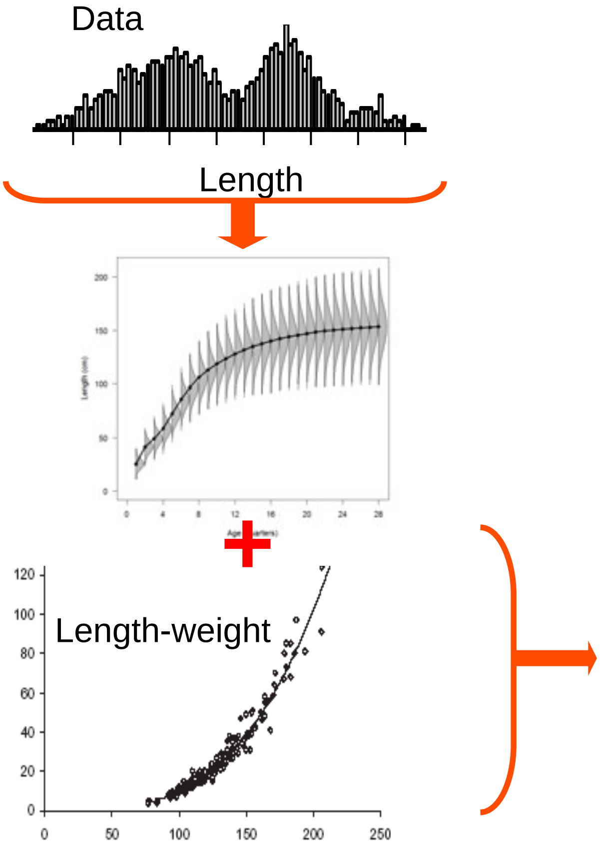
1. The parameters ***K*** and L_∞ are very strongly negatively correlated.
2. ***K*** and L_∞ values have a large effect on the resulting growth curve.
3. Changes in the estimates of VBGF parameters will, in-turn, alter the size-at-age relationship and ultimately estimates of biomass and other variables produced in the stock assessment (e.g. influence on the SRR and therefore recruitment strengths estimated in the stock assessment)
4. These feed into Biological Reference Point estimates (e.g. B_{curr} / B_{msy})

Understanding fish growth, is critical in an age-structured stock assessment model!

How are estimates of growth used within an age structured stock assessment model?

(with MULTIFAN-CL as the example)

How are estimates of growth used within age structured models?



Step 1: collect size-frequency data from the fishery that are representative of the stock

Step 2: determine the stock length-at-age and weight-at-length relationships.

Step 3: model inputs
(to estimate biomass-at-age, recruitment strengths, etc.)

How are estimates of growth used within age structured models?

Conversion factors:

1. Conversion factors (CFs) are used to covert lengths to weights (biomass) of from one length/weight measurement to another and so on. E.g.,

   Whole weight = processed weight x CF

2. Usually, lengths are measured in a similar way for each species, although some particular differences exist (e.g., the use of fork lengths, lower jaw to fork length, pectoral fin to fork length etc. depending on species anatomy)

3. Weight data may be collected from the fishery and supplied in a number of ways (e.g., whole weights, gilled and gutted, trunked etc), some more convenient than others.

Standardisation of fish size or weight data over the number and diversity of tuna fisheries in the WCPO is difficult but is absolutely necessary for use in MFCL!

How are estimates of growth used within age structured models?

SPC CPS

Inside MFCL:

1. The VBGF parameters determined from biological research are critical, and can be used in the model as starting values or define a plausible range for estimates produced during the model fit.

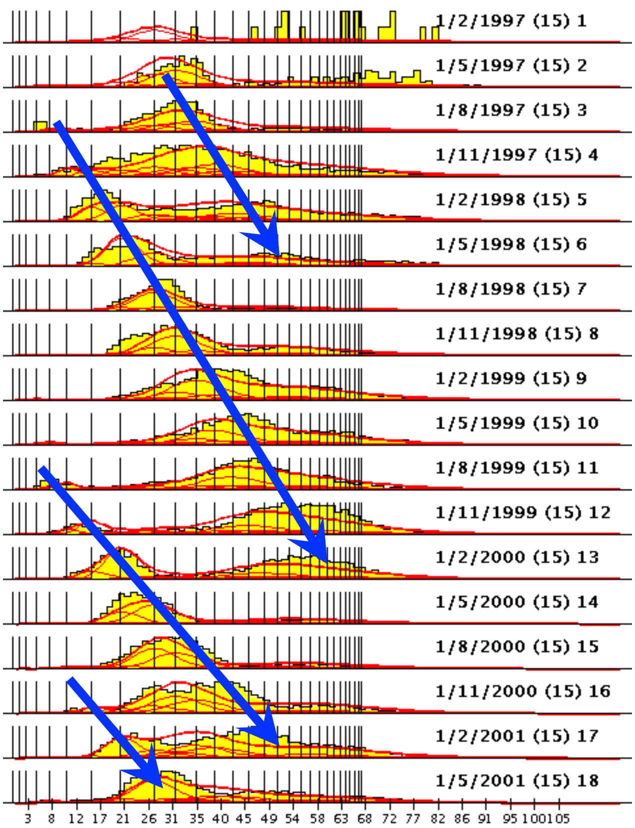
2. Weight-at-length and length-at-age relationships are used to convert lengths to ages and then to weights in order to generate the biomass of fish at each model time–step and total biomass.

3. MFCL uses these parameters to "grow" cohorts of fish through to the appropriate size class with each time step. Variations in the size-at-age of individual fish are accommodated (by incorporating variation around the mean length-at-age relationship)

Age and growth data give the model the rules to define, the model ages and grows each age-class of fish during each model time step

How are estimates of growth used within age structured models?

SPC CPS



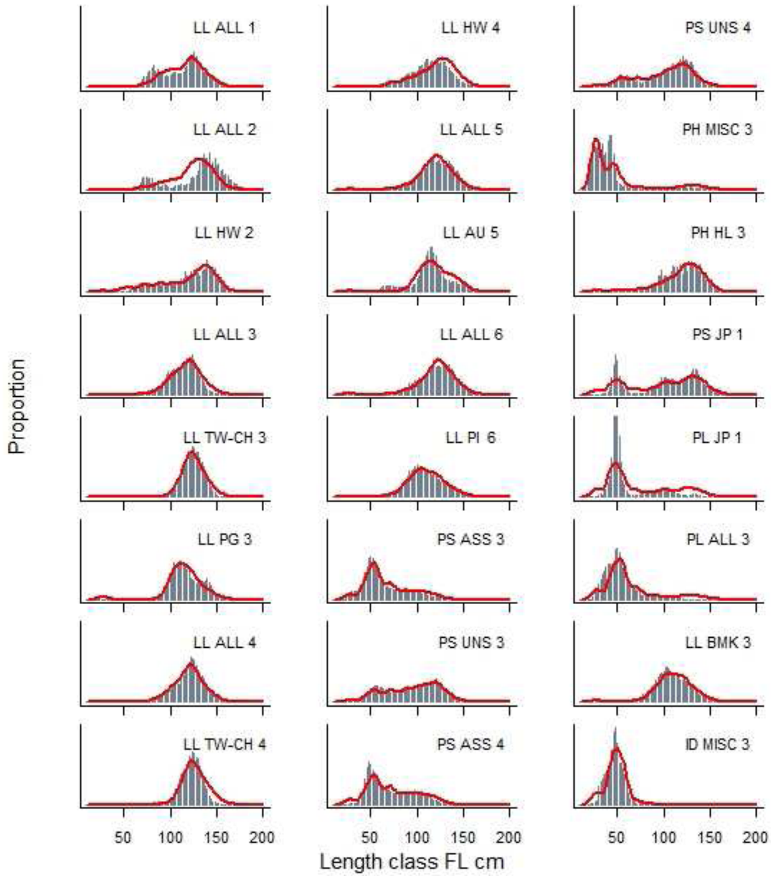
Age cohorts within MFCL

The key to an age-structured model like MFCL is to be able to identify and change ("progress") age-groups or cohorts of fish.

NB: **"age cohort"** = a group of fish generated during the same spawning season and born during the same time period.

Cohorts can be identified from length-frequency data by looking for modes in the data (NB: length-frequency mode decomposition to estimate age)

How are estimates of growth used within age structured models?

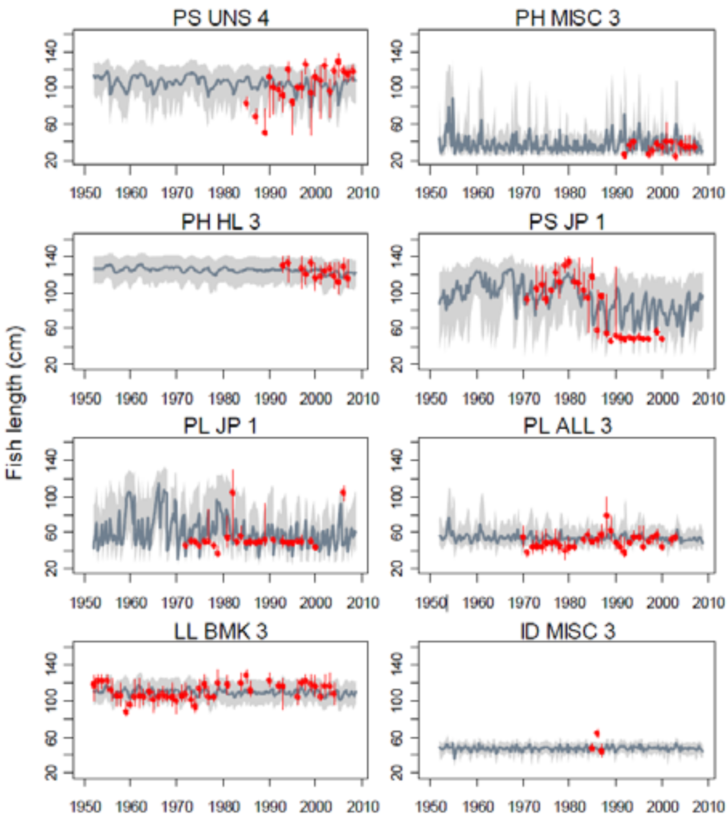


Some actual MFCL results

To the left are observed (grey) and model-predicted (estimated - red) length distributions for each fishery defined in the 2009 YFT assessment.

A comparison between observed and predicted values is always incorporated into each assessment. This can be a very important indicator of model **"goodness-of-fit".**

How are estimates of growth used within age structured models?



Some actual MFCL results

Grey – predicted size
Red – observed sizes

"Residual" fits to the length data for YFT from the 2009 assessment. (Residual = a way of measuring the distance between an observed and a fitted value).

Residual plots are another important goodness-of-fit diagnostic that you will see if you read the MFCL assessment reports or attend the WCPFC-SC.

Example: for PS JP1, we see that the model predicts too many "large" fish after 1990.

How are estimates of growth used within age structured models?

YFT - (SC-5 SA-WP-3)

Table 7. Details of objective function components for various model options.

Objective function component	CPUE low, LL sample high, LL q incr	CPUE high, LL sample low, LL q incr	CPUE low, LL sample high	CPUE high, LL sample low	Base 2007	Base 2007, steepness 0.75
Length frequency log-likelihood	-372,200.20	-344,431.70	-372,206.00	-344,424.90	-410,082.70	-410,082.20
Principal LL fisheries	-89,221.58	-61,168.68	-89,220.20	-61,165.51	-97,652.02	-97,652.35
Other fisheries	-282,978.60	-283,263.00	-282,985.80	-283,259.40	-312,430.70	-312,429.80
Weight frequency log-likelihood	-670,570.30	-592,920.70	-670,564.10	-592,909.40	-735,160.80	-735,160.40
Principal LL fisheries	-402,445.10	-324,736.20	-402,442.00	-324,735.70	-440,745.90	-440,745.90
Other fisheries	-268,125.30	-268,184.50	-268,122.20	-268,173.70	-294,414.90	-294,414.60
Tag log-likelihood	2,598.64	2,608.71	2,594.68	2,600.83	2,640.06	2,639.57
Total catch log-likelihood	89.65	172.80	89.61	172.15	486.18	486.24
Penalties	2,485.21	3,641.19	2,485.81	3,627.23	5,953.26	5,949.79
Total function value	-1,037,597.00	-930,929.70	-1,037,600.00	-930,934.10	-1,136,164.00	-1,136,167.00
gradient	0.00081	0.02958	0.07894	0.01785	0.00092	0.00084

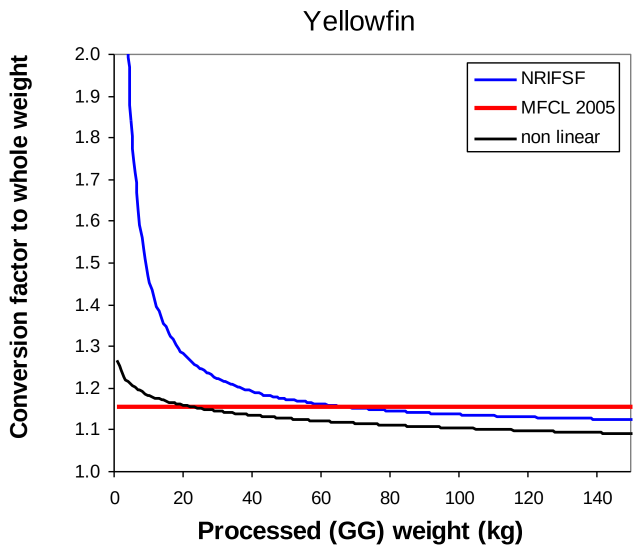
What problems are associated with using “growth” data in stock assessment models?

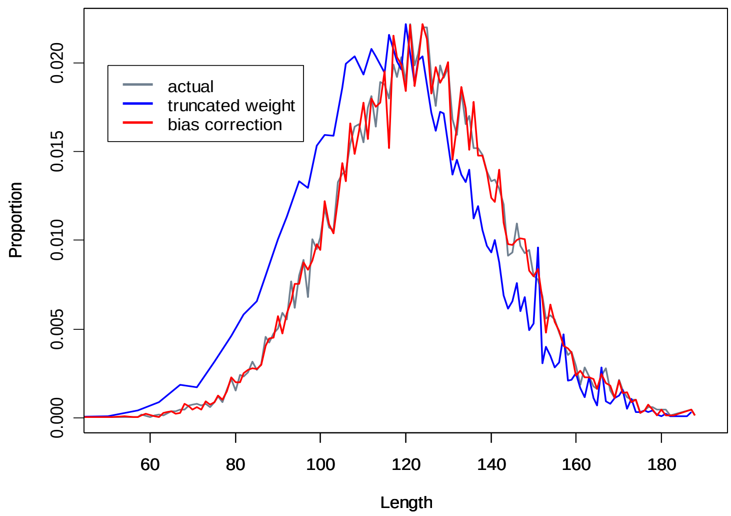
Why the difference between observed and expected lengths and weights?

Possible explanations include:

1. Variability in size-at-age
2. Lack of data for very small fish
3. Gear selectivity – catching the faster growing young fish
4. Rounding errors in weight data
5. Differences in processing methods among fleets and through time. The application of a single CF may not be appropriate
6. Others?

Why the difference between observed and expected lengths and weights?





Potential to introduce biases into biomass estimates

May explain some differences between observed and expected size data

Summary

Why do we worry about fish growth?

1. Growth is a key factor in influencing 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.

Summary

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 L_∞ (mean maximum fish length), K (rate at which L_∞ is approached) and t_0 (theoretical length at age 0).

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.

Chapter 6

Parameter estimation – Recruitment

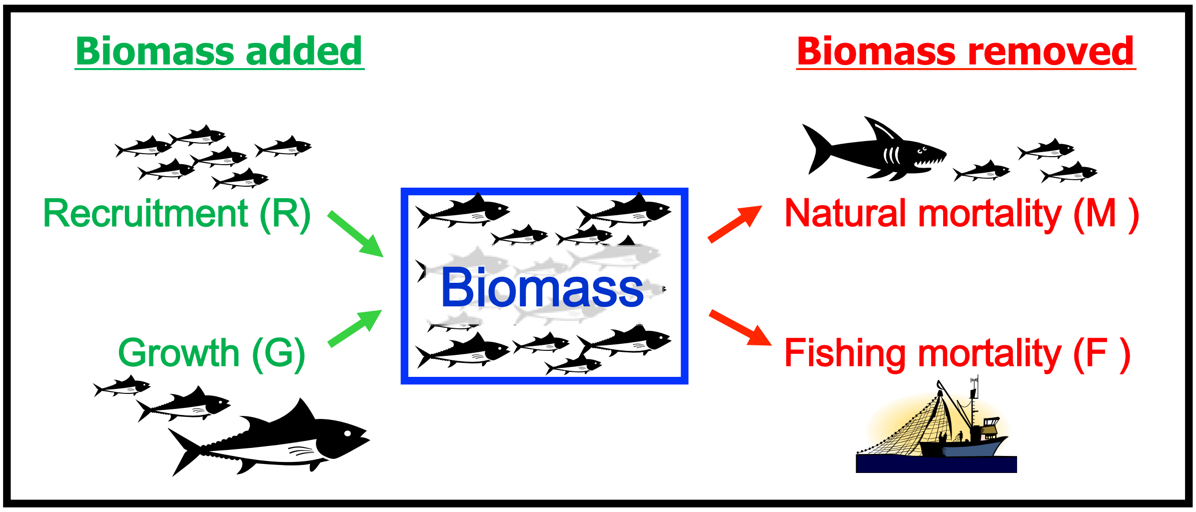
Session overview

You were briefly introduced to the concept of recruitment yesterday. Today we are going to expand on that description

1. What is recruitment?
2. Why do we estimate recruitment in stock assessment models?
3. What are the key factors that influence the recruitment level?
4. How do we estimate recruitment
   a. Stock recruitment hypothesis
   b. Estimation of recruitment by MULTIFANCL for WCPO assessments

Our conceptual model of a fish population

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



What is recruitment?

What is Recruitment?

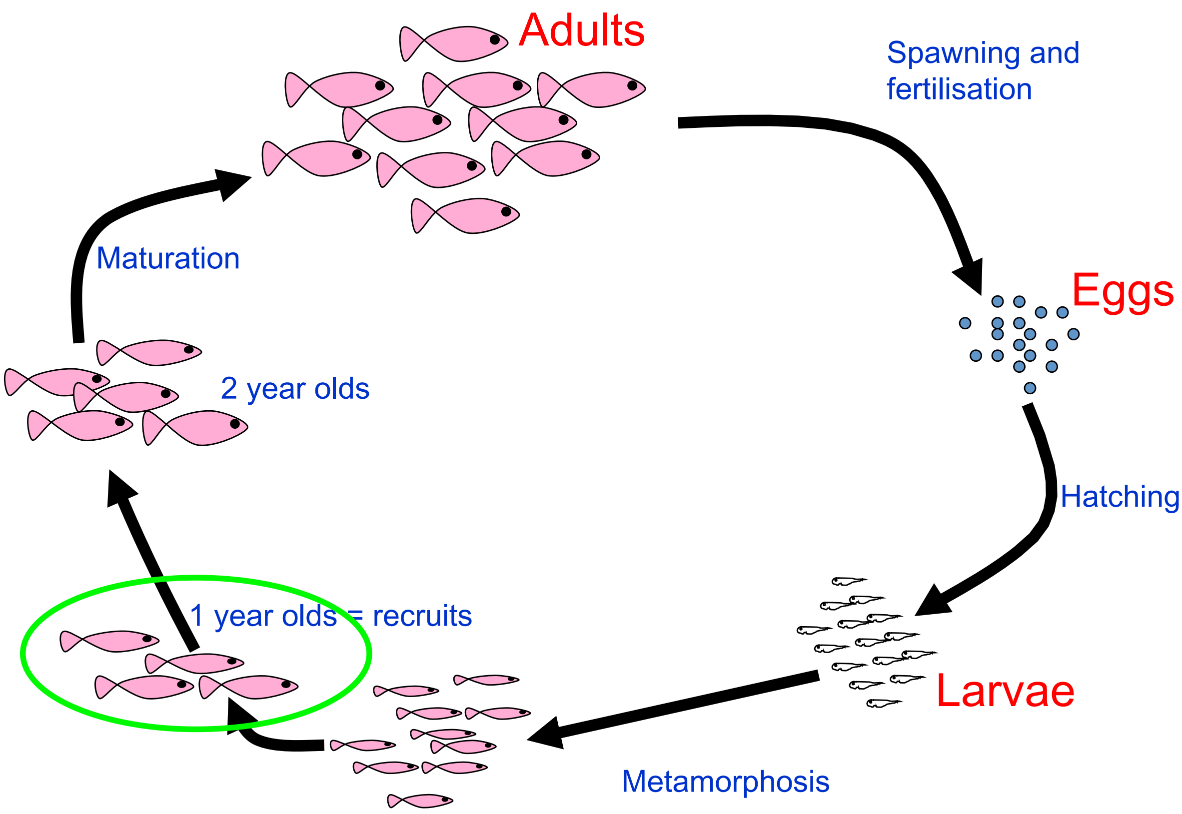
$B_{t+1}=B_t+R+G-M-F$

- Annual recruitment is defined as the number of animals “added to the population” each year.
- However, recruitment is also defined by when recruitment occurs:
  - at birth (mammals and birds);
  - at age one (mammals and birds, some fish);
  - at settlement (invertebrates / coral reef fishes);
  - when it is first possible to detect animals using sampling gear; and
  - when the animals enter the fishery.
- All of these definitions are “correct” but you need to be aware which one is being used.

WCPO Skipjack, yellowfin and bigeye tunas all recruit to the purse seine fishery at around 0.5-1 years of age. Before that point it would appear that they are too small to be caught by any commercial gear. Albacore tuna recruit to the troll fishery at around 2 years of age.

What is recruitment?

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



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

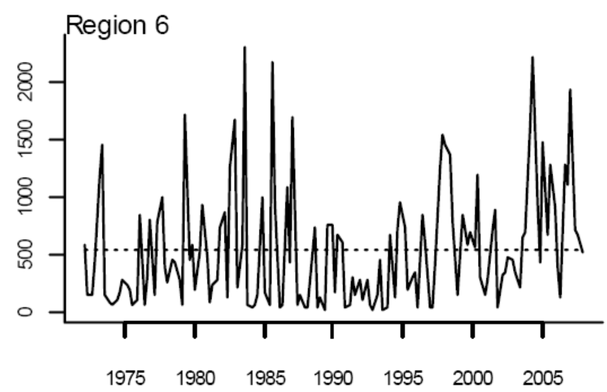
What are the factors that influence recruitment level?

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

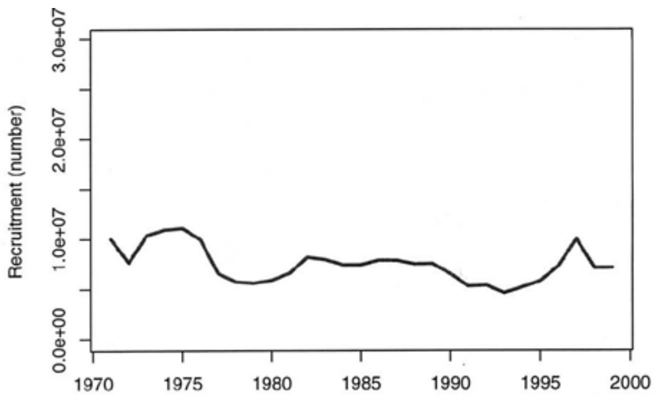
Recruitment trends

Recruitment over time for......

A tuna species



A shark species

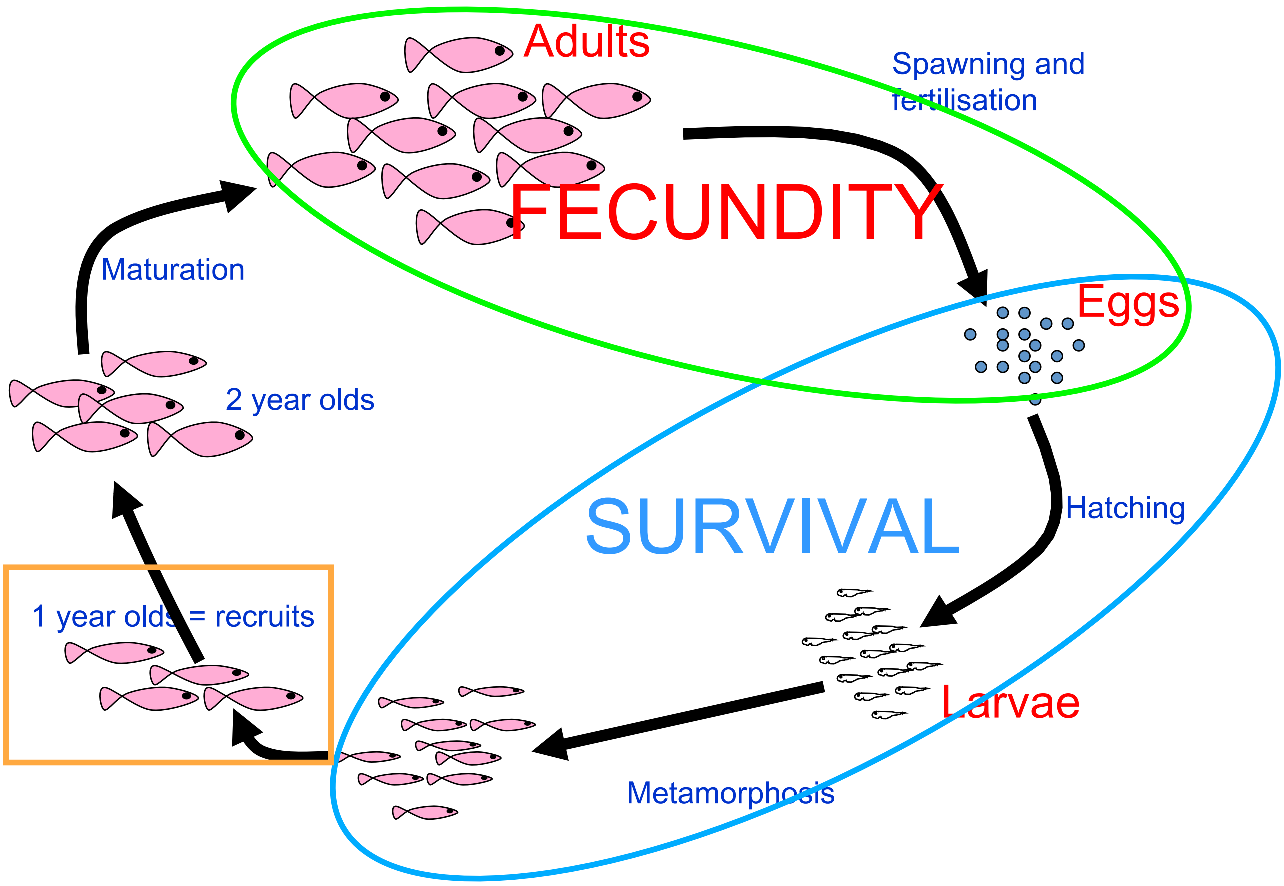


How would you describe the trend in recruitment over time for the tuna species? For the shark? Stable? Highly variable?

How can tuna recruits in one year be 2-3 times higher than the next? Why is there less variation for the shark?

Key factors influencing recruitment

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



Key factors influencing recruitment

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

Fecundity: Processes that effect egg production

Total stock egg production per time period (e.g. year) will be a product of:

- Number of spawnings per year
- **Number of mature females**
- Age (e.g. older adults might produce more eggs)
- Eggs per spawning

Many of which might be also effected by

1. Adult condition: e.g. Nutritional condition and stress factors
2. Environment (e.g. water temperature)
3. Other

Key factors influencing recruitment

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

Survival: Processes that effect egg, larval and juvenile survival

Biotic (e.g.)

- Starvation
- Predation
- Disease

Abiotic (e.g.)

- Temperature
- Salinity
- Oxygen

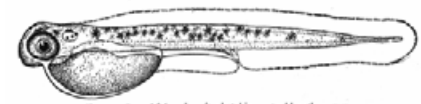
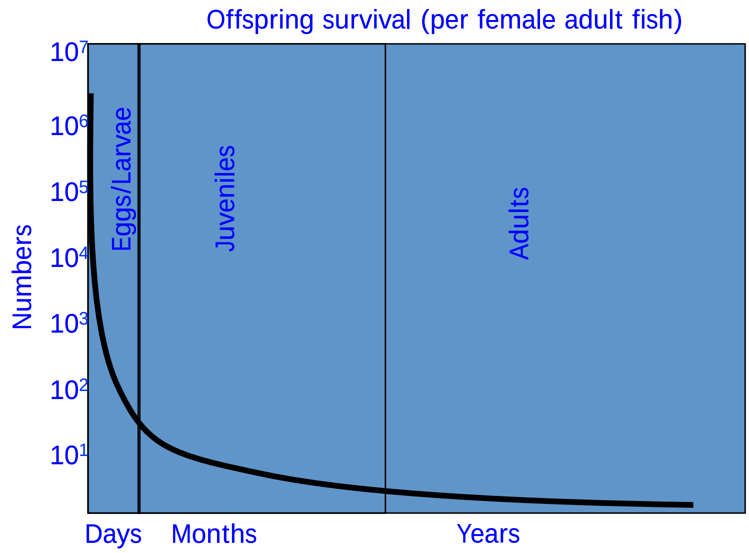


Fig. 12.—Larval fish, 1 day after hatching, actual length 2.9 mm.



Small variations in survival = big variations in recruitment

Key factors influencing recruitment

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

E.g. **Starvation**: Many marine fishes time their reproduction so that larval development "matches" periods of high oceanic productivity (i.e. larval food availability)

– period of "first feeding" is probably important

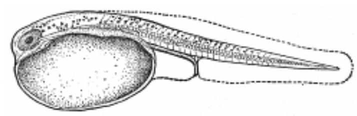


Fig. 11.—Newly hatched fish, actual length 2.1 mm.

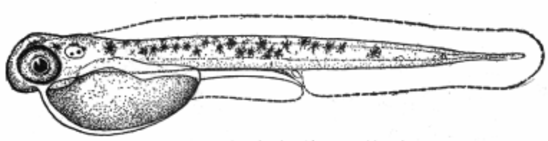


Fig. 12.—Larval fish, 1 day after hatching, actual length 2.9 mm.

Fig. 13.—Larval fish 4 days after hatching, actual length 3.3 mm.

David Cushing: Proposed the *"match – mismatch" hypothesis*

Successful year-classes are the result of spatio-temporal "match" between first feeding larva and availability of suitable food

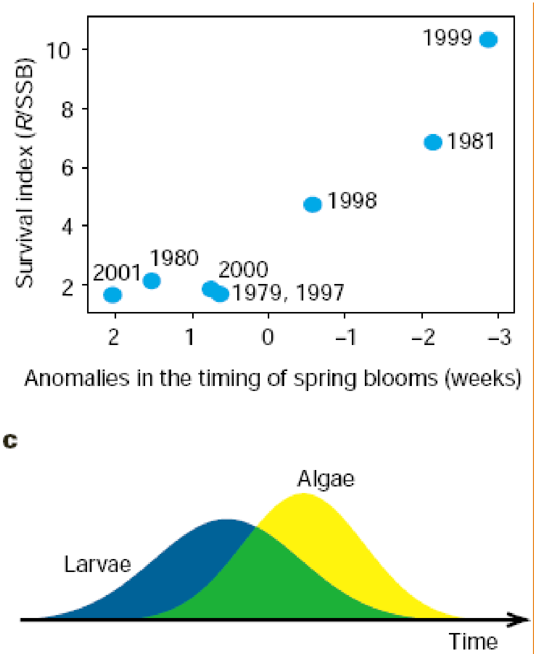
$B_{t+1}=B_t+R+G-M-F$

Key factors influencing recruitment

Evidence supporting match-mismatch hypothesis

Haddock recruitment is related to timing of algal bloom on Georges Bank

Platt et al. 2003 .Spring algal bloom and larval fish survival. Nature 423: 398-399



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

How do we estimate recruitment?

How do we estimate recruitment?

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

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?

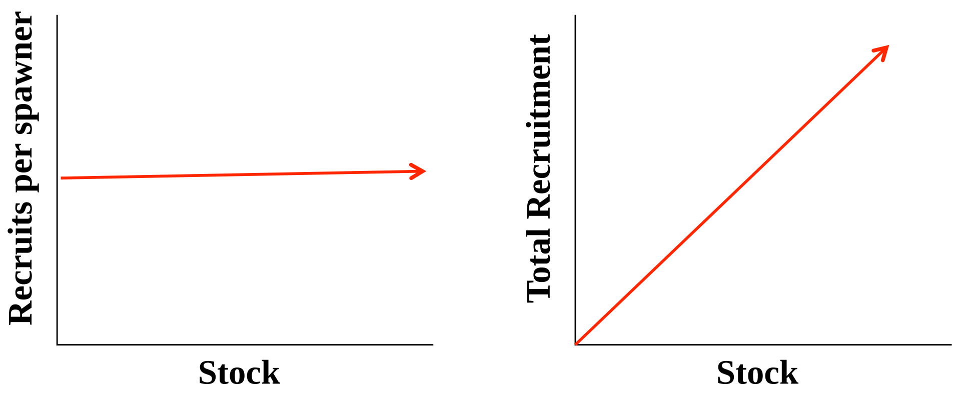
1. Sampling regimes targeted at juveniles.
2. Size specific indices of abundance from catch/effort data.
3. Where information pertaining to 1 and 2 above aren't available (often the case), scientists are generally forced to make an assumption – that there is a relationship between recruitment and adult stock size (called "the **stock-recruitment relationship**" **SRR**) , and that that relationship can be used to predict recruitment.

So what exactly is this SRR (Stock Recruitment Relationship) all about?

Estimating Recruitment
The stock-recruitment hypothesis

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

Density Independance



i.e: if each adult produces 2 recruits, regardless of population size, then 2 adults will produce 4 recruits, 10 adults produce 20 recruits, 1000 adults produce 2000 recruits total and so on.

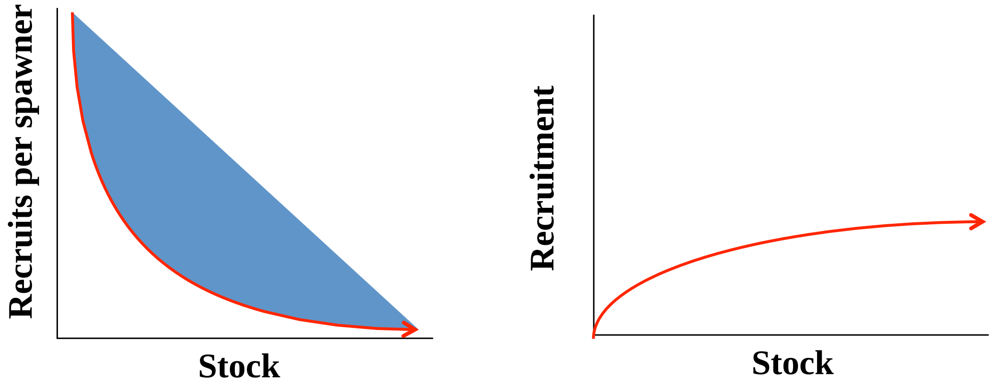
The simplest relationship assumes that the number of **recruits per spawner** does not change regardless of the adult population size (i.e. it is independant of the number of adults), hence **total recruitment** increases with increasing stock size.

.......HOWEVER! This doesn't take into account limited habitat/resources

Estimating Recruitment
The stock-recruitment hypothesis

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

Density Dependance - Compensation



i.e: as stock gets larger, fewer larvae/ juveniles from each adult survive to recruitment age.

A more commonly accepted model assumes that the number of **recruits per spawner** declines as the stock gets larger, hence **total recruitment** plateaus after an initial phase of increase.

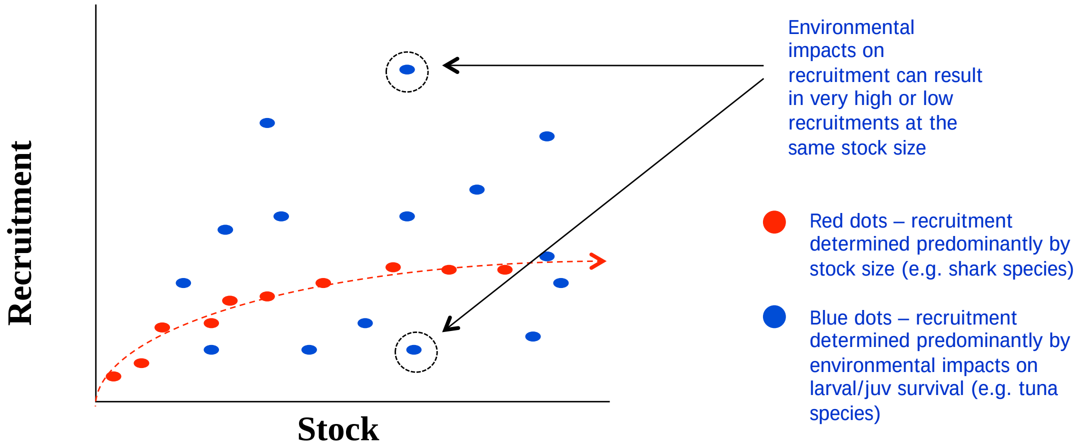
This model takes account of resource limitation (increasing competition = lower fecundity and lower survival, increased cannabalism by adults, disease transmission, predation etc).

There are other variations on this relationship, but we will concentrate on the *compensatory SRR, as it is what we use in tuna assessments in the WCP-CA*

Estimating Recruitment
The stock-recruitment hypothesis

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

Compensation



If recruitment was really tightly related to stock size as in the diagram here, then our stock assessment model could easily predict recruitment strength.

However, as discussed before, we know that for many species, environmental variability also has a very large impact on recruitment, and that for any given stock size, recruitment could be very large or very small, due to environmental impacts on larval and juvenile survival.

General rules for stock-recruitment relationships

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

From W. Ricker:

- Curve should pass through origin: no parents … no progeny
- Recruitment should not go completely to zero at highest levels of density
- Rate of Recruits/Spawner decreases continuously with increase in Stock size
- Recruitment must exceed parental stock (when measured in same units) else stock cannot persist

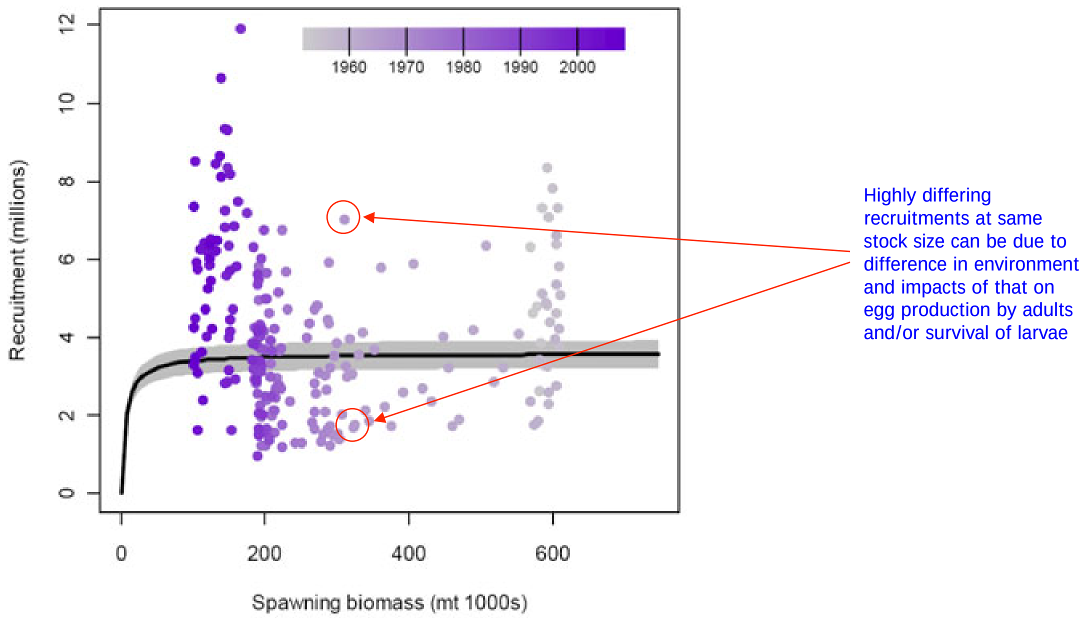
From R . Hilborn:

- R should generally increase with S
- Higher variance with larger stock
- Underlying curve should be generally smooth

Estimating Recruitment

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

Lets look at a real example: Estimated recruitment of bigeye tuna in the WCP-CA….

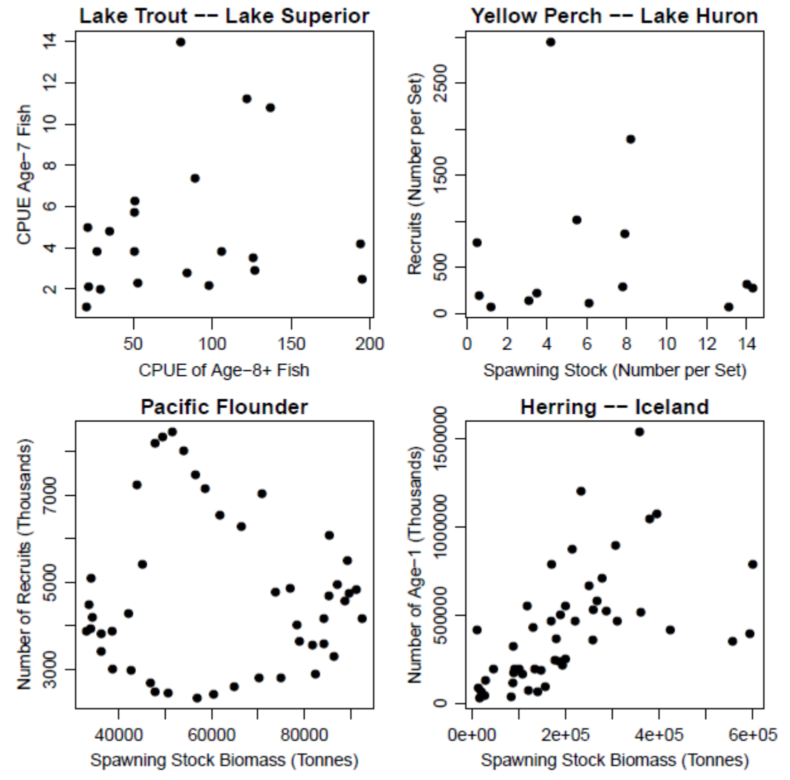


This looks as though there is no relationship to spawning biomass (adult population size)…..why do we know there MUST be a relationship?

Recruitment trends

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

Stock Recruitment data are always “noisy”



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

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

Remember our basic conceptual model:

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

If the fish population we are exploiting is to remain stable (or increase in size), recruitment (number of fish added to the population) *must* be equal to or higher than fish removed by natural mortality and fishing.

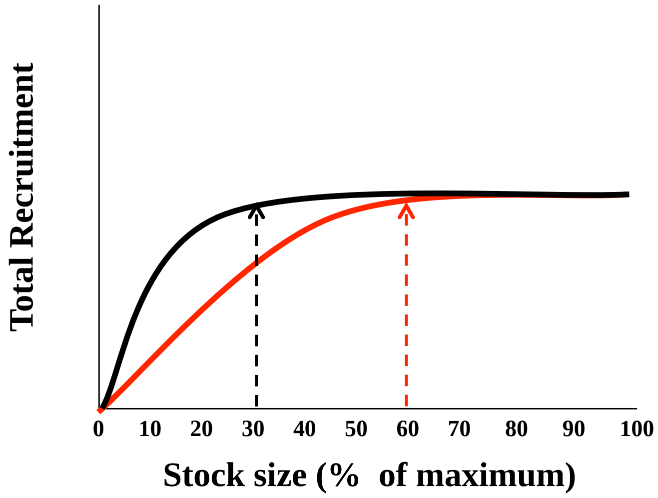
If the average number of recruits falls below the average number of deaths (natural or fishing based) over a significant period, then the mean size of the population will reduce, and the fishery will no longer be able to catch the MSY.

The SRR is important because it defines the point at which recruitment will start to decline because there are not enough adults to produce enough recruits to replace the fish removed by natural mortality and fishing.

When this occurs, the fishery is OVERFISHED (under the MSY based definition of overfishing used in the WCPO)!

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

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



Example:

For Stock A (black line), total average recruitment starts to fall when the adult stock has declined by 70% (to 30%) of its “virgin” stock size.

For Stock B (red line) recruitment falls when the stock has declined by only 40%

When average recruitment starts to decline significantly (at biomass <30% for stock A, and <60% for stock B), the fishery is OVERFISHED. More specifically, this type of overfishing is called RECRUITMENT OVERFISHING – meaning there are no longer enough adults to produce sufficient recruits to replace the fish that die.

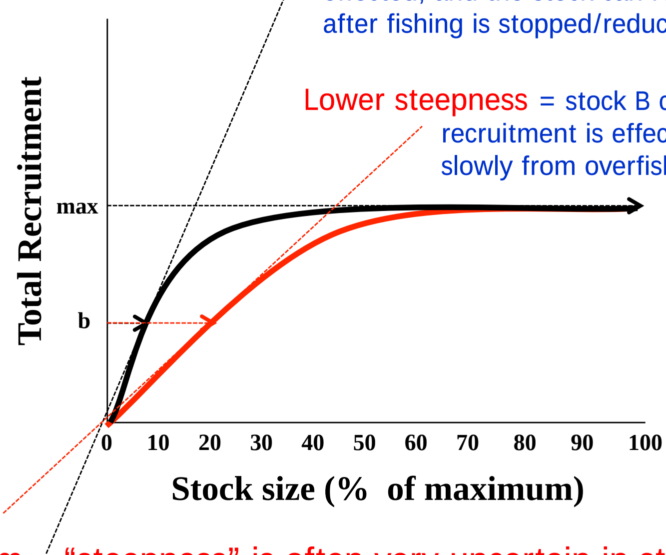
Why is the stock recruitment relationship (SRR) so critical to stock assessment?

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

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 is 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 affected (and overfishing occurs) is also uncertain.

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

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

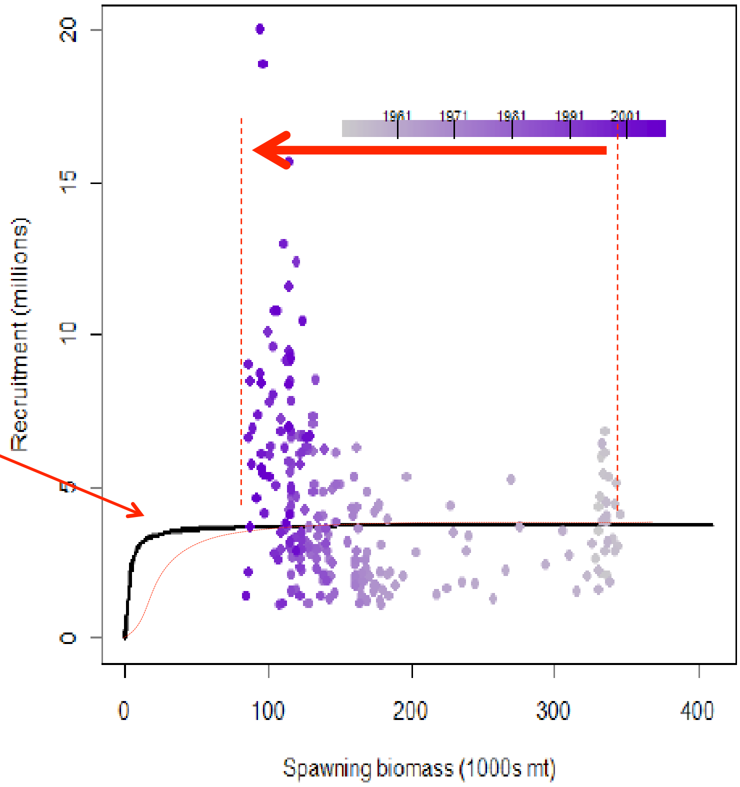
Implications of the SRR in a real example: Estimated recruitment of bigeye tuna in the WCP-CA....

In the 50 years since industrial fishing commenced, the bigeye spawning biomass has been reduced by 85%

1. Where is the point at which we predict recruitment will start to significantly decline (ie; the fishery become overfished)?

2. How long do you think, if fishing isnt reduced, until we pass this point?

3. What if we got the estimate of steepness wrong?



Recruitment Models

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

Attributes of SR models

	Beverton Holt models		Ricker models	
$R =$	$\frac{aS}{b+S}$	$\frac{aS}{1+bS}$	aSe^{-bS}	$Se^{a[1-(S/b)]}$
Slope at origin	$\frac{a}{b}$	a	a	e^a
Rmax	a	$\frac{a}{b}$	$\frac{a}{b}e^{-1}$	$\frac{be^{a-1}}{a}$
Smax (for Rmax)	∞	∞	$\frac{1}{b}$	$\frac{b}{a}$

We will use this one

-*a* is a productivity parameter, related to recruits-per-spawner at low stock size ... optimum harvest rate depends on *a*
-*b* is a capacity parameter that describes how recruits-per-spawner decreases with increasing stock size

Recruitment Models

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

Definition: steepness

- When spawners are at 20% of unfished levels (S_0), steepness is the proportion of unfished recruitment (R_0) that is produced
  - If steepness is 70%, then reducing the spawners to 20% of unfished levels will reduce recruitment to 70% of unfished levels
  - If steepness is 50%, then reducing the spawners to 20% of unfished levels will reduce recruitment to 50% of unfished levels

$$R=\frac{aS}{b+S}$$

$$a=\frac{1-h}{4hR_0}S_0$$

$$b=\frac{5h-1}{4hR_0}$$

h = steepness

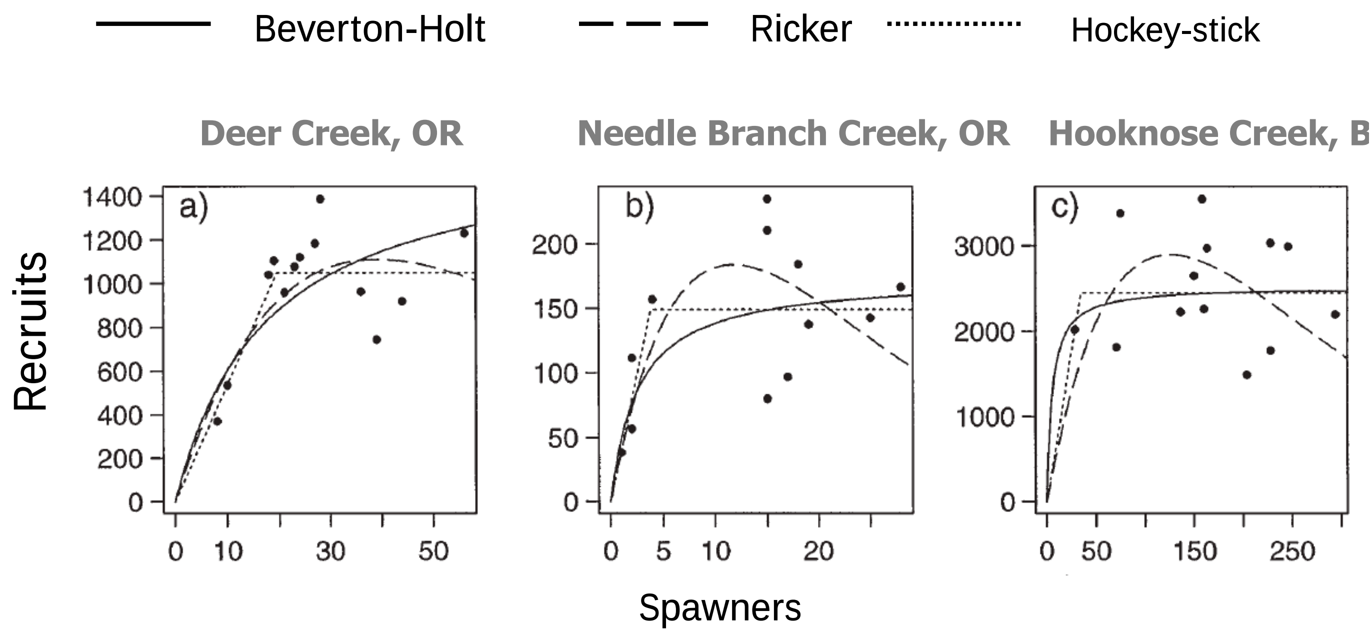
R0 = max. recruitment

S0 = unfished spawning stock size

Recruitment Models

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

Model comparison



Barrowman NJ & Myers RA (2000) Still more spawner-recruitment curves: the hockey stick and its generalizations. CJFAS 57:665-676

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

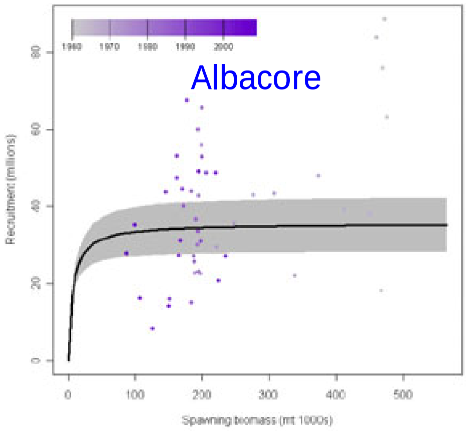
How does MULTIFAN-CL estimate recruitment?

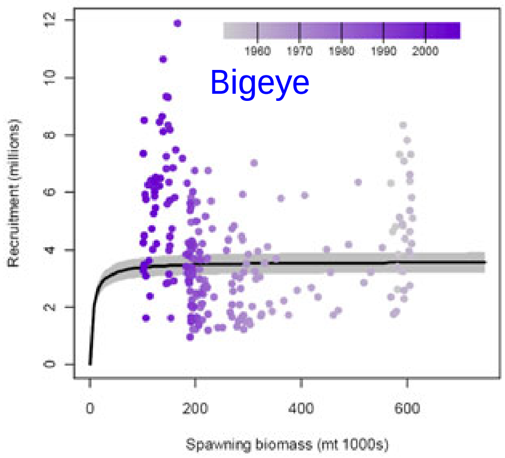
$B_{t+1}=B_t+R+G-M-F$

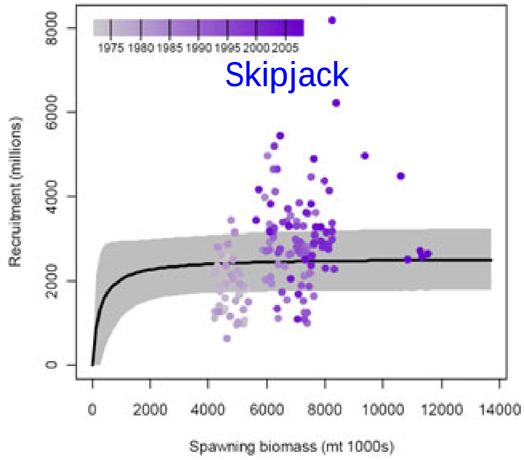
Estimation of Recruitment by MULTIFAN-CL

MULTIFAN-CL estimates recruitment in a two part process:

1. MULTIFAN-CL models the SRR typically using the compensatory Beverton and Holt curve, which sets the average stock-recruitment relationship, and ensures that the point at which recruitment might start to decline



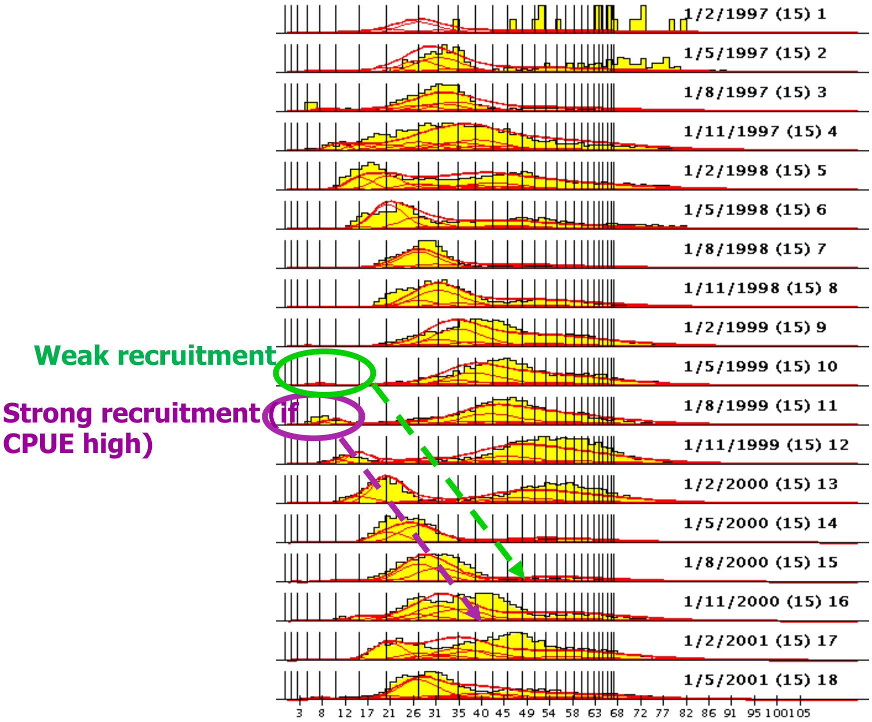




Estimation of Recruitment by MULTIFAN-CL

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

2. Deviations from this relationship are then determined by the strength of the size modes and the CPUE associated with those size modes.

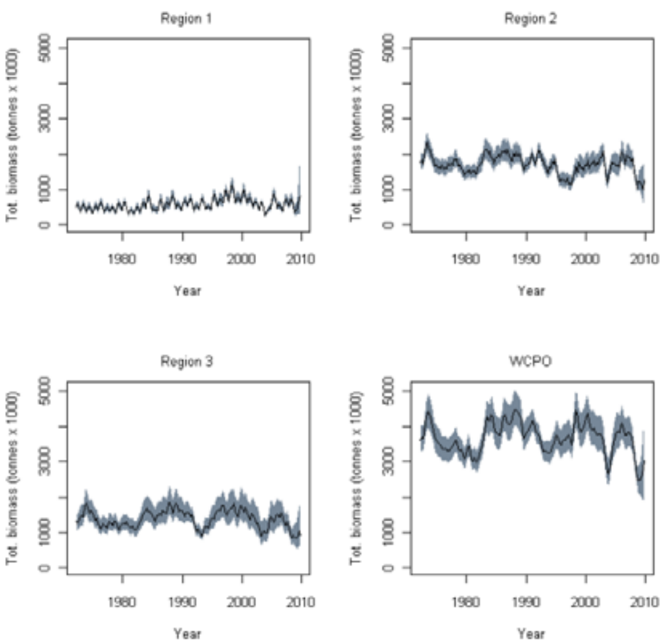


Stock-Recruitment Estimation in MULTIFAN_CL: Skipjack 2010

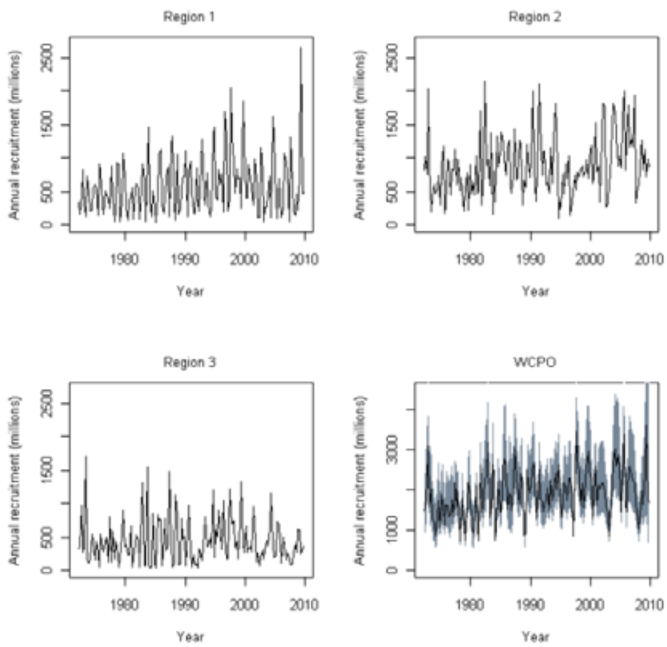
$B_{t+1}=B_t+R+G-M-F$

* In light/moderate exploited fisheries, biomass and recruitment show similar trends

Biomass



Recruitment



Session overview

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

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 determine 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 affected by both biotic factors (starvation, predation, disease impacts on larvae, juveniles etc) and abiotic factors (water temperature, convection, oxygen, salinity etc).

Session overview

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

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

Session overview

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

9. 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.
10. However, even for these species, when the adult population drops too low, recruitment will be effected (zero adults = zero larvae).
11. 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.
12. 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.

Chapter 7

Natural and Fishing Mortality

Where are we going?

Overview of this session:

1. What is mortality?

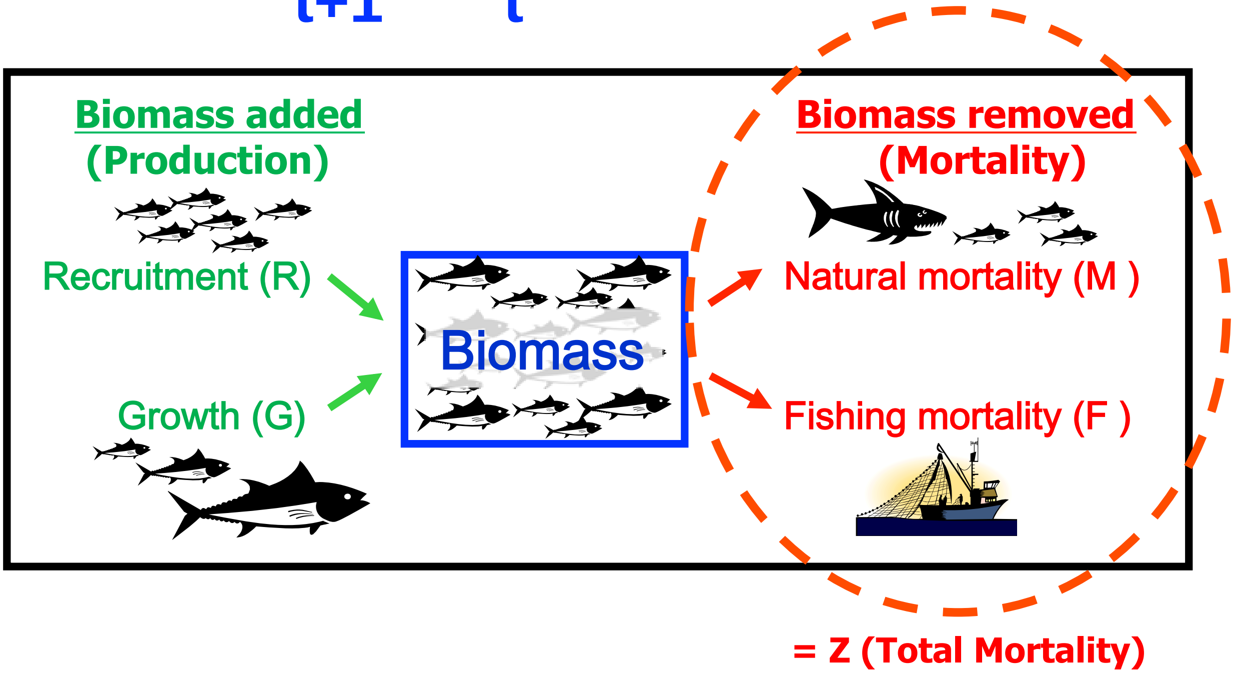
2. What is ***natural*** mortality?
   - How and why does it vary with age and size?
   - Why do we estimate it?
   - How is it estimated **outside** a stock assessment?
   - How is it estimated **within** a stock assessment (MFCL)?

3. What is ***fishing*** mortality?
   - How and why does it vary with age and size?
   - Why do we estimate it?
   - How is it estimated **outside** a stock assessment?
   - How is it estimated **within** a stock assessment (MFCL)?

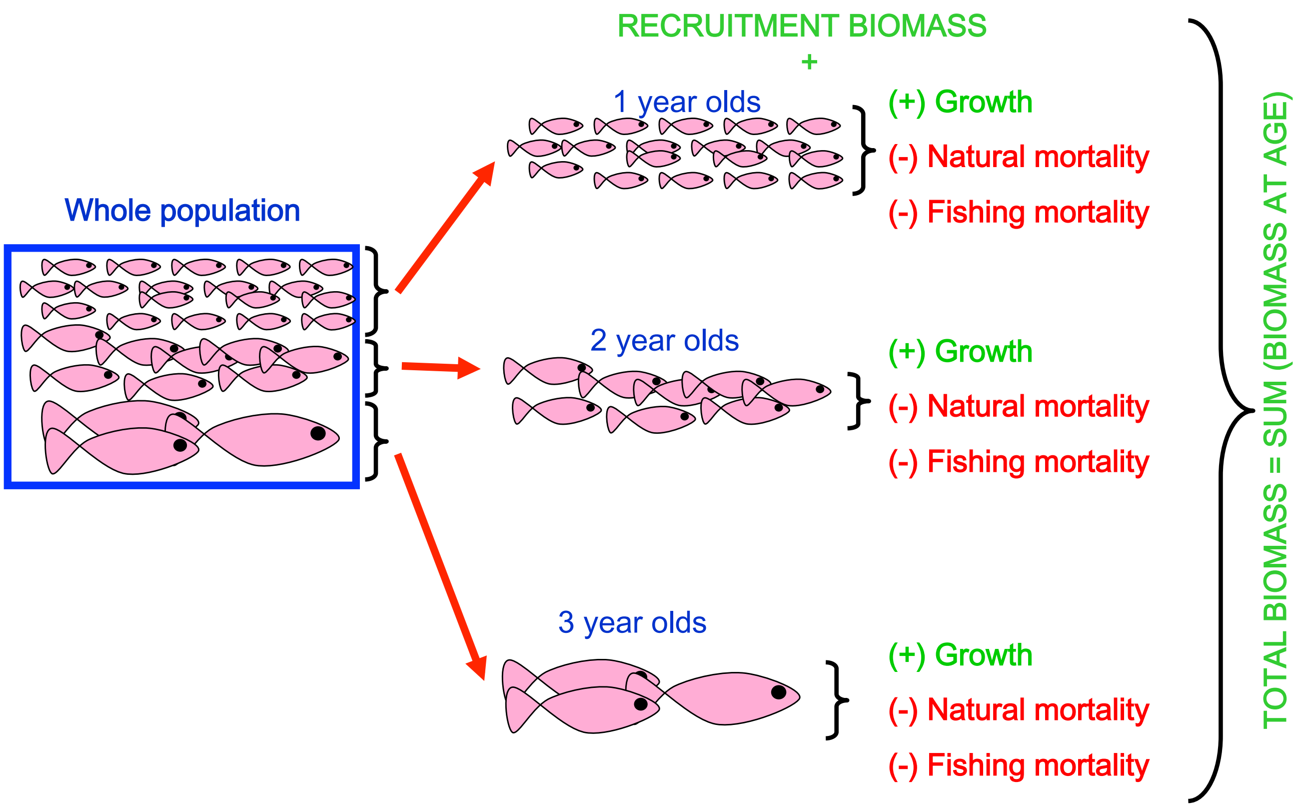
4. Summary

Our conceptual model of a fish population

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



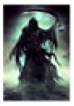
Age-structured models



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

What is mortality?

1. Simply, the process of mortality (i.e., the rate of death or loss) of fish from the population by all causes, usually expressed as:



$$Z = M + F$$

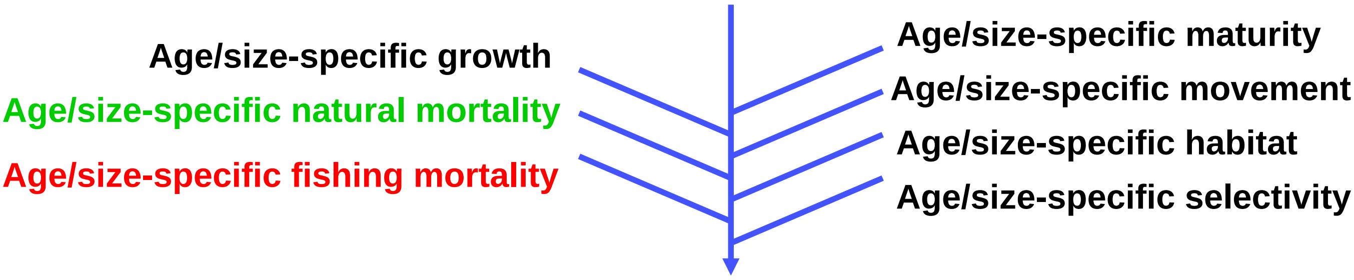
2. Natural and fishing mortality, **M** and **F**, are generally treated separately in stock assessment models, as the implications for management of high **F** or high **M** can be very different. (What might these be?)

3. Also, **F** can be managed (at least in theory), whereas **M** generally can't be controlled

4. Expressing **F** as a proportion of **Z** is often referred to as the ***exploitation rate***, or **E**, where **E = F / Z**.

How are mortality estimates incorporated into age-based models?

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



$$B_{a+1,t+1} = B_{a,t}+R_{a=1,t}+G_{a,t}-M_{a,t}-F_{a,t}$$

$$B_t = \Sigma B_{a,t}$$

Natural Mortality

What is natural mortality (*M*)?

Overview:

1. It is the process of mortality or death of fish in a population due to natural causes such as predation and disease.

2. By "natural mortality" we typically refer to mortality **post-recruitment** as mortality during pre-recruitment life-history stages is usually dealt with separately in the assessment model.

3. Unlike other parameters such as growth where methods to estimate it are uniform, many different approaches are taken to estimate M.

4. M is a difficult life history trait to measure in the laboratory or the field.

What is natural mortality (*M*)?

How do we express natural mortality?

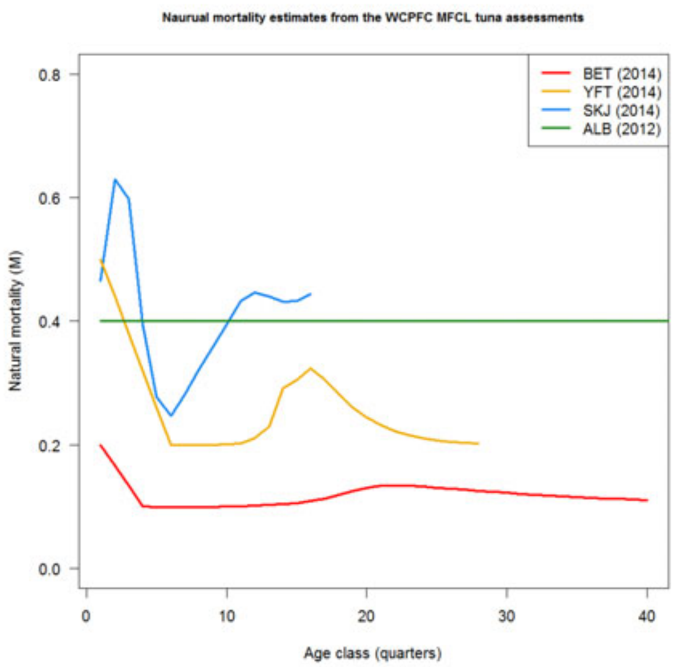
1. **Natural mortality is usually expressed as an instantaneous rate.** This is a relative change in the proportions of a size or age classes that suffer natural mortality during each time period.

2. Natural mortality rates are critical in understanding the 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.

What is natural mortality (*M*)?

Fluctuations in M with age

M tends to decrease with age as fish out-grow predators and condition improves, but it may increase again in older fish due to the stress associated with reproduction, and can increase as they near maximum age



What is 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-dependent effects such as intra-specific competition or cannibalism.

What is natural mortality (*M*)?

What benefits does a good understanding of M offer within a stock assessment?

1. It gives us an understanding of the likely robustness of the stock.

2. It is a critical parameter within our understanding of fish population dynamics:

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

3. It allows an understanding to be gained of the relative effect of fishing on the population (e.g., by comparing natural and fishing mortality rates; natural and fishing mortality are defined to sum together to produce **total** mortality):

$$Z = M + F; E = F / Z$$

What is natural mortality (*M*)?

Direct and indirect effects:

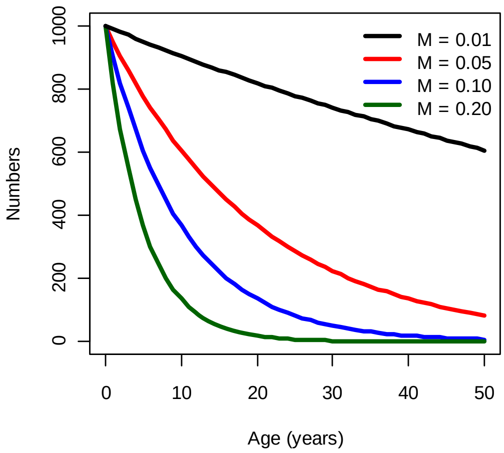
1. Natural mortality has **direct** and **indirect** impacts on populations and fisheries which are important to be able to understand and account for within stock assessment models.

2. Direct impact:

- **The number of fish available to the fishery**

The actual value of M directly affects the number of fish that survive to become available to the fishery.

NB: $N_{t+1} = N_t e^{-(M+F)}$



What is natural mortality (*M*)?

Direct and indirect effects:

3. Indirect impacts:

- **Reproductive biomass**

There is a need to ensure that sufficient numbers of fish survive to reproductive age to ensure future recruitment success.

- **Possible need to restrict fishing mortality on specific life-history stages**

Species with low M are typically longer lived and less productive (produce fewer young, grow more slowly, mature later). They typically have a stronger stock- recruitment relationship.

For species with low-M and a strong stock recruitment relationship, the impacts of fishing on recruitment will occur at much lower levels of F than for species with high-M

How is *M* estimated?

In general:

1. It is one of the more difficult population parameters to estimate as its effects are confounded with the effects of recruitment and fishing mortality.

2. Often, it involves measuring the disappearance of fish from the population that can not be attributed to other sources such as fishing mortality or movement.

3. Total mortality (Z) and fishing mortality (F) can be estimated first, and M calculated by subtraction (NB: it is more common to calculate F estimates in this manner):

$$Z = M + F$$

$$M = Z - F$$

How is *M* estimated?

In general:

1. Many methods have been developed to estimate M. These methods can be grouped into:

    1. **Life history methods** - Life history-based methods for estimating natural mortality describe relationships between M and traits like age, growth rate, and weight.

    2. **Predation methods** – using multispecies virtual population analyses to derive M.

    3. **Catch analyses methods** – for example, catch curve analyses, tagging data based analyses (tag attrition models).

How is *M* estimated?

Outside a model:

1. Maximum-age relationship (Hoenig 1983)

There is a relationship between the maximum age of a species and mortality: the higher the estimated maximum age, the lower the mortality rate must be.

$$\ln(M) = 1.44 - 0.984 \ln t_{max}$$

2. Maximum-length relationship (Beverton & Holt 1957)

Extends the relationship between growth rate (*K*) and size, incorporating the mean size and smallest size of captured fish.

$$Z = K \times [(L_{inf} - L_{mean}) / (L_{mean} - L_{smallest})]$$

How is *M* estimated?

Outside a model:

3. Application of the relationship between *M* and *K*

- The ratio between natural mortality and the von Bertalanffy growth rate parameter has been estimated to be between 1.5 and 1.6 with a standard error of 0.58.
- This is thought to be a result of biological tradeoffs between growth and mortality and the influences of reproduction and survival.
- So, if you have an estimate of *K* (e.g., from fitting the VBGF), then you also have a starting point for M: e.g., $K = 0.4$, $M \approx 0.6$
- Like all of these biological relationships, this is ***crude***, but in the absence of any other information it can be useful.

How is *M* estimated?

Outside a model:

4. Catch-curve analysis

- Requires adequate sampling of the stock to develop representative age-frequency distribution. *Potentially expensive*.
- The slope of the declining age-frequency curve after the assumed age-at-full recruitment provides an estimate of mortality.
- Note that in the absence of fishing or when the stock is lightly exploited, this can be assumed to be **natural mortality**, ***M***. In the presence of fishing, this will be **total mortality**, ***Z***.

M = -1 × slope or **Z = -1 × slope**

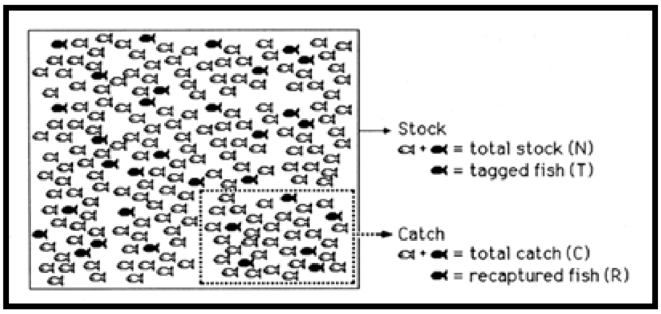
How is *M* estimated?

Outside a model:

4. Mark-recapture (tagging) studies

- We have a known number of returns of tagged fish from fishers.
- There is a reduction in the number of returns through time.
- We can fit a regression to the numbers of returns over time and the slope of the regression line is an estimate of mortality. This is *Z* or total mortality if the stock is fished; *M* if the stock is un- or lightly-fished.

More tagged fish = higher number of returns = better estimates of mortality and all other parameters



How is *M* estimated?

Outside a model:

4. Mark-recapture (tagging) studies….continued

- E.g. Hampton (2000)
- The Tag-attrition model (Kleiber et al. 1987; Hampton 1997) is a size aggregated capture-recapture model. Hampton (2000) builds upon the Tag-attrition model to estimate mortality in tropical tunas.
- In Hampton's model, the tagging data were classified based on the size-at-release. A VBGM was used to calculate growth while the tagged fish was at liberty. Then, using maximum likelihood, natural and fishing mortality are estimated.
- Hampton (2000) found that natural mortality increased at the latest age classes.

How is *M* estimated?

E.g. Hampton (2000)

Fig. 7. Observed (circles) and predicted (line) (*a*) skipjack, (*b*) yellowfin, and (*c*) bigeye tuna tag returns by time at liberty.

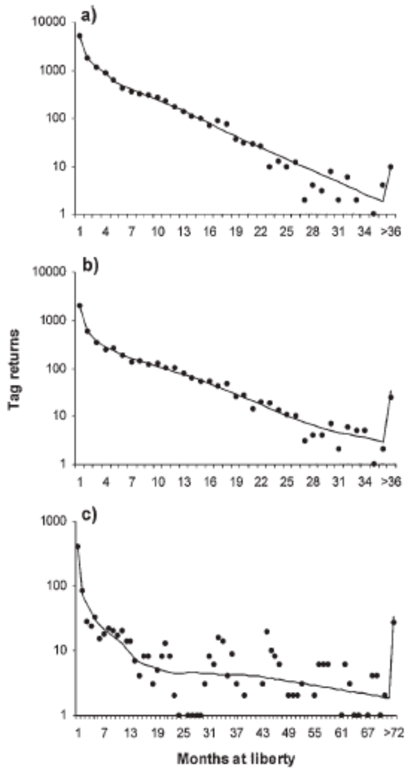


Fig. 9. Estimates of skipjack tuna (*a*) natural mortality rates and (*b*) fishing mortality rates by size-class. The circles represent the medians of 1000 bootstrap replicates; the ranges are the 2.5–97.5 percentiles.

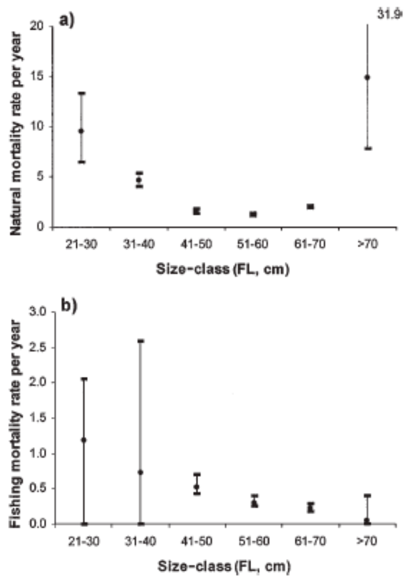
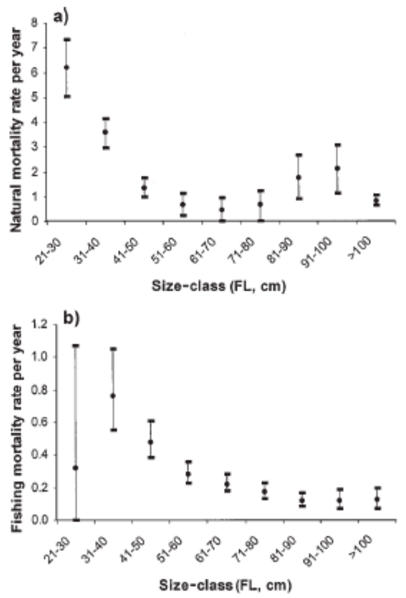
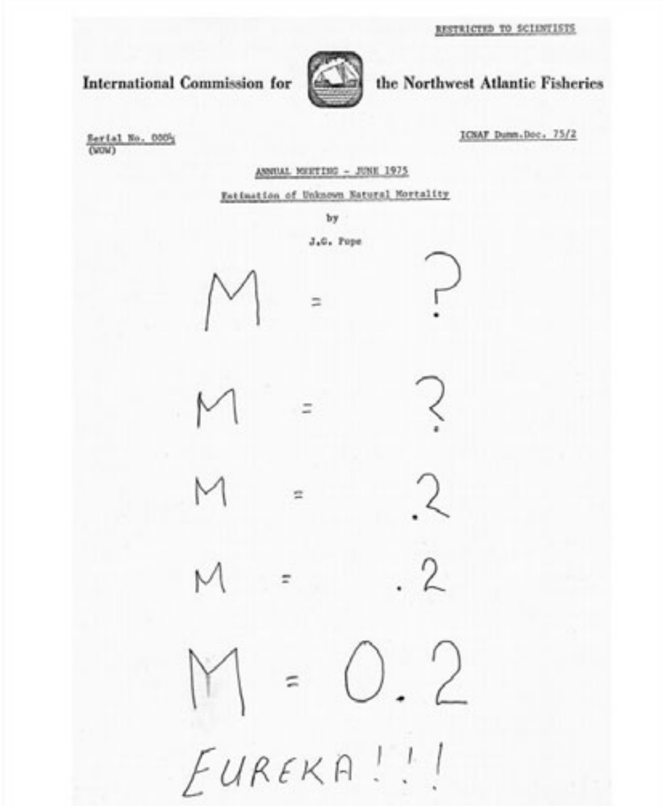


Fig. 10. Estimates of yellowfin tuna (*a*) natural mortality rates and (*b*) fishing mortality rates by size-class. The circles represent the medians of 1000 bootstrap replicates; the ranges are the 2.5–97.5 percentiles.



How is *M* estimated?

Sometimes its just a guess - “derived”



RESTRICTED TO SCIENTISTS

International Commission for the Northwest Atlantic Fisheries

Serial No. 0005
(WOW)

ICNAF Dumm.Doc. 75/2

ANNUAL MEETING - JUNE 1975

Estimation of Unknown Natural Mortality

by

J.G. Pope

M = ?

M = ?

M = .2

M = .2

M = 0.2

EUREKA!!!

Figure 1. ICNAF Dumm. Doc. by John Pope drawn at the April 1975 meeting of the ICNAF Assessment Subcommittee entitled "Estimation c Unknown Natural Mortality".

How is *M* incorporated into stock assessments?

Within a model:

1. A constant *M*

- An estimate of *M* from another study is assumed and fixed in the model for all age-classes.
- At each time step, *M*-proportion of fish from each age-class are removed from each age class.
- This allows the model to incorporate mortality for each age-class at each time-step, but the mortality ***rate*** does not vary by age-class.
- Typically, we test the sensitivity of the model outputs to the assumed value of *M* systematically varying the value of *M* and re-run the model (sensitivity analysis).

How is *M* incorporated into stock assessments?

Within a model:

2. Fixed age or size-class specific *M* values

- Mortality estimates for some age or length classes may be available from other studies.
- These can also applied at each time step to the corresponding age-classes in the model partition to remove fish from the model.
- Everything else being equal, the use of age-specific *M* values provides a greater degree of realism—biomass estimates and other outputs will incorporate age-specific *M.*

How is *M* incorporated into stock assessments?

Within a model:

3. M can be estimated during the assessment model fit

- **Starting value**
  However, this still requires a plausible starting value (prior) and range [usually from previous studies].
- **Sources**
  Starting values can be compiled from the published scientific literature or from the results of previous assessments
- **MULTIFAN-CL**
  MULTIFAN-CL has considerable flexibility in how it handles *M*. *M* can be treated either as a single, average value or as age-specific values.

Fishing Mortality

What is fishing mortality (*F*)?

Definition:

"The process of mortality of fish due to fishing. This includes the landed catch as well as any discarded catch."

Total removals =
landings + discards + losses

What is fishing mortality (*F*)?

Why do we give fishing mortality so much attention?

1. We wish to understand the past, present and future impacts of fishing upon the fish stocks that we are responsible for, so that we can meet our long-term goals for these resource(s).

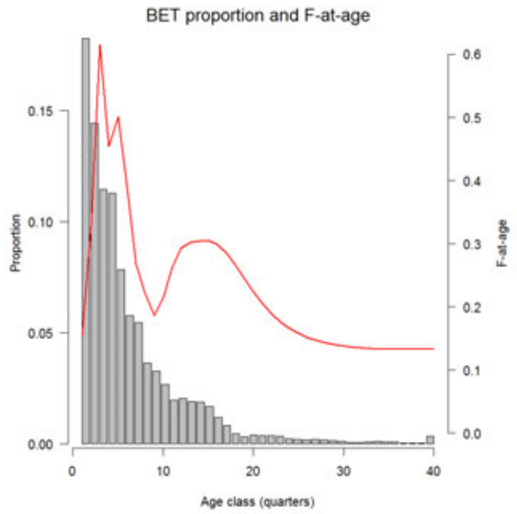
2. With age structured models we can go one step further, and identify which components (age classes) within the stock are the most affected by fishing.

3. In situations where the resource is being overexploited, we can simulate different alternative management options by simulating different fishing mortality rates by different gears on different age classes within the stock.

How and why does fishing mortality vary with age and size?

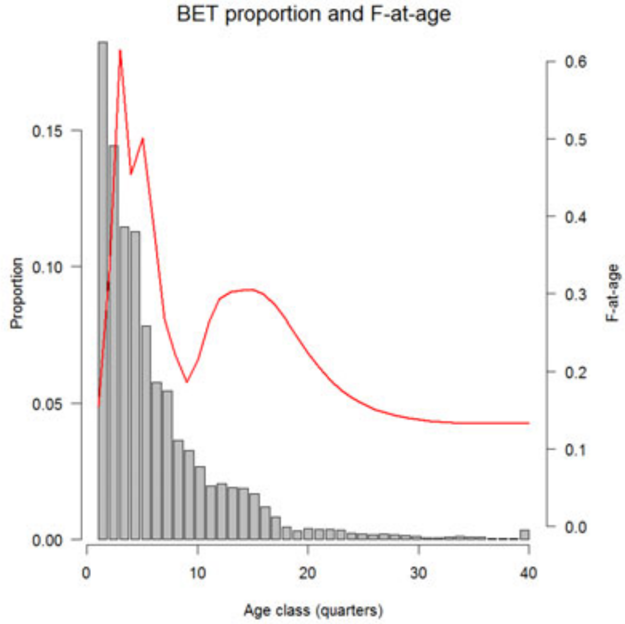
1. Fishing mortality often varies by size or age class for one main reason - fishing gears tend to be ***size selective***, that is, more likely to catch fish of a certain size and less likely to catch fish of other sizes.

2. For example, small bigeye tuna tend to be caught by purse seine sets on floating objects, but larger (adult) bigeye tuna are much less frequently caught. In contrast, adult bigeye are caught by longlining, but very small juvenile bigeye are not often caught by the same gear.



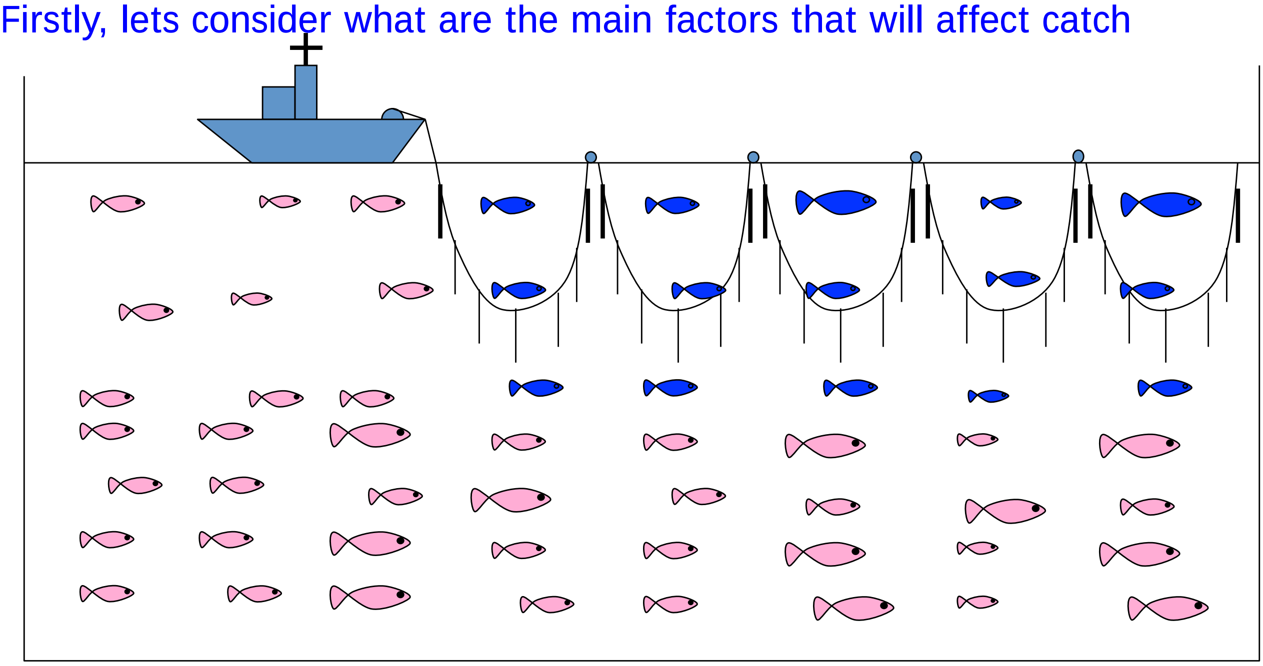
How and why does fishing mortality vary with age and size?

3. Estimating age-specific fishing mortality also yields important information for fishery managers, e.g., which parts of the stock are being fished hardest and in the identification of growth and recruitment overfishing



How is *F* estimated?

Firstly, lets consider what are the main factors that will affect catch

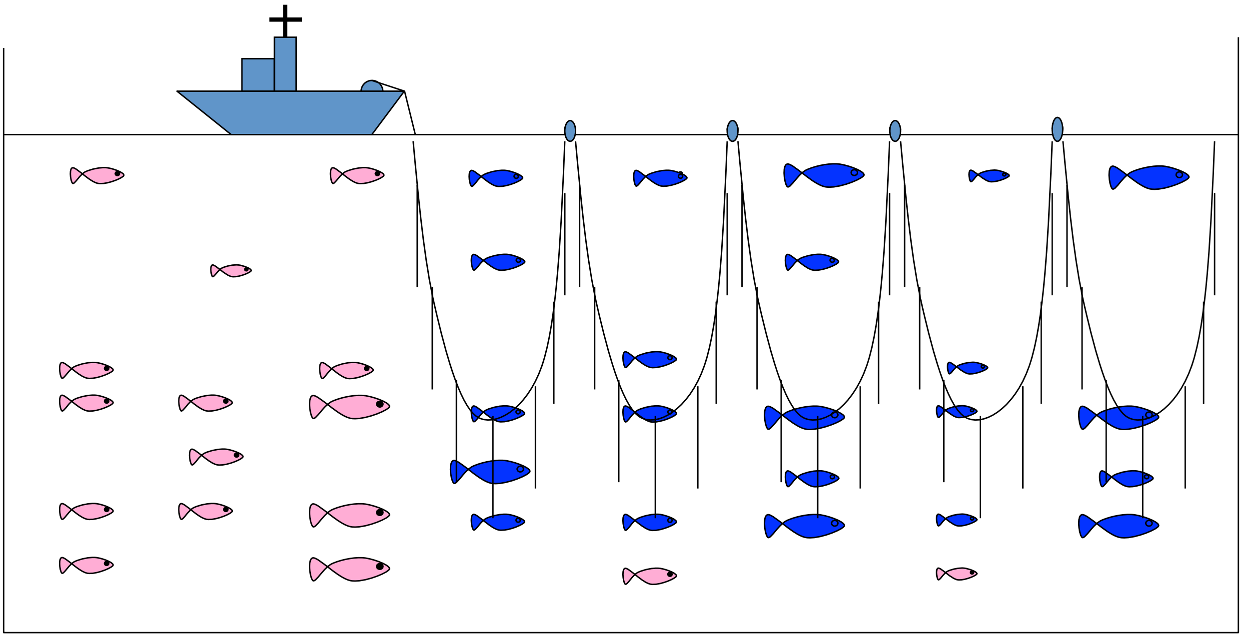


What happens to catch if we increase the number of hooks or effort (E)?

What happens to catch if biomass (B) decreases?

What happens to catch if the fish swim deeper?

How is *F* estimated?



What happens to catch if we increase the depth of our hooks to target the deep swimming fish?

How is *F* estimated?

Age-specific fishing mortality:

1. Typically, we assume that catch, *C*, is proportional to biomass and to fishing effort:

   $$C = qEB$$

2. We can rearrange this equation to show that CPUE is proportional to biomass (abundance):

   $$C/E = qB$$

3. And catchability is the proportion of the stock caught by one unit of fishing effort (e.g., one set, 100 hooks, etc.)

   $$q = C/EB$$

How is *F* estimated?

4. And fishing mortality rate is the proportion of the population removed by fishing over time, (e.g., one year, one quarter):

   $F = C/B$

5. Then using the previous equations, fishing mortality rate will be the product of catchability and fishing effort

   $F = qE = C/B$

6. Therefore, we can also state a relationship between catch and fishing mortality rate:

   $C = FB$

7. In age-structured models we calculate *F* at age *a*, and this requires an additional parameter, selectivity:

   $F_a = qE_a s_a$

Fishing mortality in MULTIFAN-CL

How does MFCL turn fishing mortality into catch?

"Catch by age, time period, and fishery is determined by fishing mortality at age, time period and fishery applied to estimated abundance by age and region."

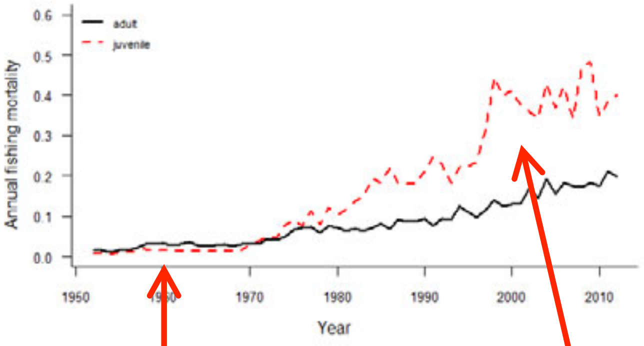
(i.e., C = F x B for each age class, time period and fishery)

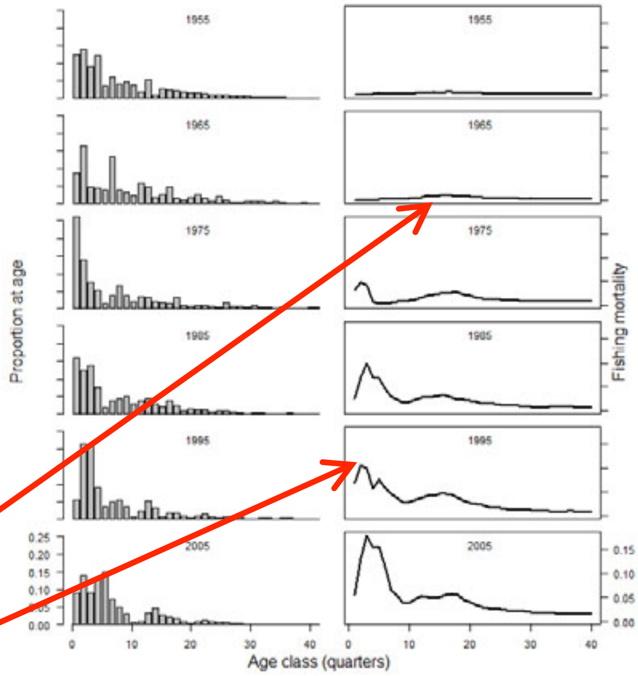
1. Fishing mortality in MULTIFAN-CL is a product of:

- Fishery and time-specific **effort** or $E_{f,t}$
- A fishery-specific **catchability** or $q_{f,t}$ that can vary with time
- A fishery and age-specific **selectivity** ogive or $s_{a,f}$ that does not vary with time.

$$F_{a,f,t} = q_{f,t} \times E_{f,t} \times s_{a,f}$$

Example: BET SC-10 2014

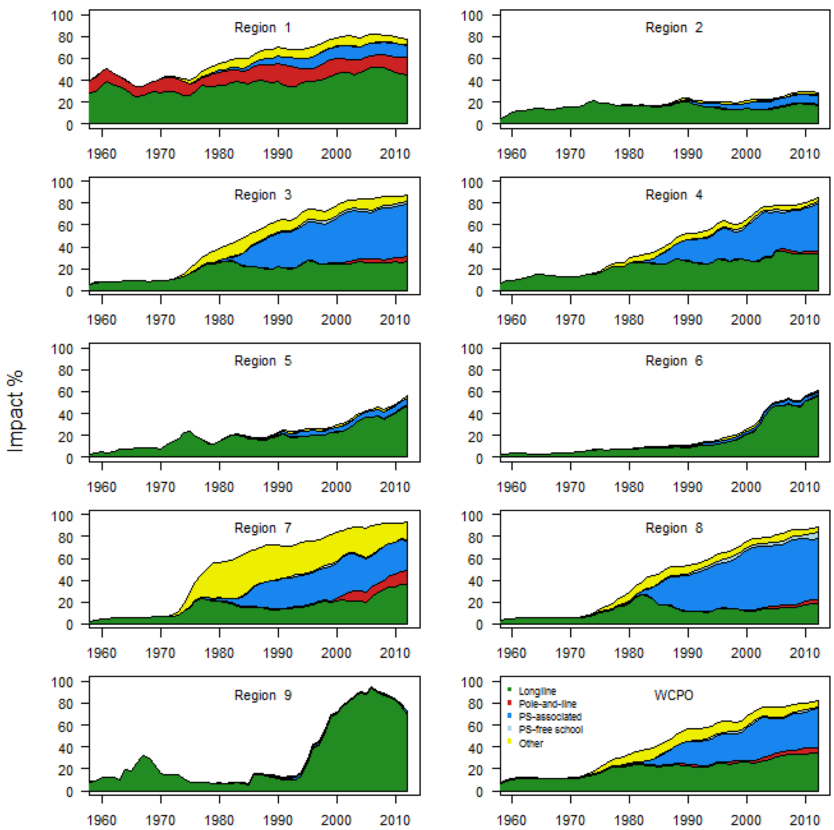




Initial *F* is high for older age classes, due to the predominance of the longline fishery.

However the purse seine fishery on floating objects, and particularly drifting FADs since 1995, has led to high *F* on juvenile age classes also. (NB: age classes are quarters)

Example: BET SC-10 2014



Impacts of fishing on total biomass by gear

Fishing mortality in MULTIFAN-CL

Calculating unfished biomass:

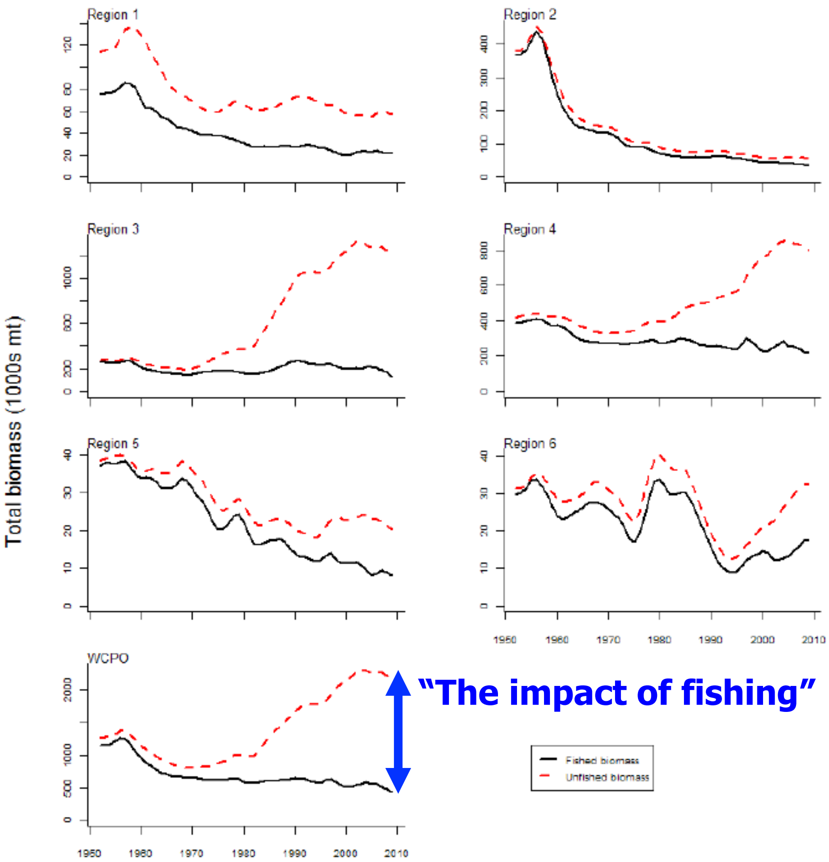
1. MFCL models can be used to estimate biomass that would have occurred in the absence of fishing. This is achieved by "turning off" fishing mortality, i.e.,:

   $$Z = M + F \quad = M + 0 \quad = M$$

2. This allows the calculation of biomass trajectories in the absence of fishing, but utilising all other assumptions made in the model (e.g., year-class strength estimates, etc.).

3. This can be used to estimate the reduction in biomass as a result of fishing, given the assumptions made in the model.

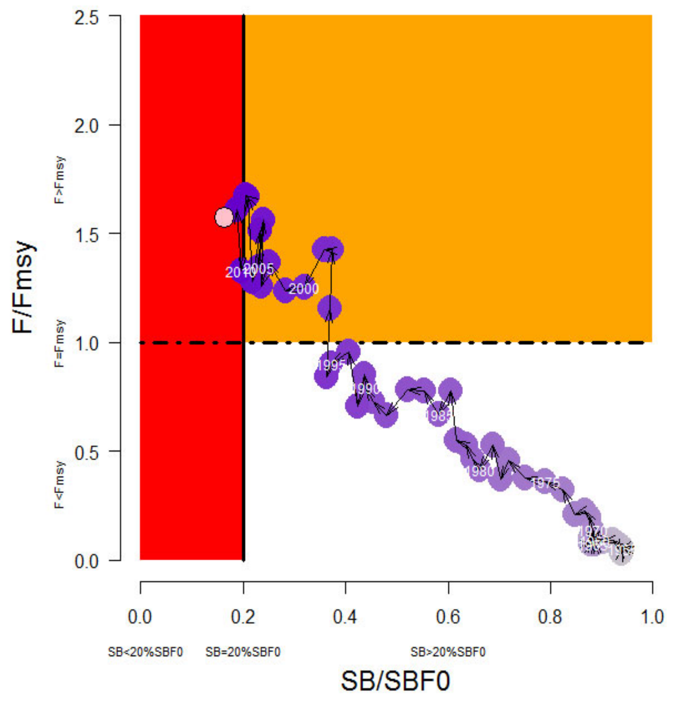
Example: BET SC-6 2010



Black: $Z = (F + M)$

Red: M only

Example: BET SC-10 2014



Comparing (current) F to F required to achieve maximum sustainable yield (MSY)

Summary

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.

Summary

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.

Summary

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)

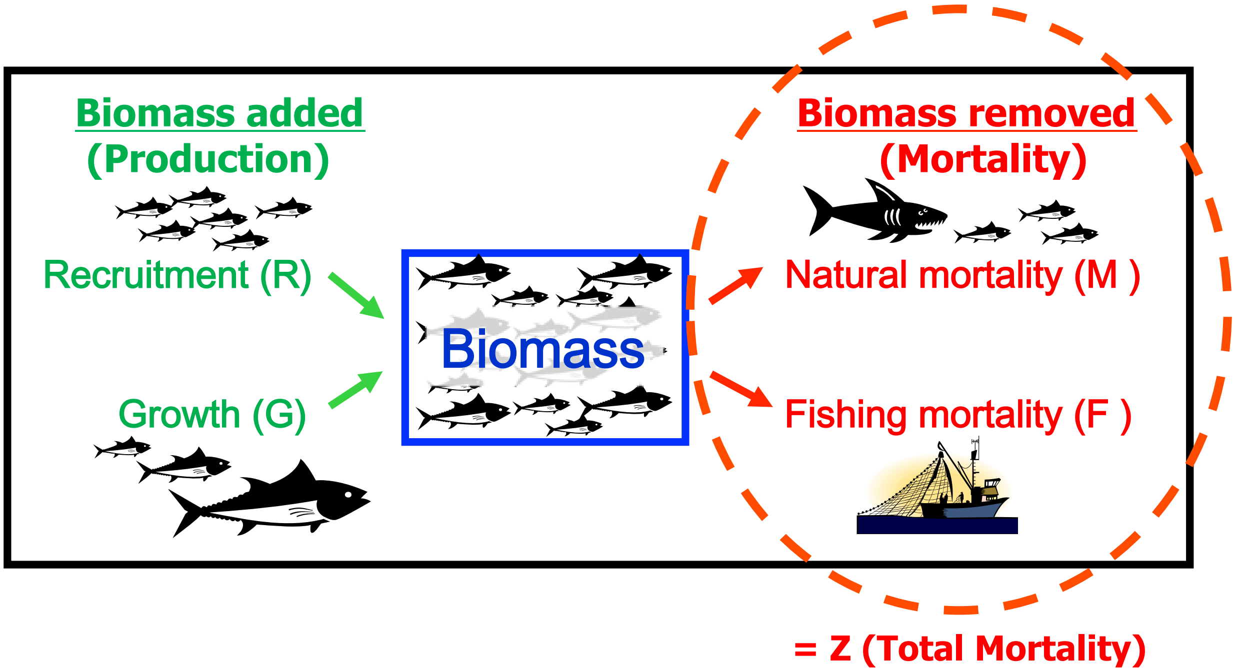
2. In an age-structured stock assessment model fit, *F* is usually calculated for each time, age and fishery as a function of selectivity, catchability, and fishing effort.

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.

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



Biomass added
(Production)
Recruitment (R)
Growth (G)
Biomass
Biomass removed
(Mortality)
Natural mortality (M)
Fishing mortality (F)
= Z (Total Mortality)

Chapter 8

Abundance indices - CPUE

Overview

1. **What is abundance?**
2. **Why do we need an index of abundance?**
3. **Indices of abundance**
4. **CPUE**
   - **Catch per unit effort and biomass**
   - **Why do we need to standardise CPUE?**
5. **Catch rate standardisations**

What is abundance?

Overview:

1. Abundance is simply how many fish are in the stock at a given point in time.

2. It can be defined either in terms of numbers or weight (biomass).

3. In age-structured models, numbers and biomass are estimated for each age class for each point in time, and then summed together across age classes (for a given point in time) to produce the total biomass at that time.

$$B_{a+1,t+1} = B_{a,t} + R_{a,t} + G_{a,t} - M_{a,t} - F_{a,t}$$

$$B_t = \Sigma B_{a,t}$$

What is abundance?

Why do we need to determine abundance?

Primarily - To determine harvest rates (we need to know how many fish there are before knowing how many we can take, in order to achieve our management objective; e.g. MSY)

Typically abundance is measured as absolute or relative abundance:

1. **Absolute Abundance:** An estimate of the total number of fish present (in the population) – difficult to determine in very large stocks like tunas.

2. **Relative Abundance:** A measure that provides an ***index*** of the number of individuals in the population over time, but not the *actual* numbers. Generally get abundance indices from:
   1. Fisheries (fisheries-dependent data)
   2. Surveys (fisheries-independent data)

Why do we need an index of abundance?

Our *model* needs to be connected to reality

1. Our model is a series of interconnecting equations which describe the fish population dynamics (recruitment, growth, natural mortality) and its interaction with the fishery (fishing mortality)……

2. ….but so far, the model has nothing to connect it to reality, to what is actually happening in the fish population. The model needs a guide to tell it if abundance (biomass) is increasing or decreasing or stable at any point in time.

Why do we need an index of abundance?

"Counting fish is just like counting trees…except that they are invisible and they move"

3. Because we can not:

   a. Count the fish directly (we cant "see" the fish and they are constantly moving and mixing)

   b. Get a direct ***absolute*** estimate of abundance – the tuna stocks and their distribution are too large to make this practical for tuna.

……we need some kind of ***relative indicator*** of abundance.

Abundance Indices

What makes a good abundance index?

An abundance index needs to be based on data which we are confident will relate directly to the biomass or abundance of the population, and ***change proportionately*** with biomass over time.

i.e. We assume that our index is proportional to biomass (abundance)

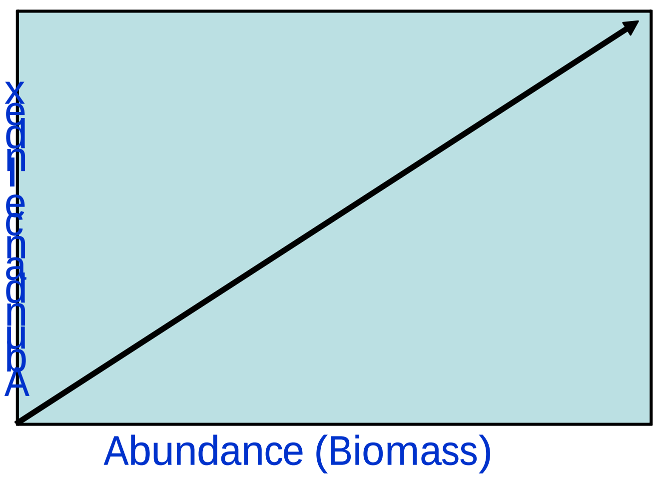
$$\text{Index} \propto B$$

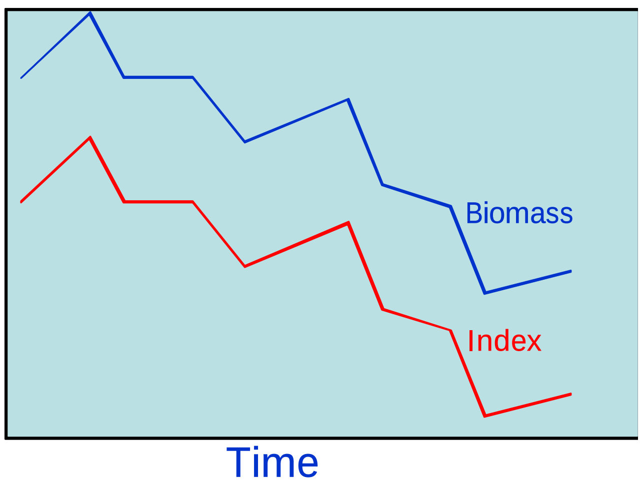
Where **B** is the population biomass

Abundance Indices

Key assumptions:

1. Relationship between the index and abundance is linear (proportional).
2. The relationship doesn't change over time or space.





What abundance index is used in the tuna assessments?

CPUE – Catch per unit effort

Catch and effort data are collected by all commercial fishers in the WCPFC Convention Area

Catch data examples: Numbers, Weights (kg, mt)

Effort data examples: Hooks – longline; Sets – purse seine; Days searching & fishing – pole and line

CPUE examples:

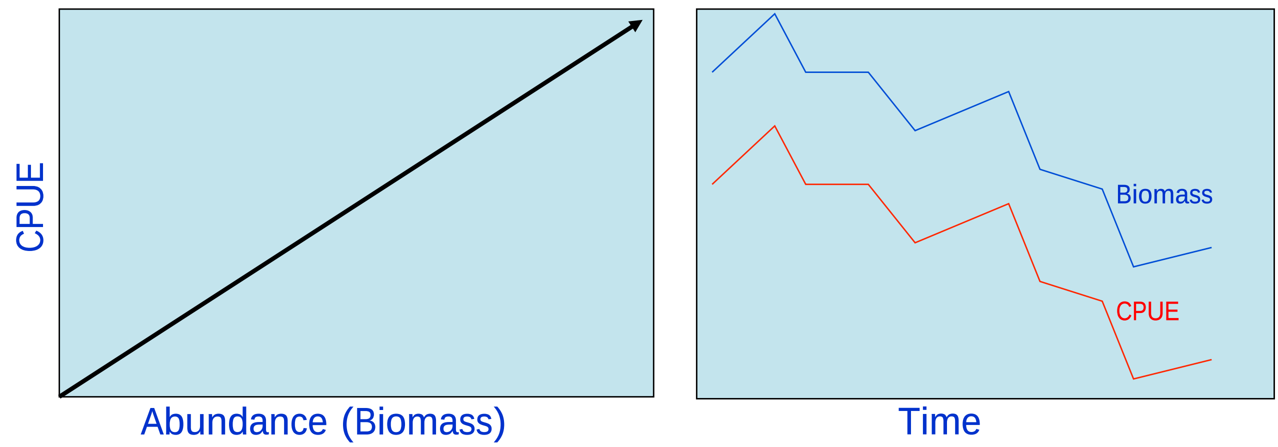
Number of fish per 100 hooks (longline)
Metric tonnes per day (pole and line)

CPUE as an abundance index

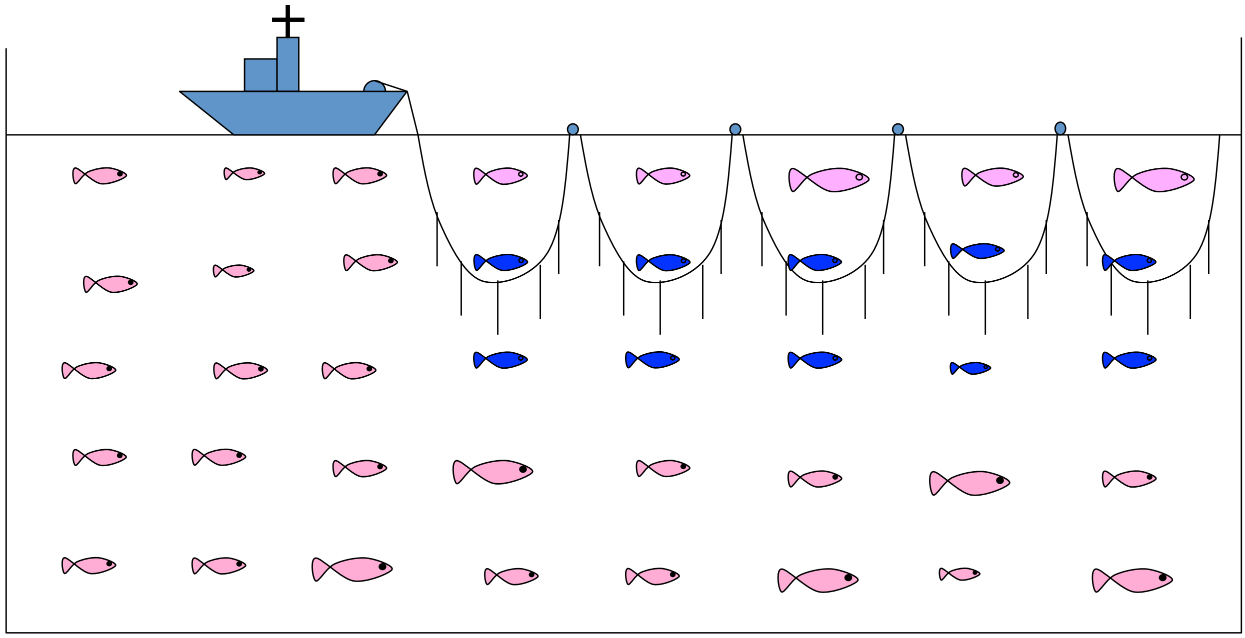
CPUE is used as an index of abundance and is based on the assumption that the amount of fish caught per unit fishing effort will be proportional to the abundance of the fish:

C/E = qB

Catch/Effort = Catchability x Biomass



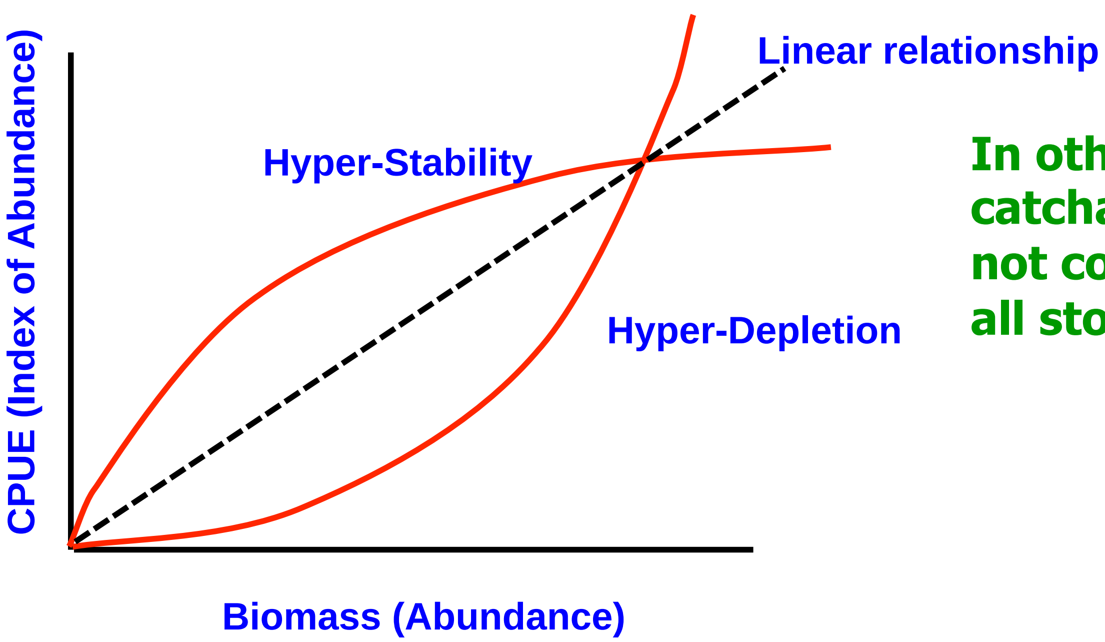
CPUE as an abundance index



So, if the number of fish in the population is halved, then the catch rate should also be halved, assuming even distribution of fish and fishing effort and thus of catchability. (Which is unlikely.)

CPUE as an abundance index

However, the assumption that catchability (the proportion of the stock taken by one unit fishing effort) does not change is wrong! The relationship between abundance and CPUE is typically non-linear



In other words, catchability is not constant at all stock sizes

CPUE as an abundance index

Why does catchability vary?

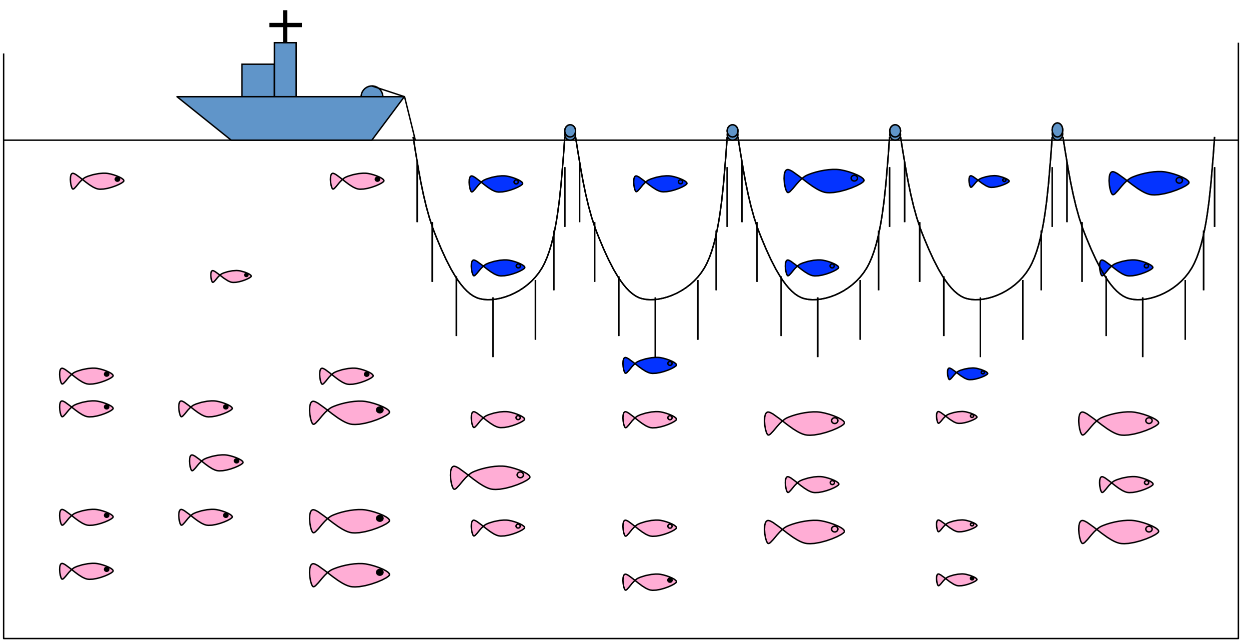
1. Many factors can act and interact to affect catchability and thus the relationship between CPUE and abundance:

- **Changes in fishing methods and techniques**
  LL: e.g., depth of setting, HBF, hook type, hook size, light-stick use, bait type, time of set, latitude, longitude, proximity of other vessels, proximity to features, etc.; PS: e.g., set type, time of set, latitude, longitude, proximity of other vessels, proximity to features, presence of other species, etc.

- **Biological factors**
  E.g., size ,maturity, age, habitat preferences, etc.

- **Environmental factors**
  E.g., habitat availability, oceanographic factors, prey abundance, etc.

Changes in catchability



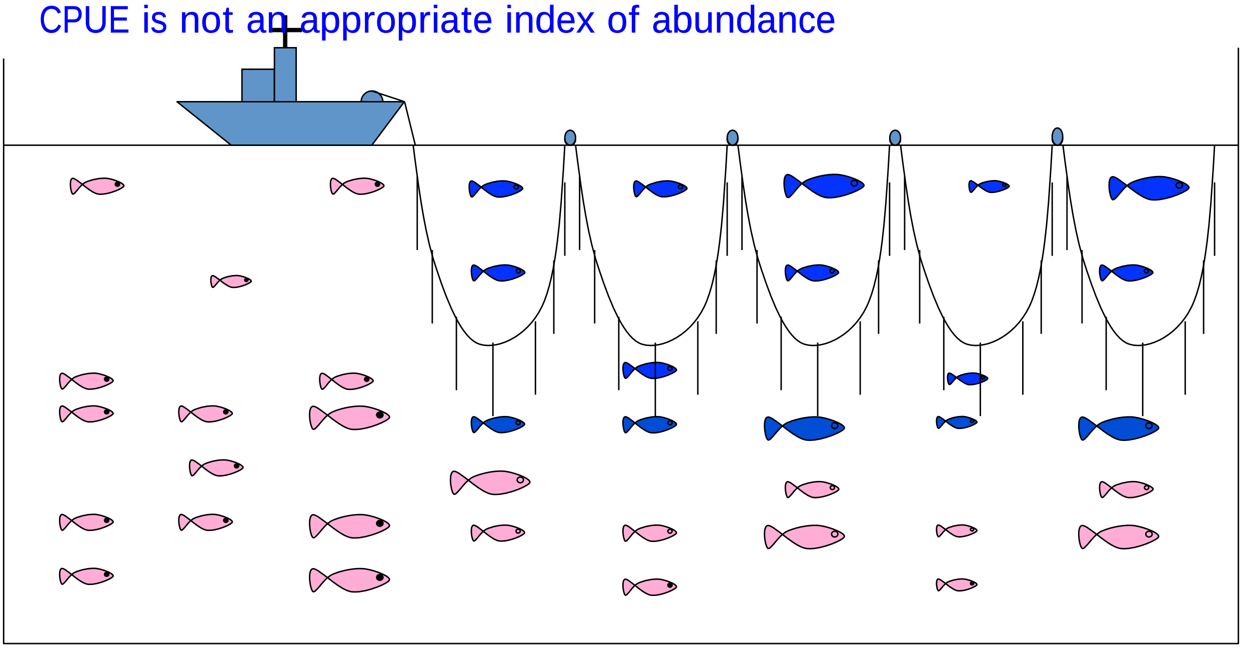
q = C/EB

q = 2/30x28

=0.00238

Changes in catchability

When the depth of the gear changes, the catch rate increases (due to increased catchability), but the biomass has not changed, hence raw CPUE is not an appropriate index of abundance



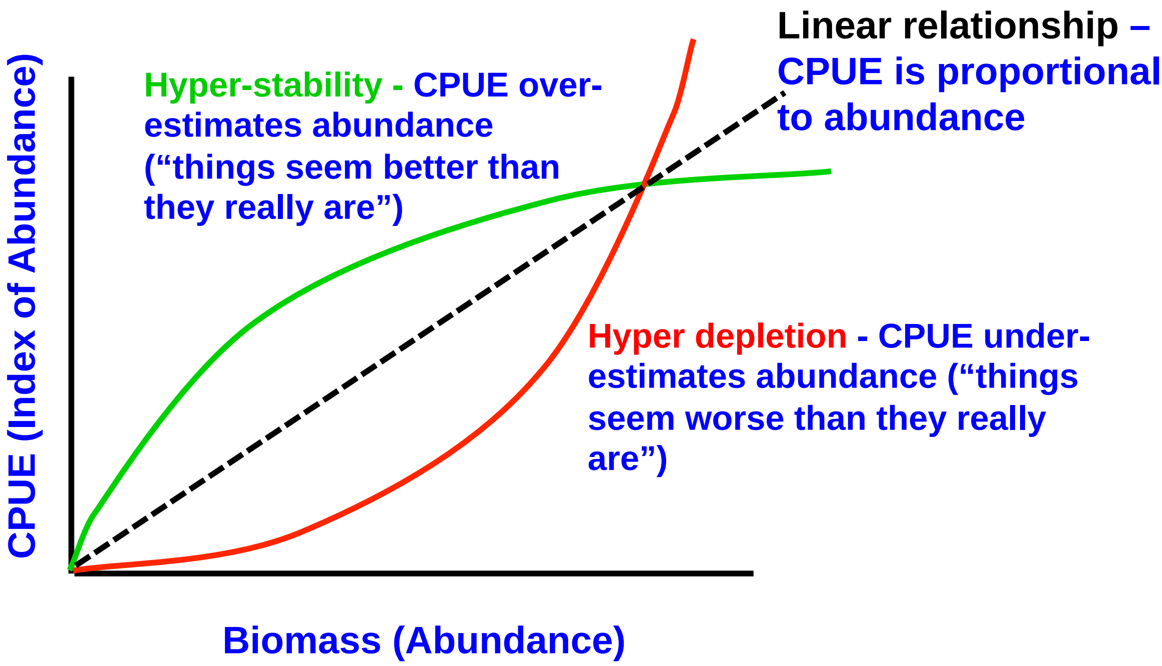
q = C/EB

q = 7/30x28

=0.00833

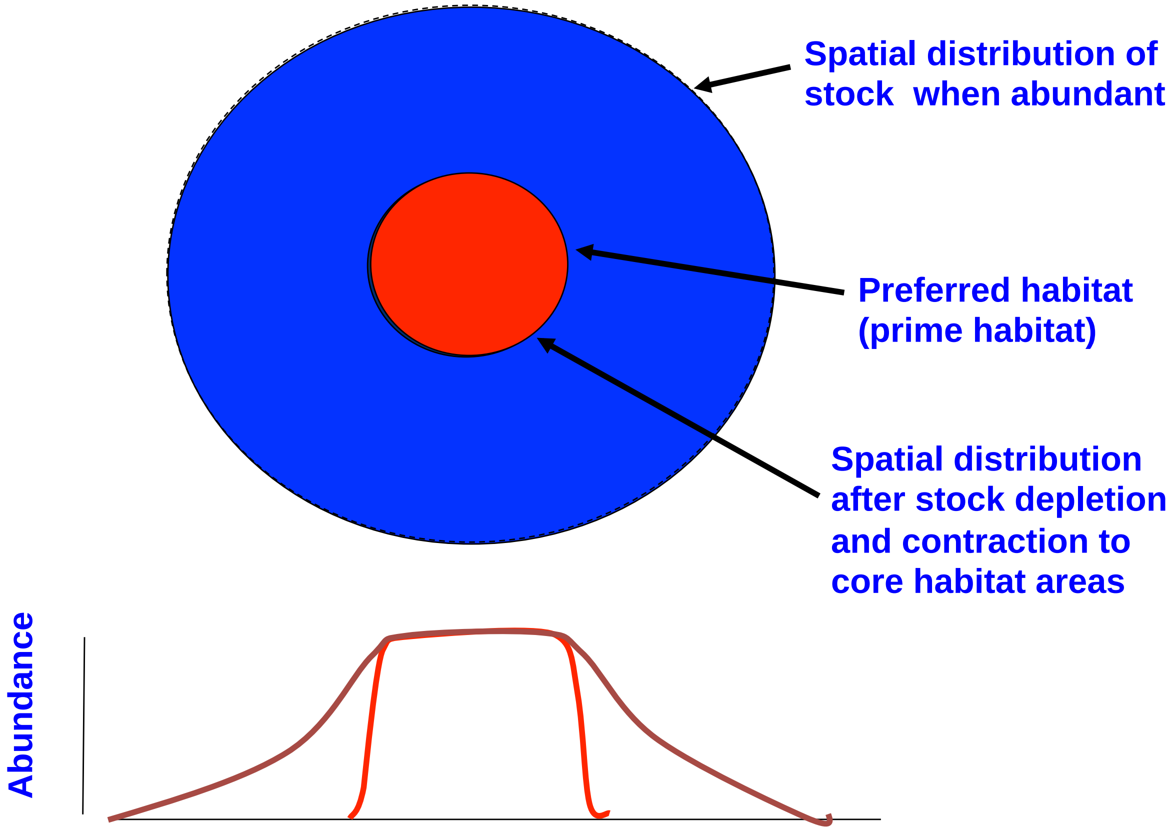
CPUE as an abundance index

Deviation of CPUE from abundance is clearly of concern



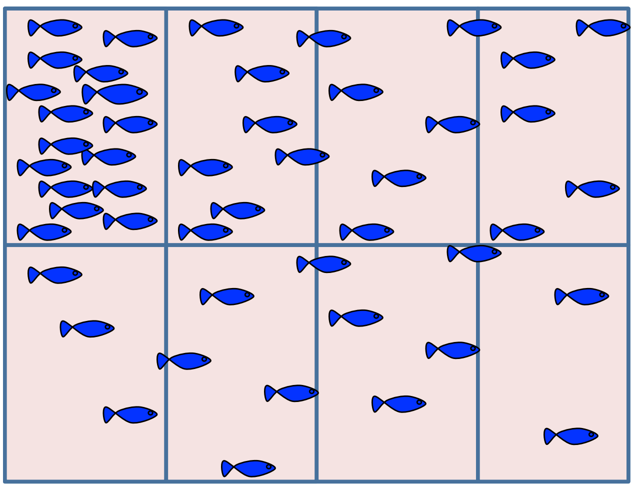
e.g. Spatial Processes and Hyperstability

(McCall Basin Theory)



Ref: http://www.fish.washington.edu/classes/fish210/

e.g. Spatial Processes and Hyper-depletion



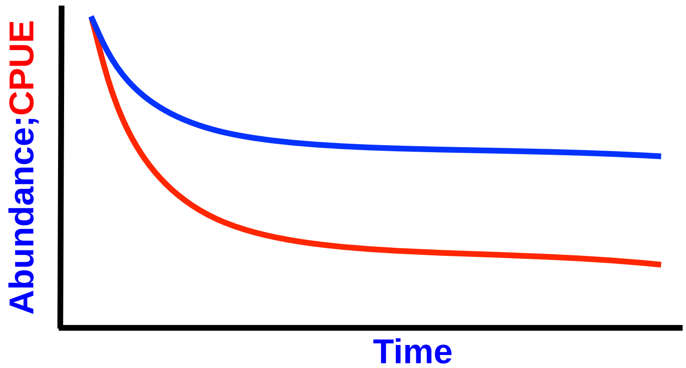
If we divide our stock region into subregions, which subregion would you go fishing in first if you were a fisherman

Expect very high initial catch rates in northwest subregion. But as that depletes and fishers move to areas with less abundance, CPUE rapidly declines

Initial CPUE over inflated (relative to stock abundance) – its not derived from a random sample.

The decline in CPUE would be faster than the overall decline in stock biomass

Need random sampling – unlikely with fisheries data



So, can we still use CPUE as an abundance index?

YES!

However, we need to make sure that any changes in catchability are estimated and accounted for prior to or during the stock assessment modelling process.

Catch rate standardisation

CPUE standardisation:

1. Today, standardising catch rates is typically a statistical model-fitting exercise, where an attempt is made to identify and remove the effect of those factors that appear to shift the relationship between CPUE and abundance away from a simple linear one.

2. Types of statistical models commonly used include:

- **Generalised linear models (GLMs)**
- **Generalised additive models (GAMs)**
- **Generalised linear mixed models (GLMMs)**

Using CPUE

CPUE standardisation:

3. All models attempt to produce a function that accurately describes the actual relationship between catch and effort, in order to develop an index of abundance (i.e., a model of "best fit" to the data)

4. The process also assists in determining which factors will have the largest influence on the relationship between catch and effort, allowing us to understand how variables "work'".

Using CPUE

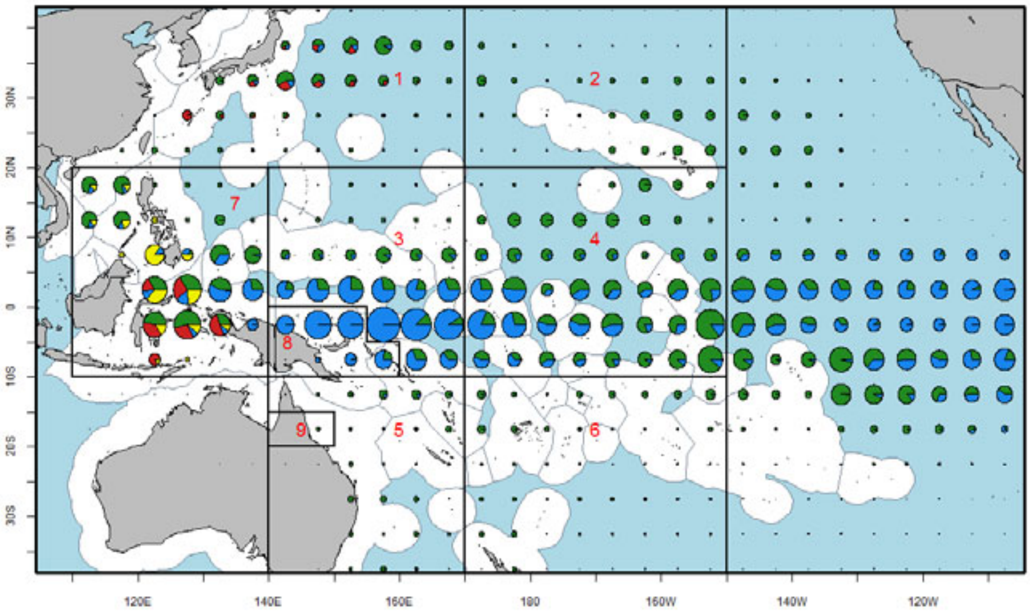
CPUE standardisation:

4. Once a model is fitted, it is possible to develop a standardised CPUE series and extract a standardised effort series to use in a stock assessment model, reducing or excluding the effects of important factors influencing the relationship between CPUE and abundance.

5. In MULTIFAN-CL, CPUE models are also used to produce standardised effort series as model inputs.

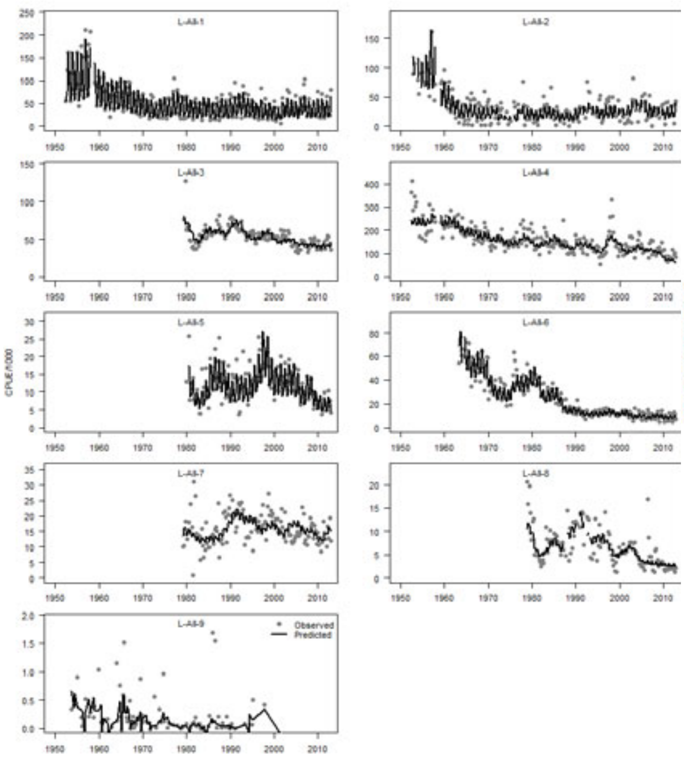
CPUE data and MFCL

Example: bigeye tuna

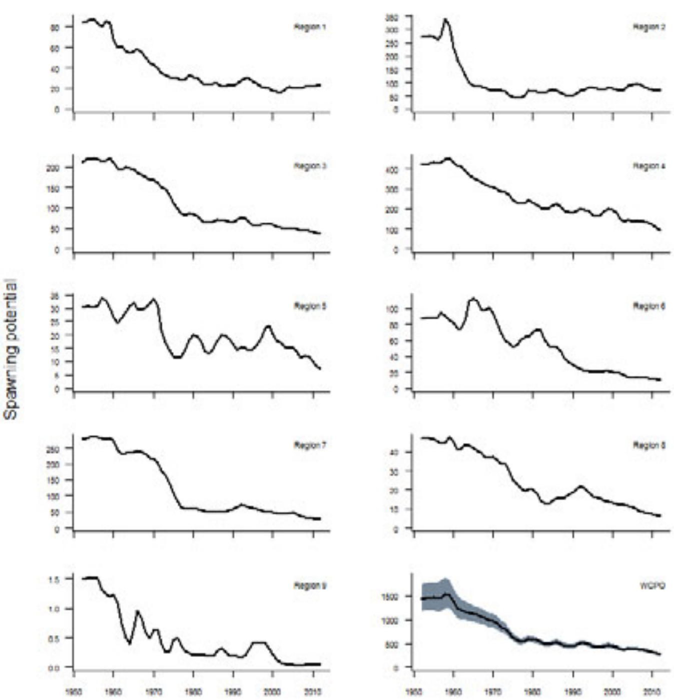


CPUE data and MFCL – Bigeye 2014

Standardised CPUE



Biomass



CPUE data and MFCL

Example: striped marlin 2006

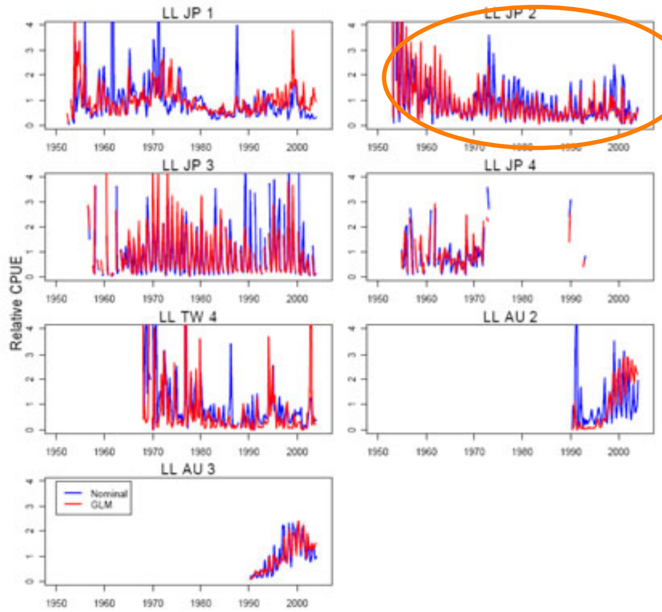
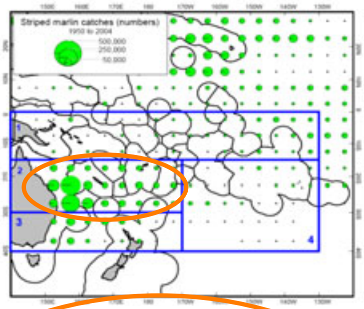


Figure 6. A comparison of nominal (blue series) and standardised (red series) quarterly CPUEs for the main longline fisheries. The CPUE indices have been normalised to the mean of the series.



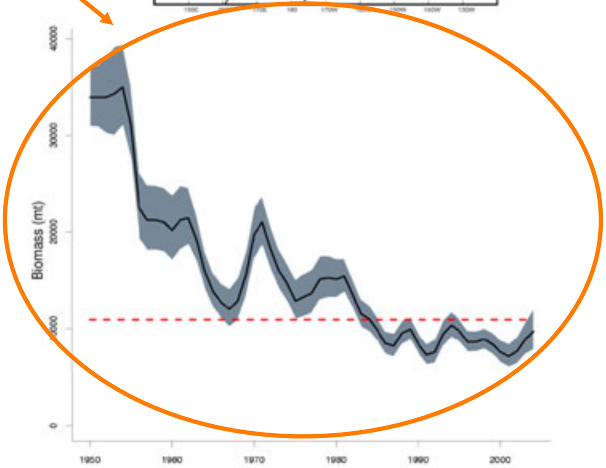


Figure 23. Annual estimates adult biomass (metric tonnes) of striped marlin in the model region. The dashed line represents the SB_{MSY} level. The shaded area indicates the approximate 95% confidence intervals. Model estimates are from the model using natural mortality of 0.4 per year, k = 0.6, and the uninformative prior on steepness of the SSR.

Summary

Abundance indices, CPUE, and CPUE standardisation:

1. A stock assessment model requires information which will guide its estimation of the actual level of biomass over time (and space) as they need something to connect the model to reality so the model needs an index of abundance derived from the fish population itself.

2. Catch per unit effort (CPUE) is probably the most commonly used (relative) index of abundance for fish stocks, as it is based on data easily collected from commercial and recreational fisheries.

3. The relationship between CPUE and biomass can be stated as:

C/E = qB

Catch/Effort = Catchability x Biomass

Summary

Abundance indices, CPUE, and CPUE standardisation:

4. CPUE can be misleading due to catch rates being influenced by a range of factors other than changes in abundance (e.g., changes in fishing technology, spatial distribution of fish etc.)

5. The process of standardising catch rates attempts to remove variations in nominal catch rates that are due to factors other than varying abundance.

6. Most standardisation procedures are based on generalised linear models and are undertaken outside the model framework to produce a **standardised CPUE or effort series as an input for stock assessment model fitting**.

Chapter 9

Parameter estimation – Catchability and Selectivity

Introduction

We have looked at the estimation of the key natural processes that influence population dynamics of fish populations.

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

We have also talked about fishing mortality rates (catch removals) and CPUE. Here look more closely at two of the key parameters involved in the estimation of fishing mortality rates:

Catchability

Selectivity

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

Overview

1. Catchability
   a. Introduction to catchability
   b. What is catchability?
   c. What factors influence catchability?
   d. Why do we need to consider (and estimate) catchability in stock assessment models?
   e. How do we account for catchability effects in stock assessment models?
2. Size Selectivity
   a. What is size selectivity?
   b. What factors influence selectivity?
   c. Why do we need to consider (and estimate) selectivity in age structured stock assessment models?
   d. How do we account for catchability effects in stock assessment models?

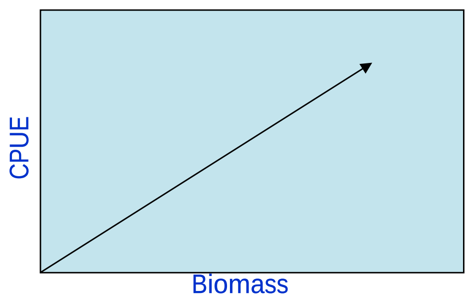
Introduction to Catchability

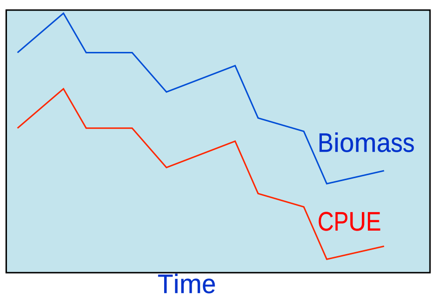
Central to stock assessment principles are two assumptions:

1. Size of the population (biomass) is determined by balance between Growth, Recruitment, Natural mortality and Fishing mortality (and movement)

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

2. Population (biomass) will vary over time proportionately with the catch rates taken in the fishery, because as biomass increases or decreases the gear will catch proportionately more or less fish per unit effort. Therefore **catch rates are effectively an index of abundance** (biomass) and can be used to help the model realistically track biomass over time.

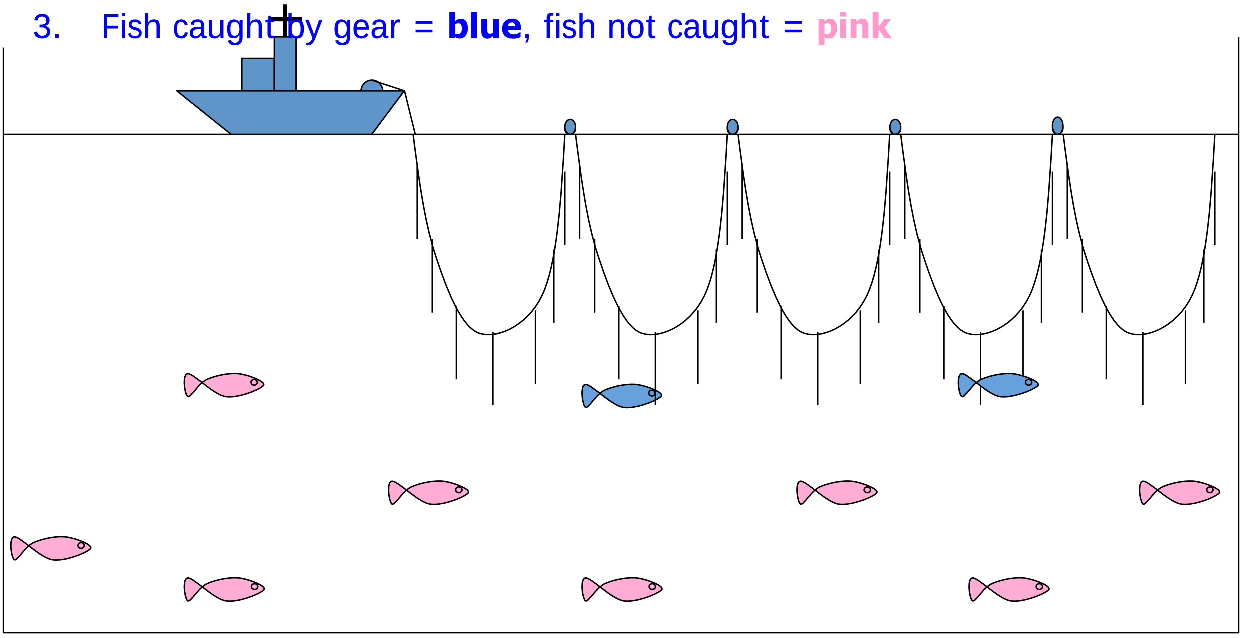




Introduction to Catchability

To remind us of how this theory works, consider the following example:

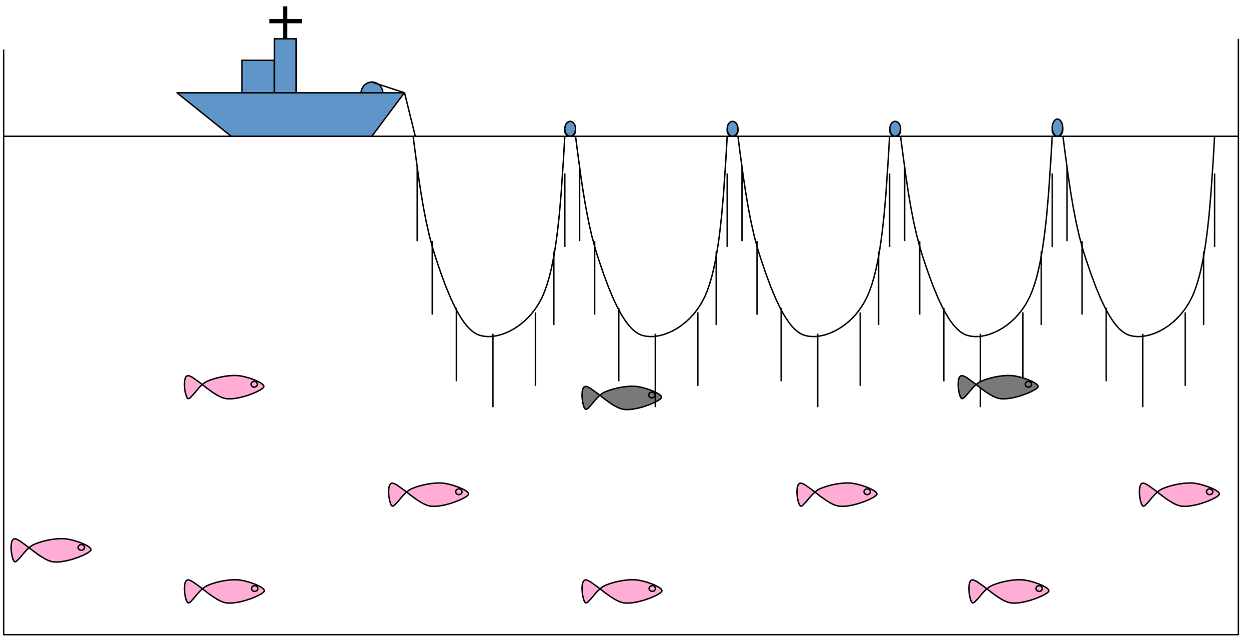
1. A longliner sets 35 hooks in the water.
2. Fish population = 10 fish, each weighs 1 kg, evenly distributed (below 50 meters)
3. Fish caught by gear = **blue**, fish not caught = **pink**



Introduction to Catchability

Noting that CPUE = Catch/Effort, and the fisher catches 2 fish (each 1kg) using 35 hooks, the catch rate is = 2 / 35 = 0.057 kg/hook or

Assuming that the fish are evenly distributed (spatially), **what will happen to the catch rate if we double the biomass** (number of fish, each 1kg) to 20 fish (20 kg)?

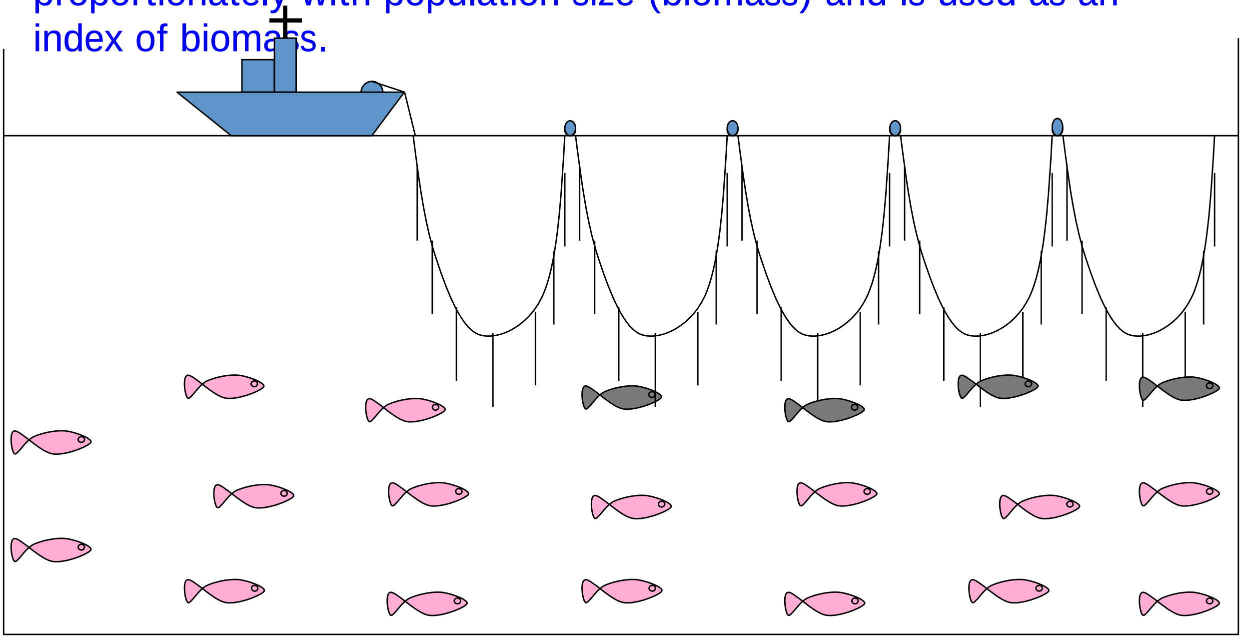


Catch rates as an index of biomass

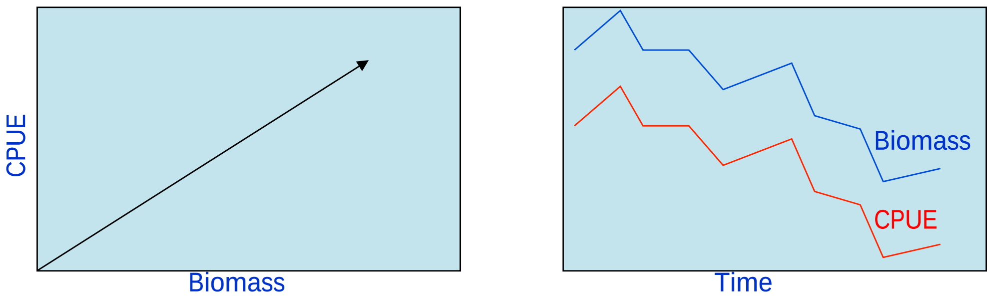
Catch per unit effort also doubles (catch/effort = 4/35 = 0.114)

If we were to double the biomass again, catch rates would double again, and so on...

......This illustrates why catch rates are assumed to vary proportionately with population size (biomass) and is used as an index of biomass.



Catch rates as an index of biomass



This assumption, however, has often been shown to be WRONG!

And to understand why, we need to understand the concept of **CATCHABILITY!** ...

What is catchability?

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

$$q = C/EB$$

Where q = catchability, C = catch, E = effort, and B = biomass

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

What is catchability?

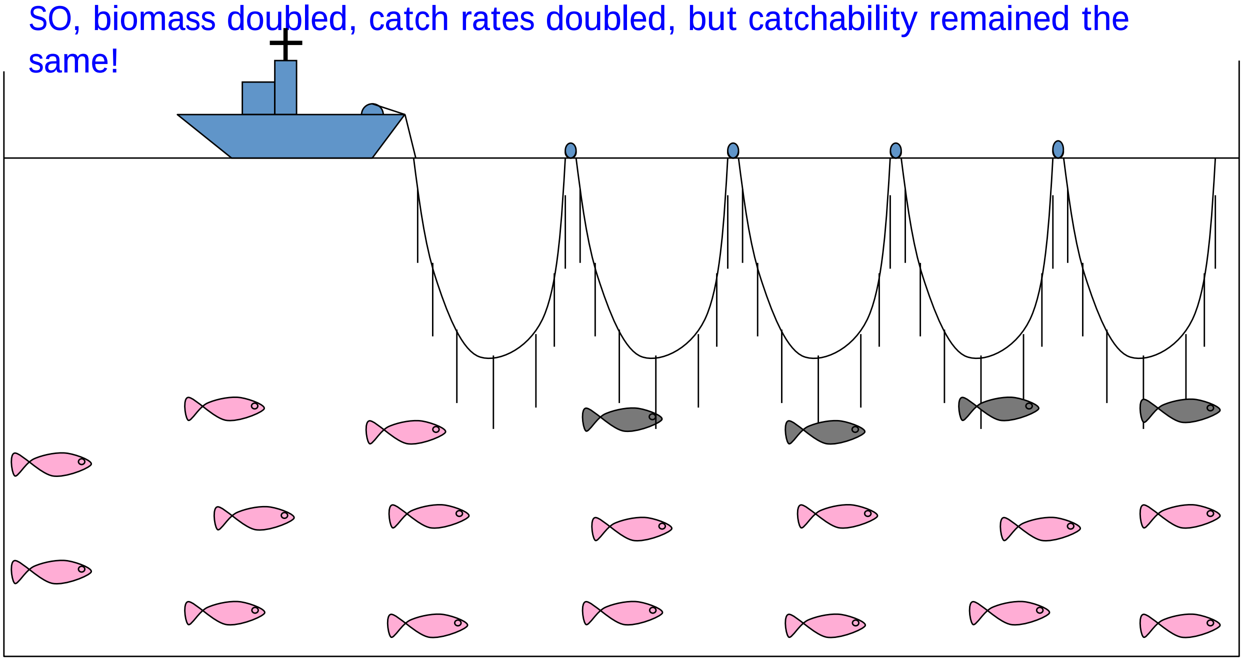
So, in our first example, the catchability (proportion of stock caught PUE) was:

q = C/EB = 2/(35*10) = 0.0057 = each hook caught 0.57% of the stock

In our second example, biomass was doubled, and catchability was:

q = C/EB = 4/(35*20) = 0.0057 = each hook caught 0.57% of the stock

SO, biomass doubled, catch rates doubled, but catchability remained the same!



What is catchability?

Where catchability remains the same over time, CPUE varies with biomass, and is a good index of abundance...however....

There is a Problem!

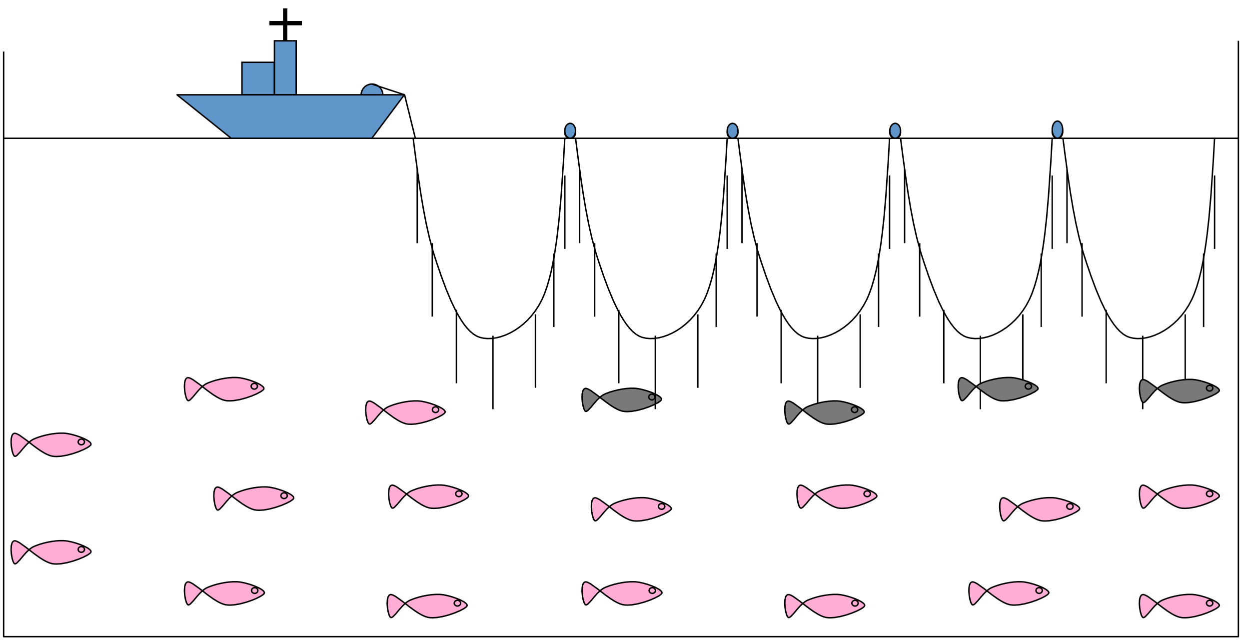
Catchability can change (increase or decrease) over time, meaning that our key assumption in stock assessment, that catch per unit effort will vary proportionally with stock size, is no longer true.

What can cause changes in catchability, ie. Changes in the mean proportion of the stock caught by one unit of effort?

What factors influence catchability?

Imagine if the fishermen in our previous example decided to sink his hooks deeper, so that more of the hooks were in the fishes habitat?

What do you think would happen to "catchability"? Why?

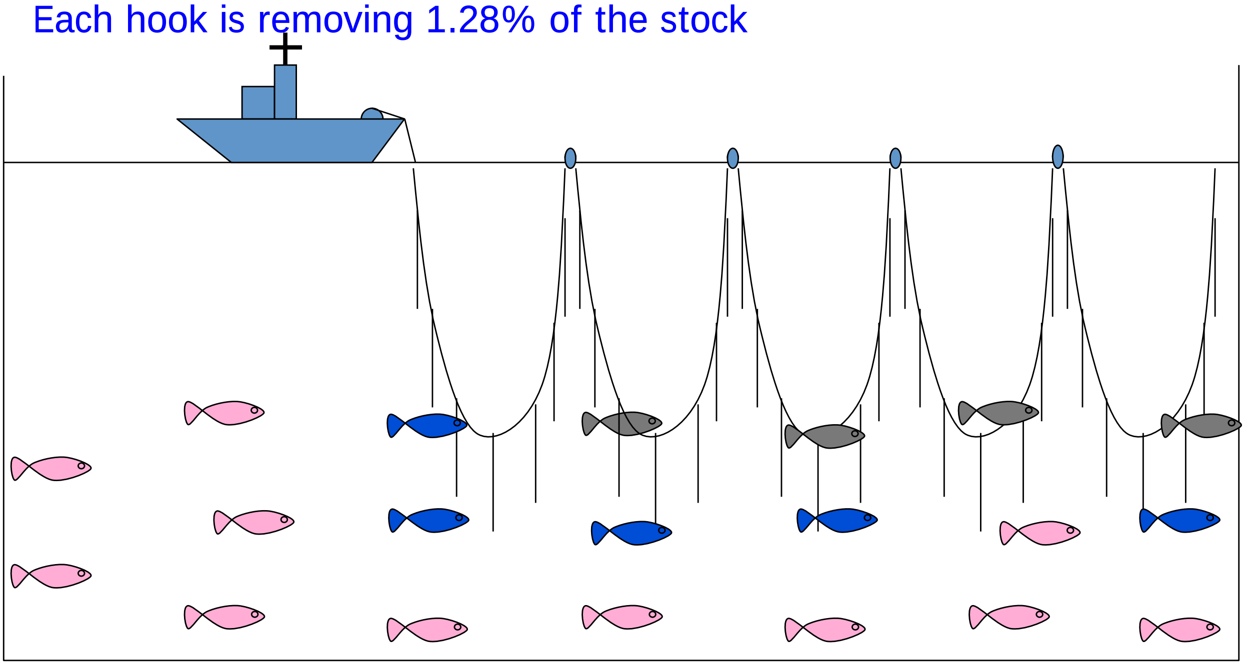


What factors influence catchability?

Now the fisher is catching 9 fish per 35 hooks. The biomass hasn't changed but his catch rate has increased, and catchability has increased:

$q = C/EB = 9/(35*20) = 0.0128$

Each hook is removing 1.28% of the stock

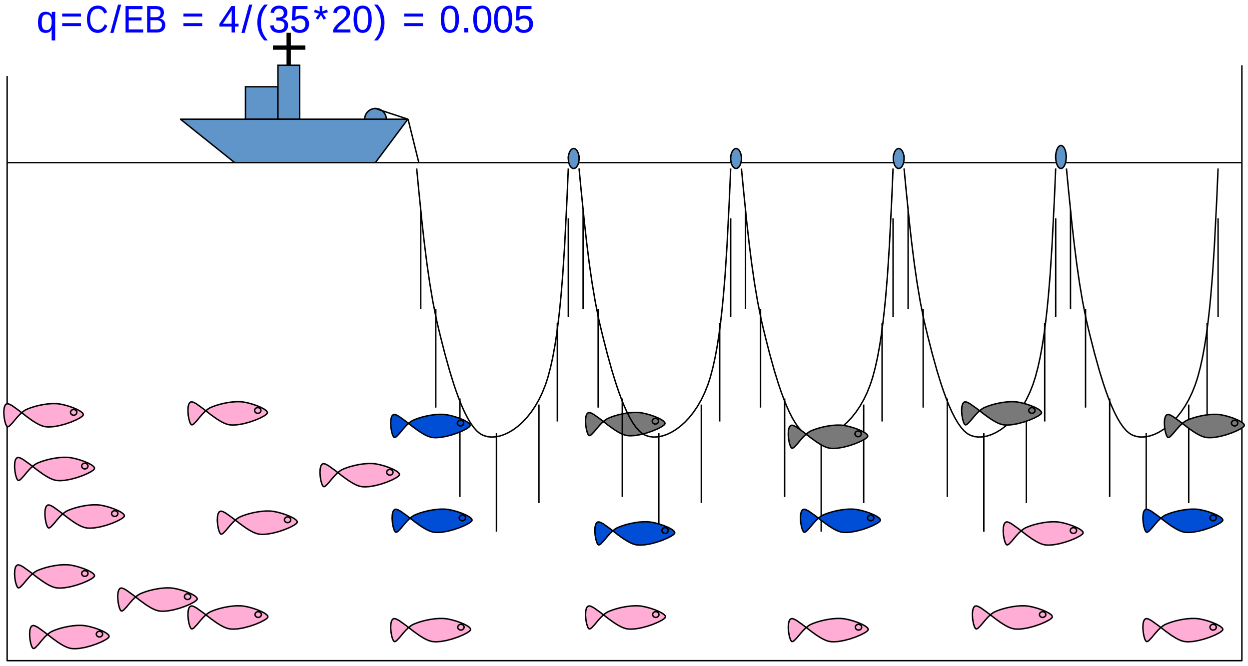


What factors influence catchability?

What if the fish migrated away from the fishing area, perhaps due to their biological urges to spawn in another area?

What happens to catchability? Whats happened to biomass? Catch rates? And why?

$q=C/EB = 4/(35*20) = 0.005$



What factors influence catchability?

In both examples, biomass was constant, but catchability (and catch rates) changed:

- Once because the fisher changed their method (deeper hooks).
- Once because the fish moved away (they were no longer evenly distributed

What else can effect catchability and catch rates?

What factors influence catchability?

Factors causing change in catchability.........

1. **Changes in fishing methods**
   e.g. Change in depth of setting by Japanese longliners in early 1970s
2. **Changes in fishing technology**
   e.g. Improved fish finding technologies
3. **Experience and skill increases over time.**

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.

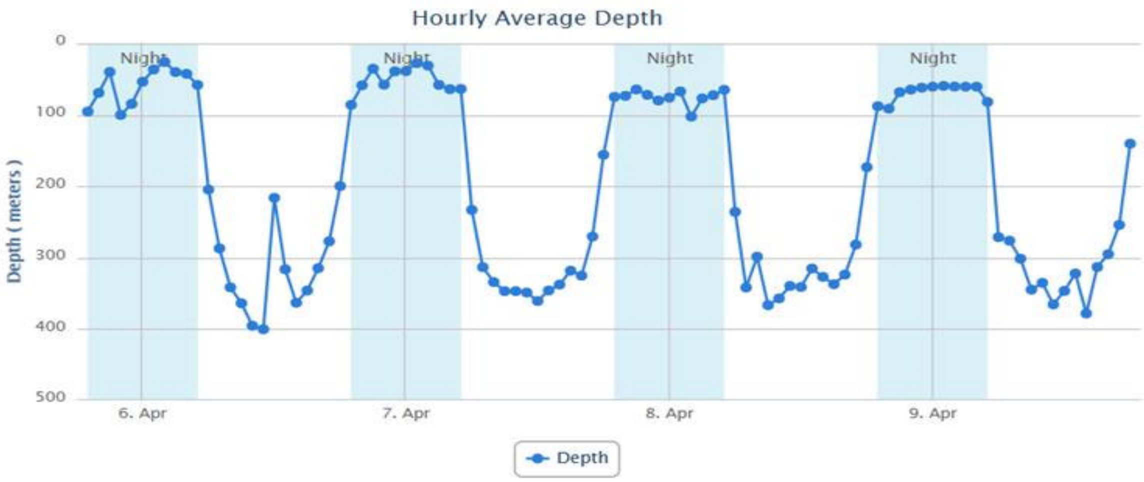
(**effort creep**)

What factors influence catchability?

4. Environmental factors

e.g. Sea surface temperatures – fish aggregate to preferred temperatures (and habitats)

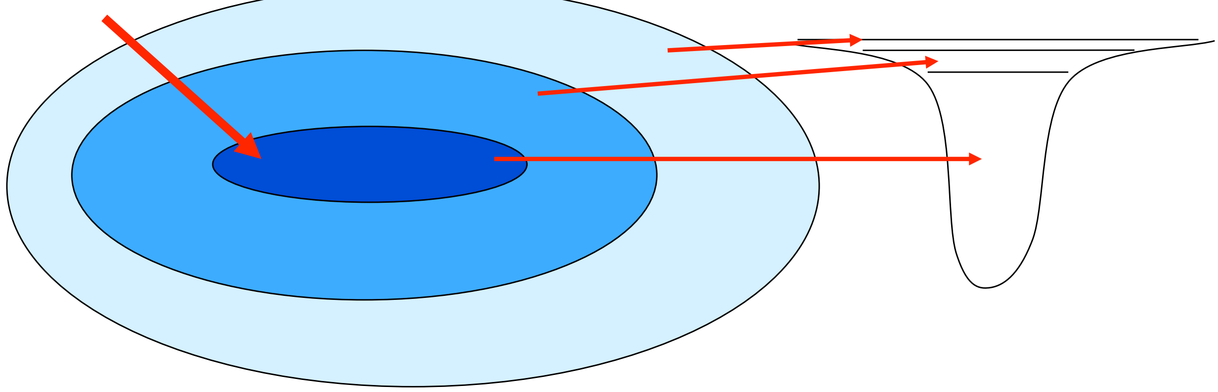
5. Behaviour – movement of fish due to spawning, feeding, habitat requirements, some fish show vertical migration habits each day and night; e.g. Bigeye tuna migrate to surface at night and deep during the day



What factors influence catchability?

5. Contraction of species to prime habitats when biomass declines (e.g. due to fishing, especially in schooling fish). “McCall basin theory”

Prime habitat



Why do we need to account for or estimate catchability in stock assessment models?

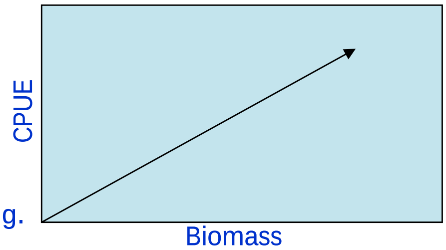
This relationship is very important to assessment modelling for two main reasons:

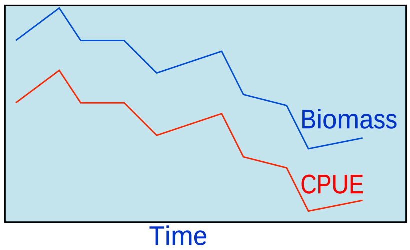
1. It relates catch rates to the stock biomass, via:

$$C/E = qB$$

Stock assessment models rely on the assumption that catch per unit effort will vary over time proportionately with biomass, so CPUE acts as an index of abundance. Having such an index is critical to the estimation of biomass.

e.g.





Why do we need to account for or estimate catchability in stock assessment models?

2. It relates fishing mortality rates to fishing effort, via:

$$C/B = F = qE$$

We will see later that in models such as MULTIFAN_CL, we estimate catches from estimated fishing mortality and that is estimated in turn from effort data.

How do we account for or estimate catchability in stock assessment models?

Because q tracks deviations from the proportional relationship between CPUE and biomass it allows us to account for these deviations to ensure that estimates of biomass derived from CPUE are not biased.

If we can estimate the value of q at each time step, we can still assume our catch rate data will provide an accurate index of biomass, despite the change in proportional relationship between CPUE and biomass!

You will be undertaking a practical to demonstrate these effects a little later today.

How do we account for or estimate catchability in stock assessment models?

MULTIFAN-CL based estimation of ***q***

In using MULTIFAN-CL there are two separate mechanisms which allow for the consideration of variation in catchability over time:

1. Catch rate standardisation (outside the model)

Catch rate standardisation is a modelling process that attempt to remove any variation in catch rates (due to changes in catchability) over time that is due to any factors other than the underlying abundance.

We can then use the standardised catch rate series as our observed CPUE data and fit the model to this time series

How do we account for or estimate catchability in stock assessment models?

MULTIFAN-CL based estimation of ***q***

2. Estimation of time series of catchability (within model)

If there is little confidence in the standardisation, MULTIFAN-CL can estimate a **time series of catchability.**

How do we account for or estimate catchability in stock assessment models?

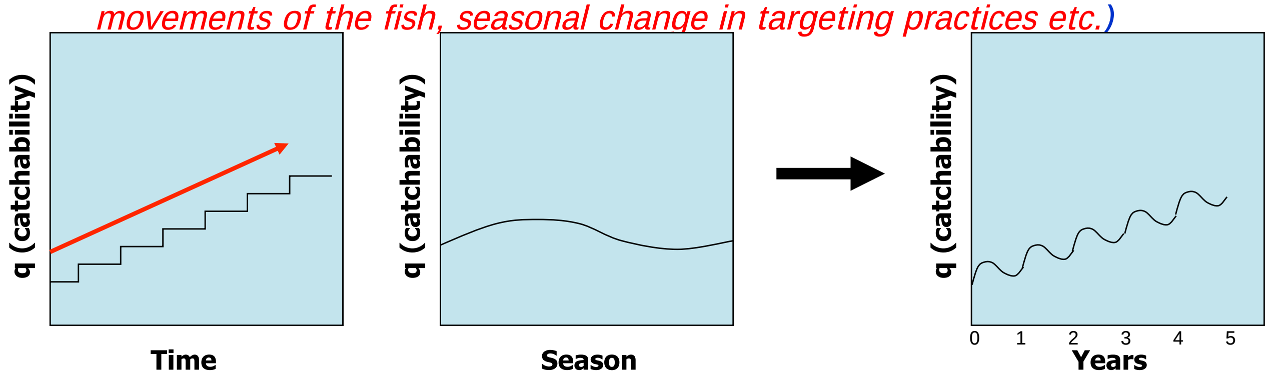
MULTIFAN-CL based estimation of *q*

MULTIFAN-CL allows for the inclusion of temporal variability in catchability at an interannual scale and at intra-annual (seasonal) scale. Time series structure in catchability is allowed by:

$$q_{t+1,f} = q_{t,f}e^{ntf}$$

where e^{ntf} represents cumulative changes in catchability assumed to occur at regular intervals.

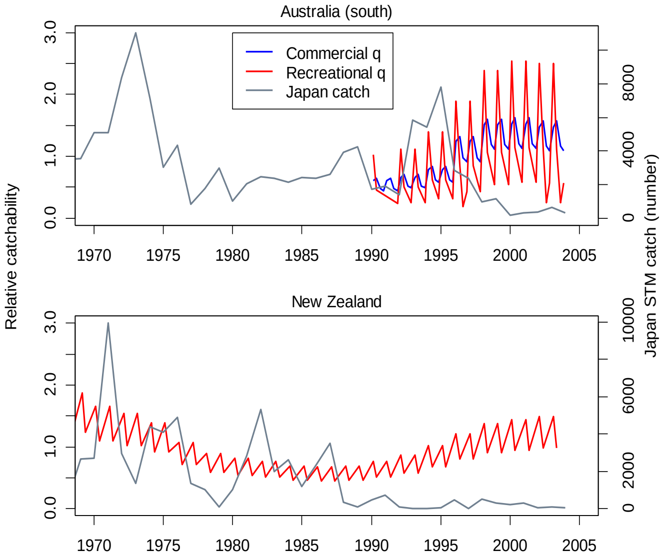
Feeding into the above equation are equations that allow for within year (seasonal, or monthly) variation in catchability (*e.g. due to seasonal movements of the fish, seasonal change in targeting practices etc.*)



How do we account for or estimate catchability in stock assessment models?

MULTIFAN_CL based estimation of *q*

Example: Striped marlin assessment in the Southwest Pacific Ocean (2006)

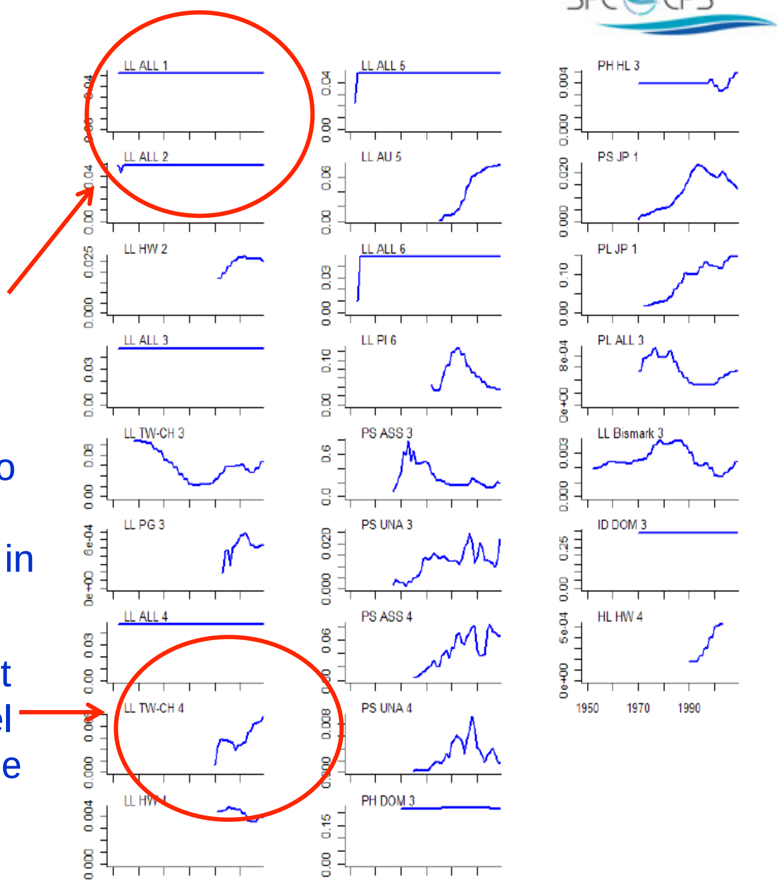


Estimation of Catchability

Note two features:

1. Fisheries whose CPUE has been standardised and is been used as the *index of abundance.* q is assumed to be constant (in this case, Japanese longline fisheries in each region).

2. Fisheries where CPUE is not standardised and the model estimates a catchability time series as part of the model fitting process.



ure 25. Average annual catchability time series, by fishery.

Selectivity

1. What is selectivity?
2. Why are gears size selective?
3. Whats the relevance of selectivity to stock assessment?
4. How do we estimate selectivity
5. How is selectivity accounted for within MULTIFANCL
6. What is the impact of selectivity on biomass estimation?

Selective fishing refers to a fishing method's ability to target and capture organisms by size and species during the fishing operation allowing non-targets to be avoided or released unharmed.

Selectivity in a modelling context is used to model the **vulnerability** of fish to the gear as well as the **availability** of fish to the gear.

What is selectivity?

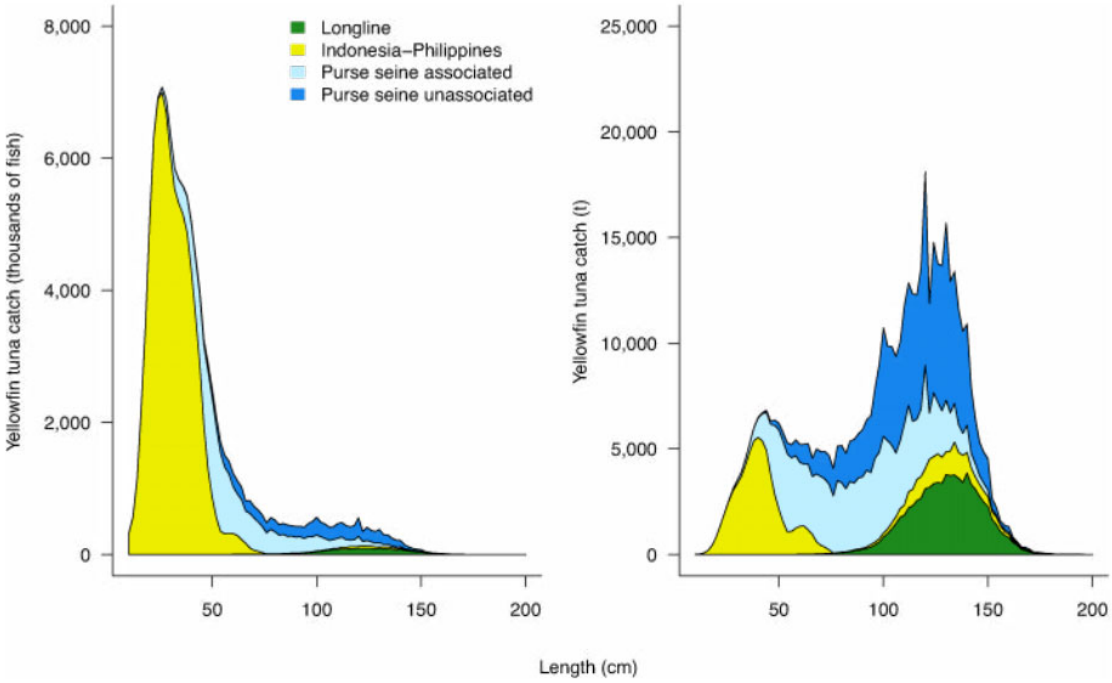
In fish populations the probability of capture by a particular fishing gear will depend on individual traits of each fish.

E.g. size of the fish…… A fishing net with a large mesh size will catch few smaller fish and many larger fish. Conversely, larger fish might be able to swim faster than smaller fish and therefore be more likely to avoid a net. Clearly, fishing methods can be size ***selective***.

If we assumed that there was no size ***selectivity*** of the fishing gear, we would underestimate the total population biomass

So in stock assessment models, we attempt to account for size (age) specific selectivity.

What is selectivity?



Why are fishing gears size selective?

1. **Physical characteristics of fish**

    e.g. Mouth size relative to hook size (LL)

    Swim speed relative to setting speed (PS?)

2. **Behavioral characteristics associated with size**

    e.g. Prey size preference (LL)

    Position in water column relative to gear (PS)

3. **Escapement capacity**

    e.g. body size relative to mesh size

.......And other size related effects

Selectivity over time: If a particular fishery (e.g. longline) changes its fishing method over time then selectivity could also change, for example, if a fishery started using larger baits and hook sizes, smaller sized fish with smaller gapes might be caught less often.

Why is selectivity important in stock assessments

What is the relevance of selectivity to stock assessment?

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.

For example, if the catch data only shows a small number of small fish in the catch, this is likely due only to the fact the gear is less able to catch the small fish, not because there are not many in the population.

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

Why is selectivity important in stock assessments

Selectivity is an important parameter required for the estimation of fishing mortality at age:

$$F_a = qEs_a$$

Where:

F_a = Fishing mortality

q = catchability

E = fishing effort

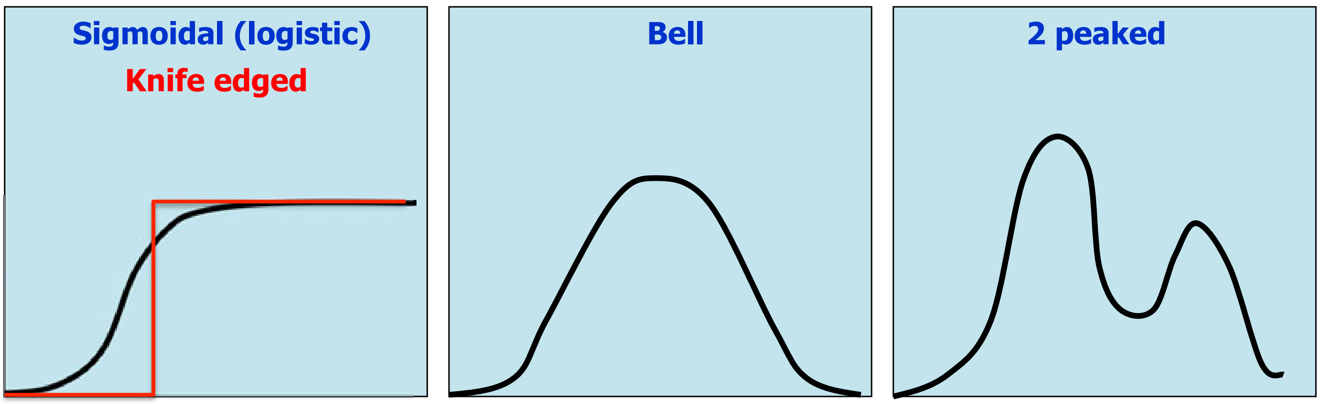
s_a = selectivity-at-age

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

How do we estimate selectivity?

The size based selectivity of a fishing gear can be described by means of a selectivity curve, which gives for each size (age) class the proportion of the age/size class which is available to the gear....

Three examples of selectivity curves



Selectivity – Bigeye 2010

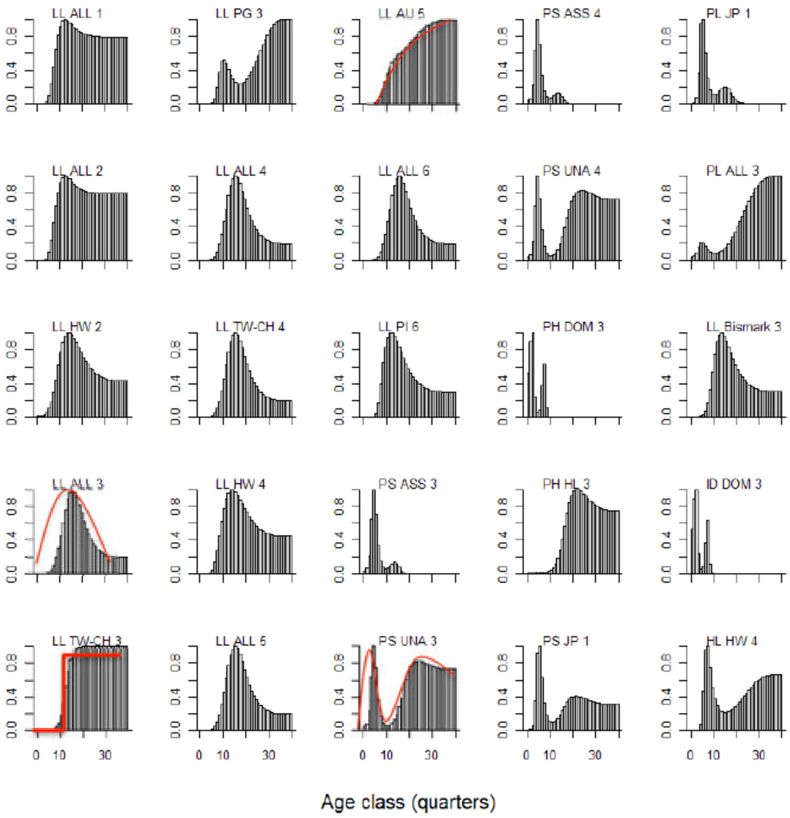
Where:

PS = purse seine

LL= Longline

HL = Handline

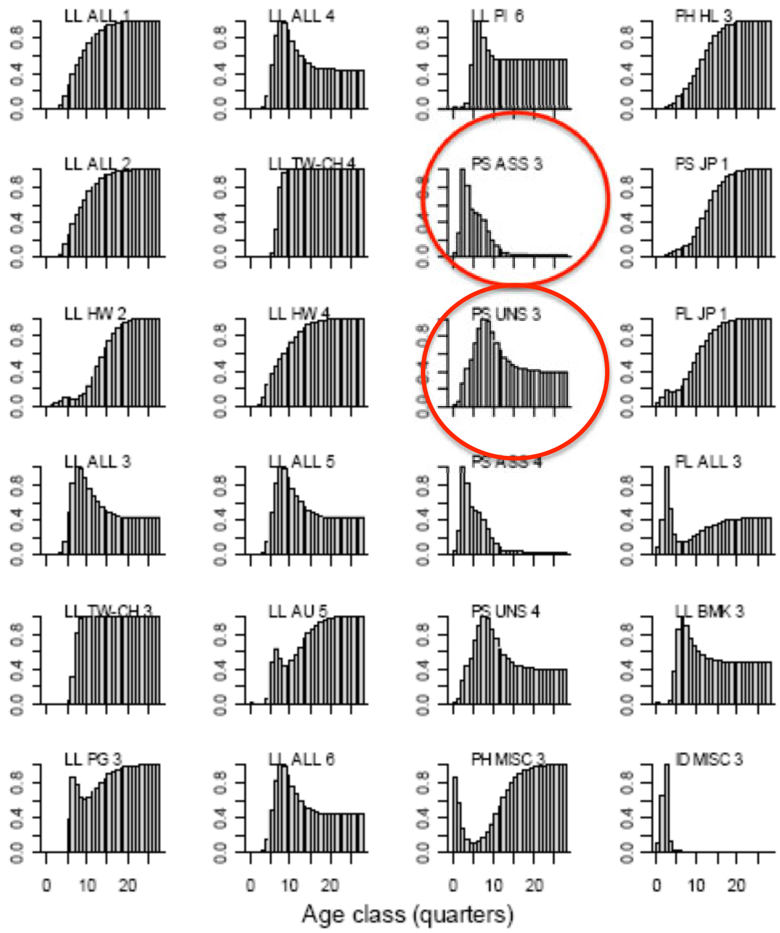
PHID = Philippines Indonesian gears



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

Selectivity – Yellowfin 2009

Why does the selectivity curve of purse seine fisheries fishing on free schools (Unassociated = UNS) differ between bigeye and yellowfin tuna?



How is selectivity estimated?

How is selectivity accounted for within MULTIFANCL?

The estimation of catch within MULTIFAN-CL is reliant on estimation of fishing mortality which in turn relies on estimation of selectivity (among other things):

It uses a variation of the base equation $\mathbf{F_a = qEs_a}$

..as follows....

$$F_{atf} = s_{af} q_{tf} B_{r_f}^{\beta} E_{tf}^{\zeta} e^{\varepsilon_{tf}} \tag{A.5}$$

and where

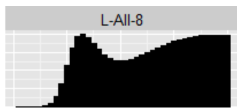
- s_{af} is the selectivity coefficient of fishery f for age-class a fish,
- q_{tf} is the catchability coefficient for fishery f in time period t,
- B is a biomass index for region r and time period t,
- $\beta_t r$ is the parameter for effect of biomass on catchability (default= 0),
- E_{tf} is the fishing effort of fishery f in time period t, and
- ζ is the parameter for effect of effort on catchability (default= 1),
- ε_{tf} represents transient deviations in effort.

How is selectivity estimated?

How is selectivity accounted for within MULTIFANCL?

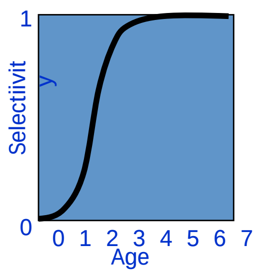
There are several methods that can be used:

1. **One parameter estimated per age class** (this does not impose any specified curve e.g. logistic, structure).
   Easily the most flexible **but** it adds way more parameters to the model.

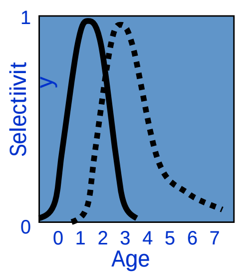


2. **Impose a specific functional form** on the relationship between selectivity and age class. In other words, force the model to fit a curve that you believe will better represent the relationship between selectivity and age.

For example, for a longline fishery you might specify the logistic function, believing that once fish reach a certain size/age, they are completely susceptible to the gear.



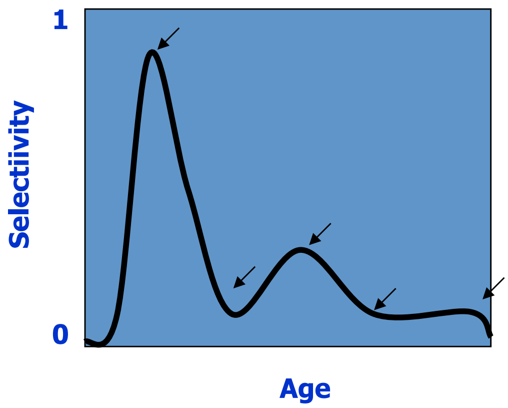
Or for a purse seine fishery you might specify the double normal (dome shaped) function, believing that selectivity increases to a certain age and then declines again.



How is selectivity estimated?

How is selectivity accounted for within MULTIFAN-CL?

3. Use of a cubic spline – effectively a function that allows multiple turning points (arrows) in the selectivity curve. This allows estimation of more complex selectivity patterns.



This is currently the method used in the bigeye and yellowfin tuna assessments

Summary of key points

1. Catchability – the mean proportion of the stock taken by one unit of fishing effort
2. This can change due to many factors (e.g. fishing efficiency increasing, environment changing, fish moving seasonally and/or daily, stock contraction with increasing fishing effort etc.)
3. A change in catchability over time will mean that CPUE may not be proportional to biomass over time (violating our key assumption)
4. We use a number of methods to adjust catch rates to ensure that we can relate CPUE to biomass despite any change in catchability
5. Selectivity – fishing gears are typically size selective and we need to specify how vulnerable fish are to capture by a particular gear at a particular age if we are to accurately estimate fishing mortality-at-age and overall biomass.

Chapter 10

What is the key information for fisheries managers, how do we interpret it?

Review of objectives for this week?

The OFPs stock assessment workshop has been structured around delivering understanding regarding 5 key questions:

1. What are stock assessment models and what are they used for? (PURPOSE)
2. How does a stock assessment model work? (MECHANICS)
3. How can we determine if it is a “good” model or assessment? (CRITICAL APPRAISAL)
4. What is the key information for fisheries management and how do I interpret it?
5. What are the potential implications of the assessment for the region and my country?

In this workshop, we have so far focused on questions 1 and 2. Question 3 is quite technical and will be a major component of next years workshop. Today, we are going to provide an introductory look at questions 4 and 5.

Todays objective

This sessions aims to assist you in learning how to identify, extract and interpret key information from stock assessment papers that will enable you to provide relevant and concise summaries and advice relating to:

1. Fishery impacts
2. Stock status (health);
3. Country level implications arising from stock assessment results and management options analyses.

This session aims to provide you a "guide".

Reference paper for theory sessions

We will use output from several tuna, shark and billfish assessments presented at SC over the past few years

These have all been reviewed

Some of you have been exposed to some of these assessment before

All WCPO countries catch some or all of these species

Key Management Outputs

To pull out the key management outputs we need to firstly identify what the key management questions are (regarding resource status):

1. How is the fishery impacting the stock? (**CAUSE**)
2. What is the current condition of the stock? (**STATUS**)
3. What needs to be done, in response, in order to meet MSY based management objectives? (**MANAGEMENT OPTIONS**)

Key Management Outputs

As the scientific advisors to your department, you need to understand the answers to these questions in some detail. However, in presenting the information to your superiors, you need to present that information in a manner easily understood.

The level of technical detail provided to them will depend on your audience, but it is critical that in simplifying your advice (if required) that the accuracy of your statements to answer those three questions is not compromised!

Key Management Outputs

Which key outputs from the assessments do we need to focus on?

Firstly, make sure you have a good understanding or picture of the fishery.

That can be quickly attained by pulling out 3 key pieces of information pertaining to:

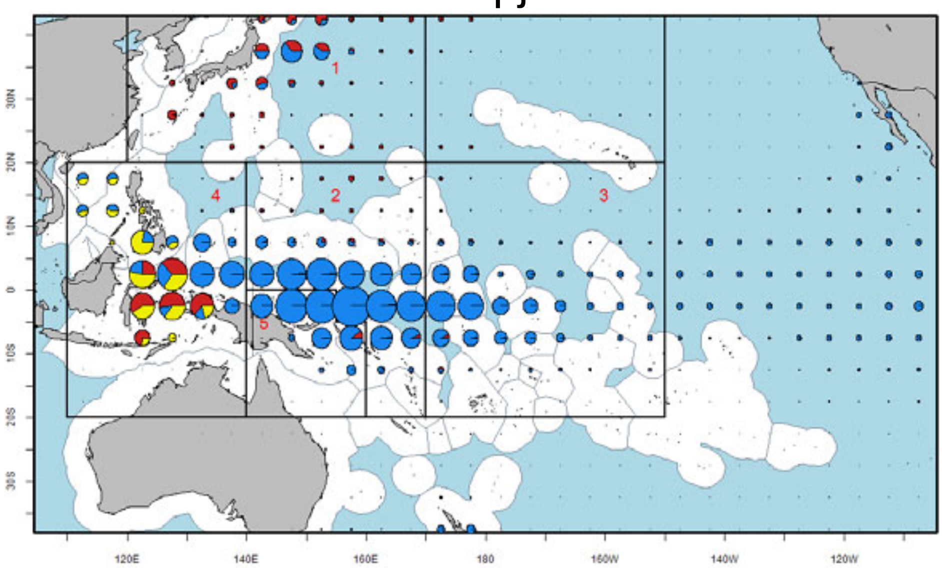
1. Where are the fish?

2. Where is the catch taken and by what gears?

3. How many fisheries are there?

Fishery Overview

2014 Skipjack



Blue – LL

Green – PS

Red – PL

Yellow – OT

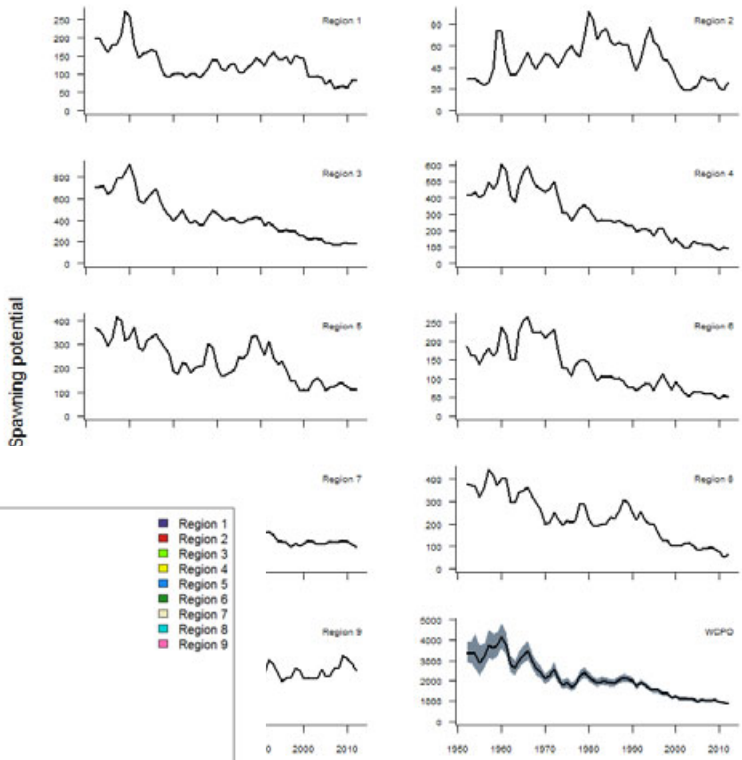
Where are the catches and by what gears?

How many fisheries?

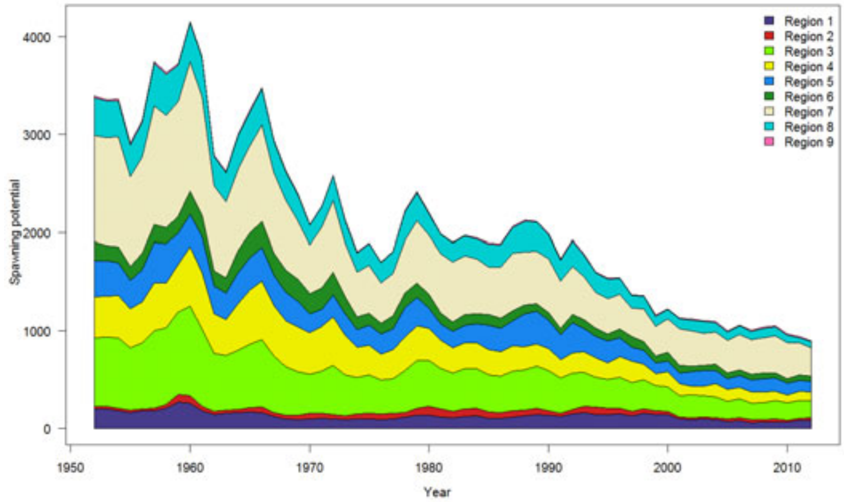
= 23! (PS ASS, PS UNASS, LL, PL, GN, PH, ID, OTH etc)

Fishery Overview

Where are the fish (biomass by region)?

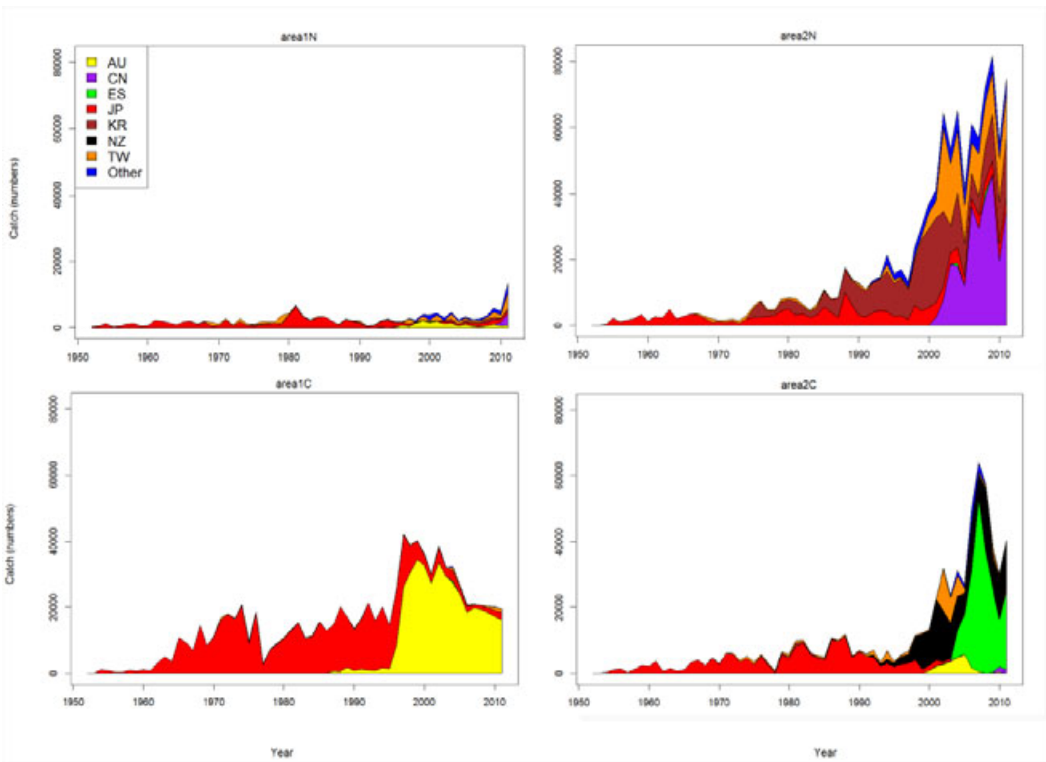


2014 Yellowfin



Fishery Overview

2013 Swordfish



Where is the catch taken and by which fisheries?

Key Management Outputs

Now we can focus on our key management questions

1. How is the fishery impacting the stock? (**CAUSE**)
2. What is the current condition of the stock? (**STATUS**)
3. What needs to be done, in response, in order to meet MSY based management objectives? (**MANAGEMENT OPTIONS**)

1. How is the fishery impacting the stock?

(Which plots best explain why the resource is in its current status?)

1. How is the fishery impacting the stock?

This question can be subdivided:

1. Where are the major impacts (which regions)?
2. Which fisheries/gears are having the highest impacts in each region and overall?
3. Which components (age classes) of the stock are being impacted upon the most?
4. Has recruitment been impacted?

Where are the major impacts occurring and which gears are responsible?

<u>Plot 1 – Catch by gear and region</u>

Most (~75%) in regions 3 and 7 [tropical, subtropical WCPO]

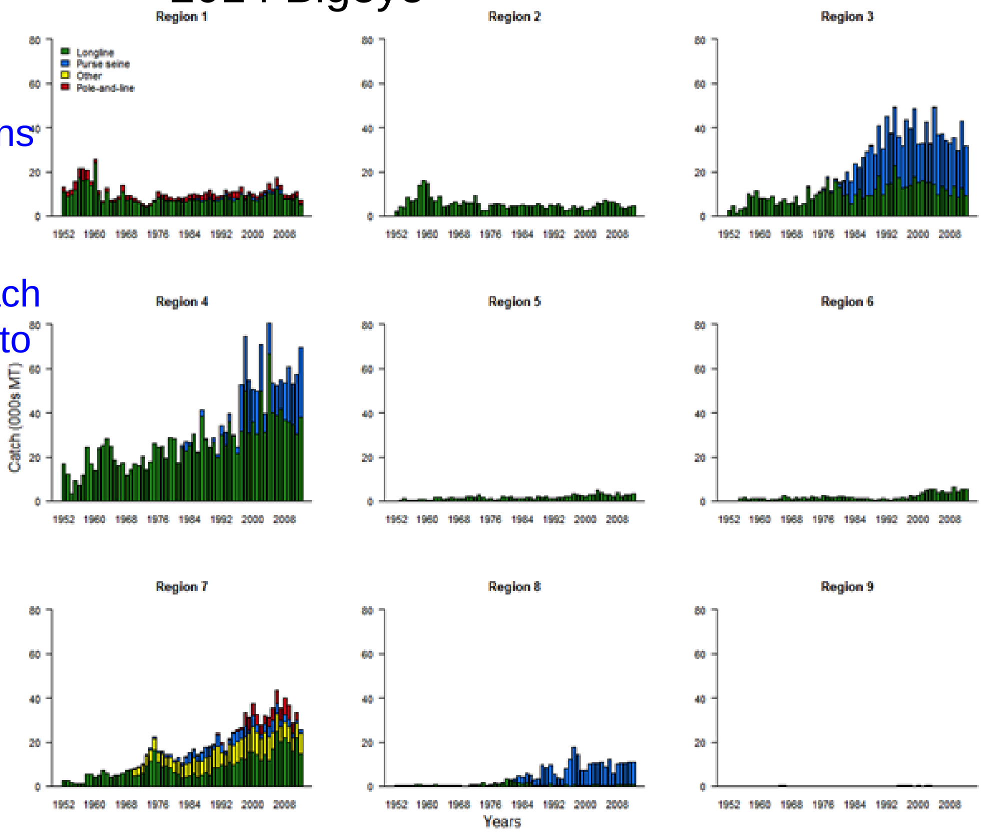
Different history in each region; e.g. late start to PS in 4

Recent catches historically high;

Strong among-year variability (why?)

Much lower catch in other regions

2014 Bigeye

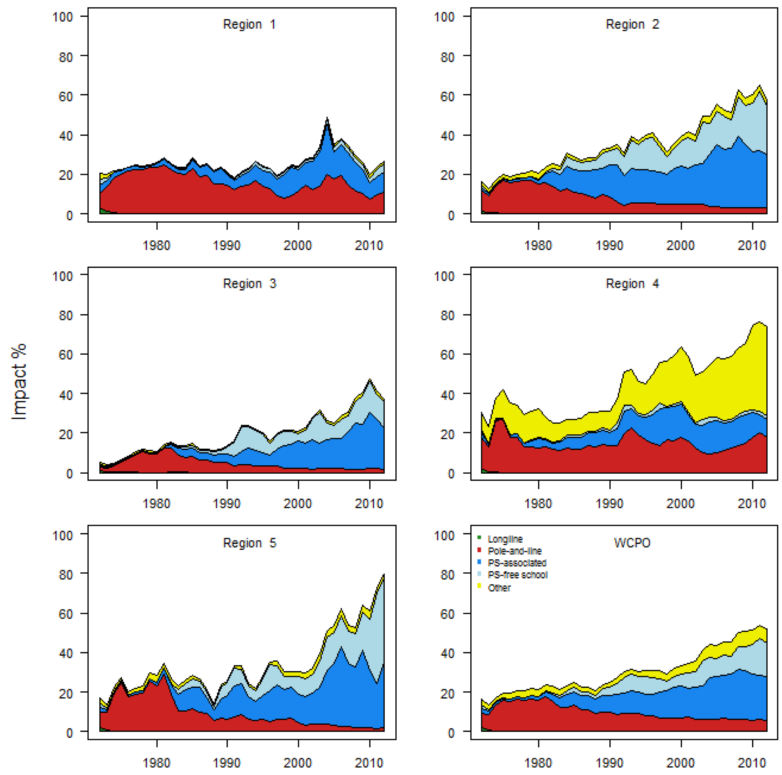


Where are the major impacts occurring and which gears are responsible?

2014 Skipjack

Plot 2 – Impacts on spawning biomass by region and gear.

- Highest in regions 2,4,5
- But low biomass in regions 2,9
- High impacts by some fisheries eg. PS – ASS in regions 5 and other fisheries in region 5.
- Impacts of some method fisheries are not restricted to the region in which they occur (Why…fish move!)

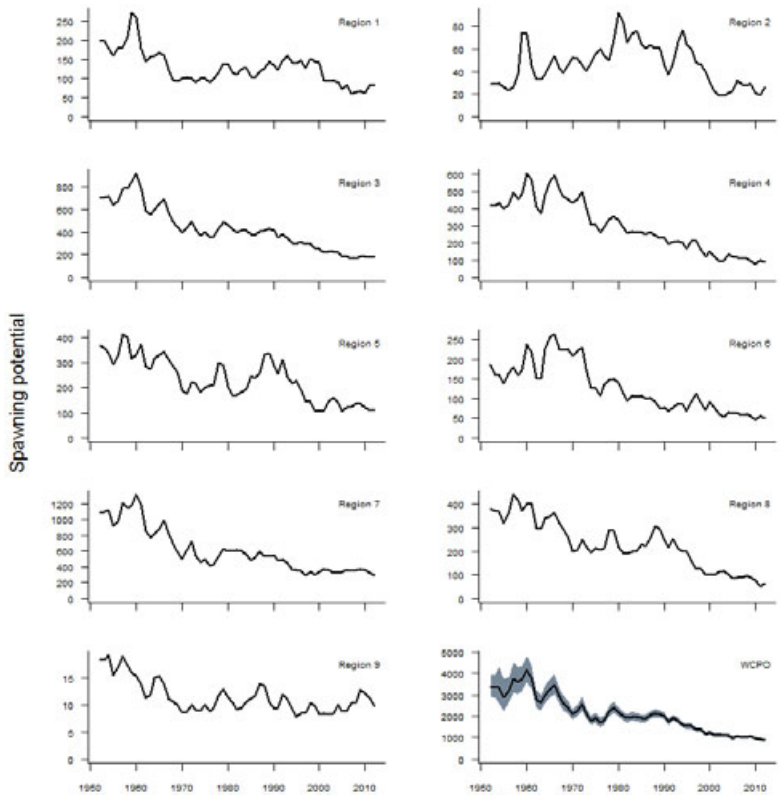


Where are the major impacts occurring?

2014 Yellowfin

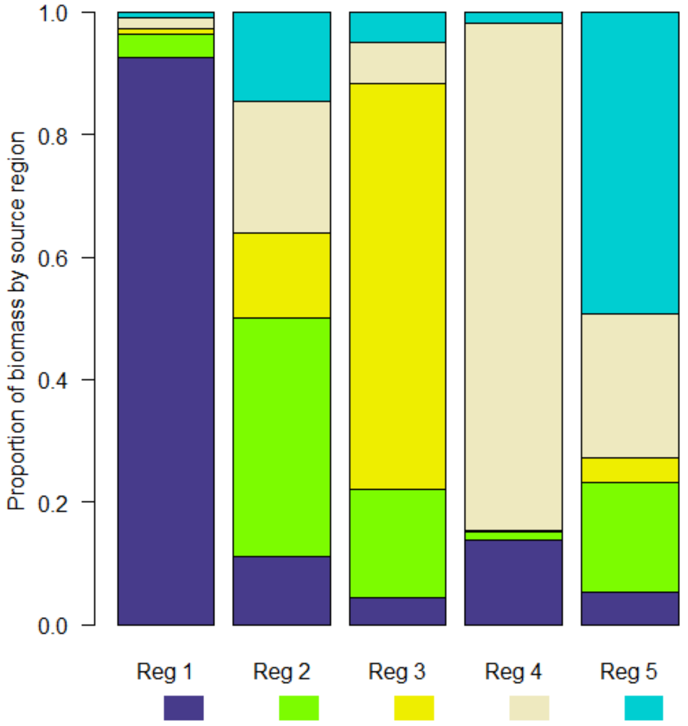
Plot 4 – Proportional Reductions in Spawning Biomass by region

- Different levels in different regions
- The least decline is apparent in regions 4 and 7
- History different in each region
- e.g. Regions 3 has the largest decline



Where are the major impacts occurring?

2014 Skipjack



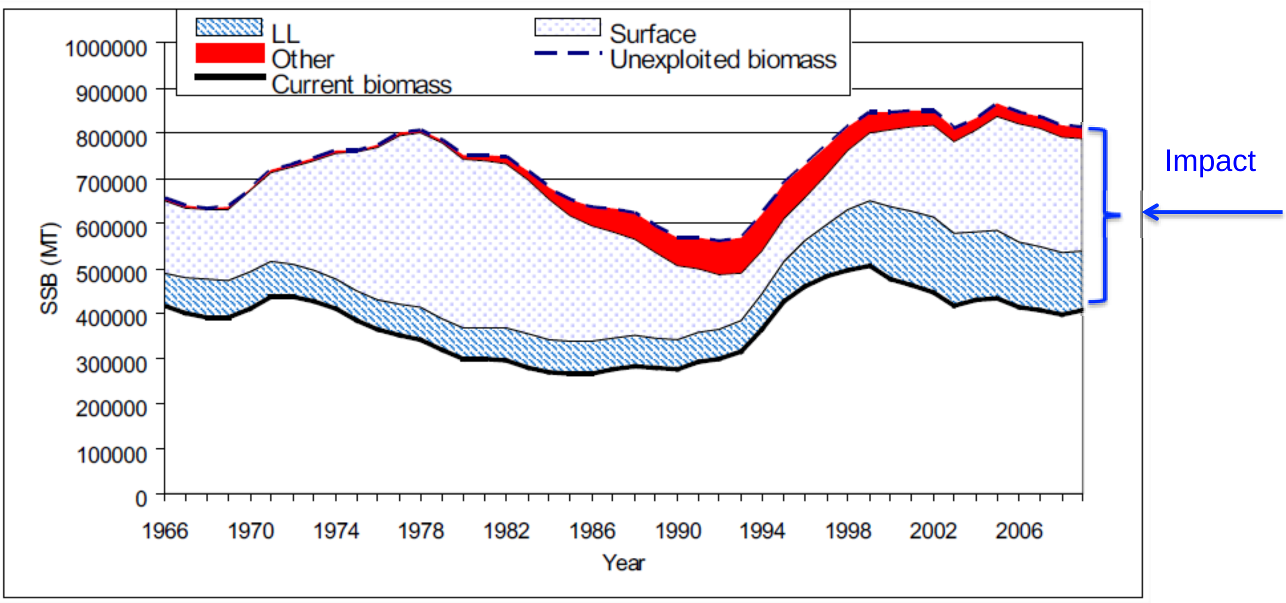
Plot 3 – Movements of regional recruits to other regions

This explains why catch by a fishery in one region can impact biomass in another region. Fisheries can catch fish that might otherwise have moved into an adjacent region.

Tagging more fish will hopefully help improve these movement estimates.

Where are the major impacts occurring?

2014 Northern Albacore



- Another way to illustrate the impact on the stock is to show the biomass trajectory and compare it to what it would be in the absence of fishing.
- Or how much of the stock has been removed as a result of fishing.

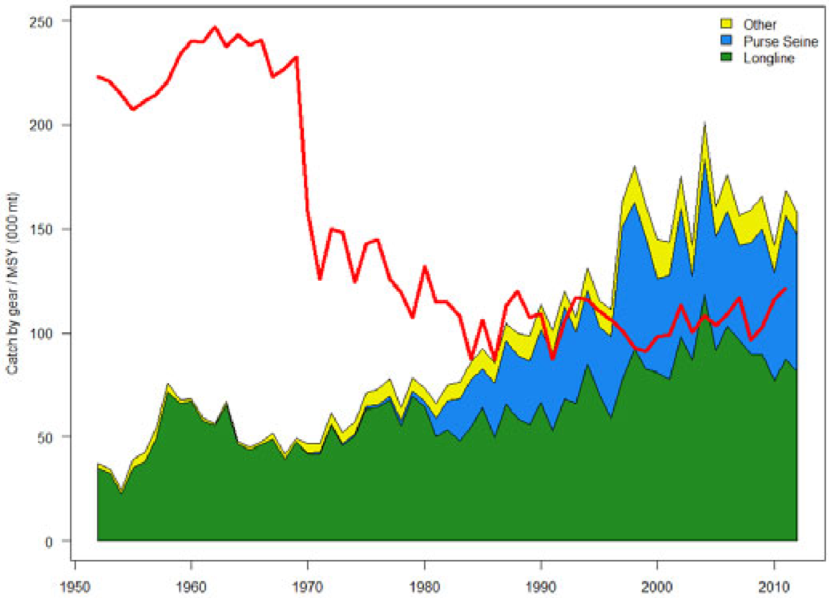
Where are the major impacts occurring and which gears are responsible?

Impacts on MSY by gear.

2014 Bigeye

MSY halved in about 1970

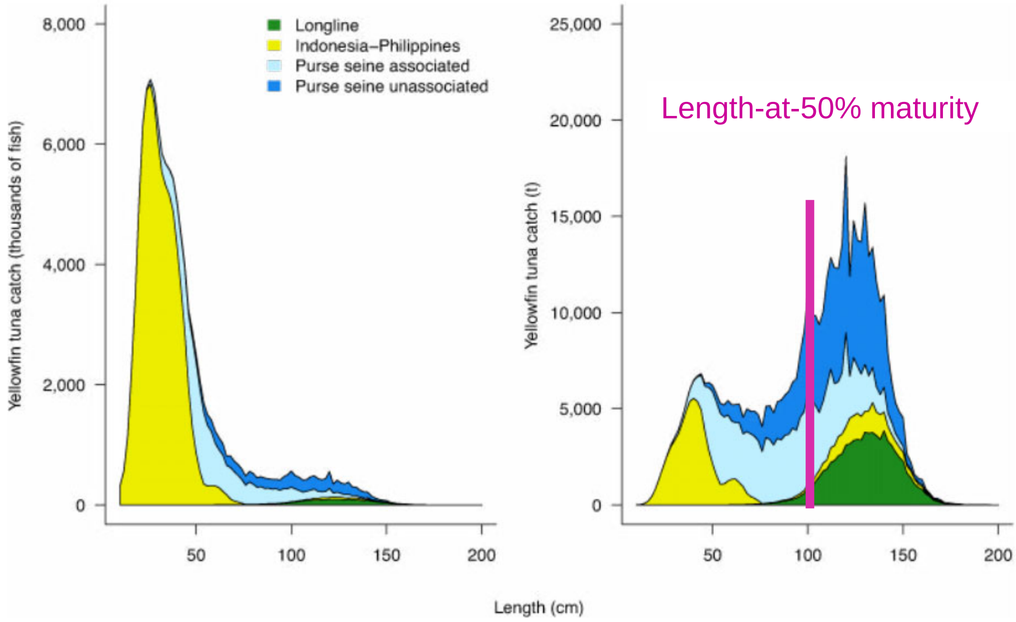
(Why?)



Which components (age classes) of the stock are most impacted?

Plot 1 - Size of fish caught by gear

2014 Yellowfin



Biological factors: significant catch both pre- and post-maturity

Which components (age classes) of the stock are most impacted?

Plot 2 - Fishing mortality at age by decade

How has fishing mortality at age changed over time? Why?

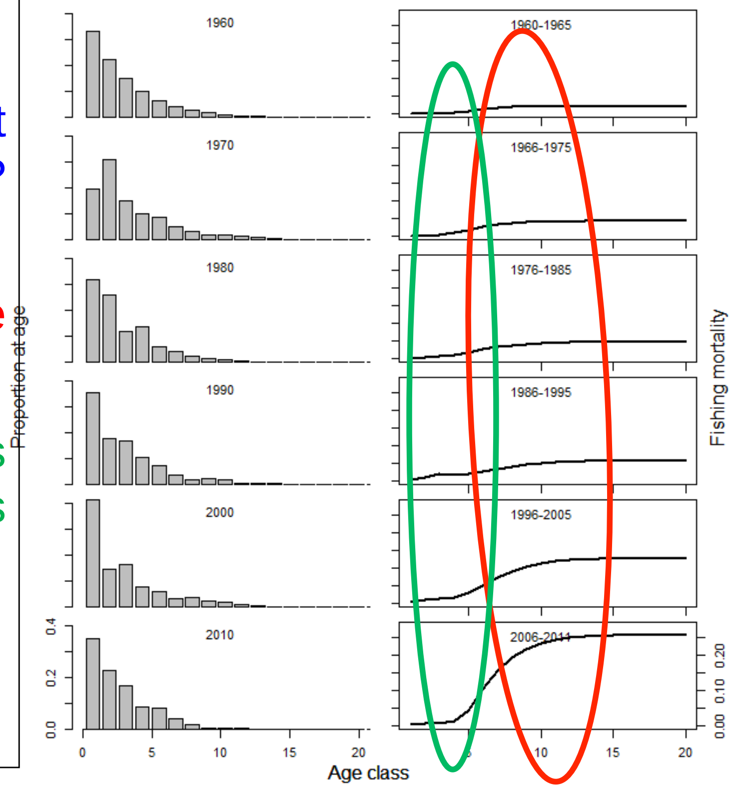
Increasing F in older age classes 80s

F in young age classes remains low from 70s onwards

F highest in the last decade

Note age truncation by 2010

2012 Southern albacore

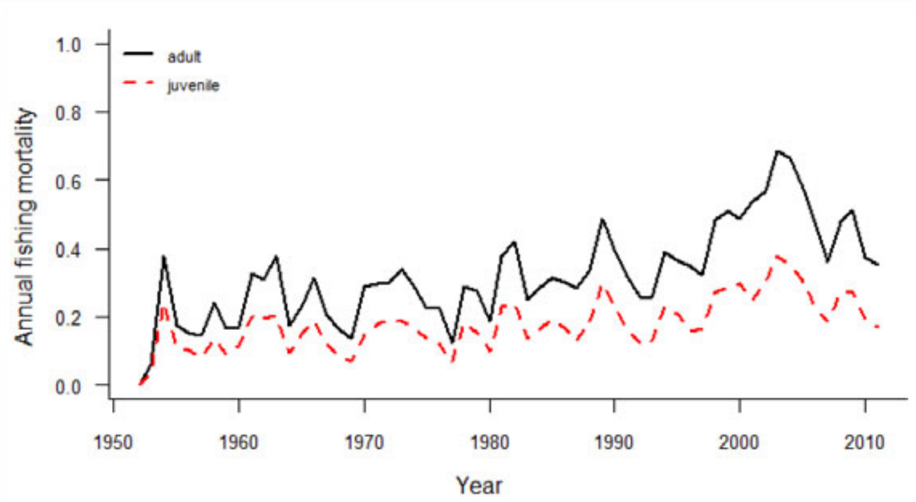


Which components (age classes) of the stock are most impacted?

2012 Striped Marlin

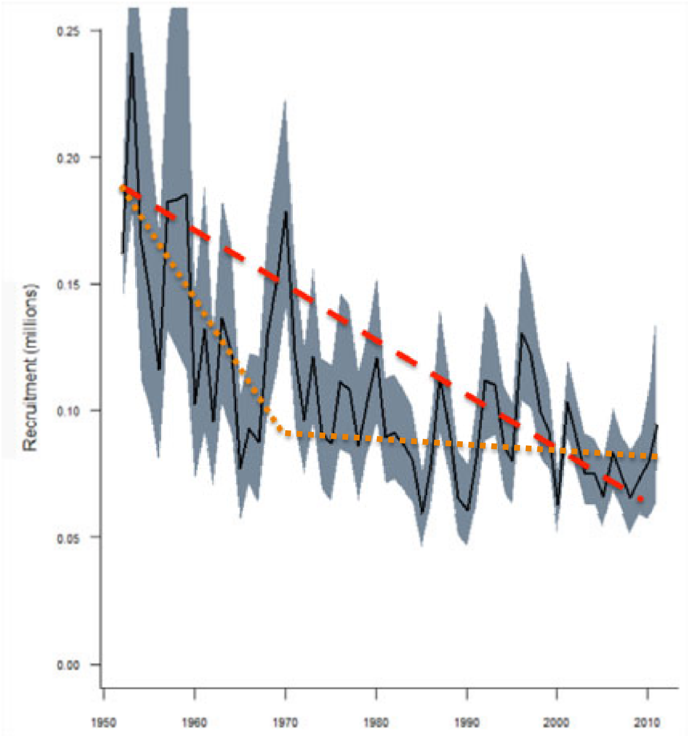
Plot 3 – Adult and juvenile fishing mortality by year

- What is happening to exploitation rates (overall)?
- Why?



Has recruitment been impacted by fishing?

2012 Striped Marlin



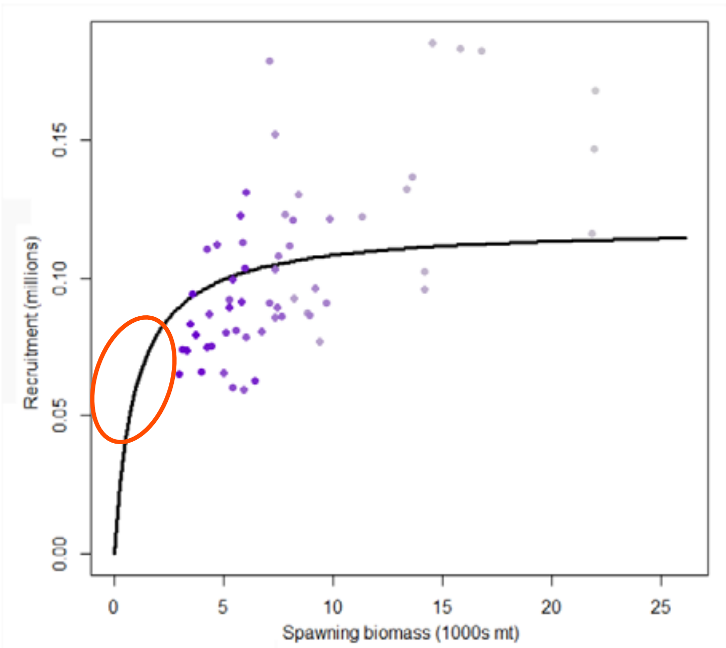
Plot 2 – Stock recruitment relationship and annual estimates of recruitment.

High steepness (0.8)

- Recruitment in modern times estimated to be half or less of recruitment in the 1950s
- But … recruitment also estimated to be relatively stable after 1970

Has recruitment been impacted by fishing?

2012 Striped Marlin



Plot 2 – Stock recruitment relationship and annual estimates of recruitment.

High steepness (0.8)

- High variability around mean (recruitment could be high or low for a given spawning biomass (SB)) Why?
- Recent SBs are relatively low as is the recent spawner biomass
- Suggests reduced SB has impacted recruitment

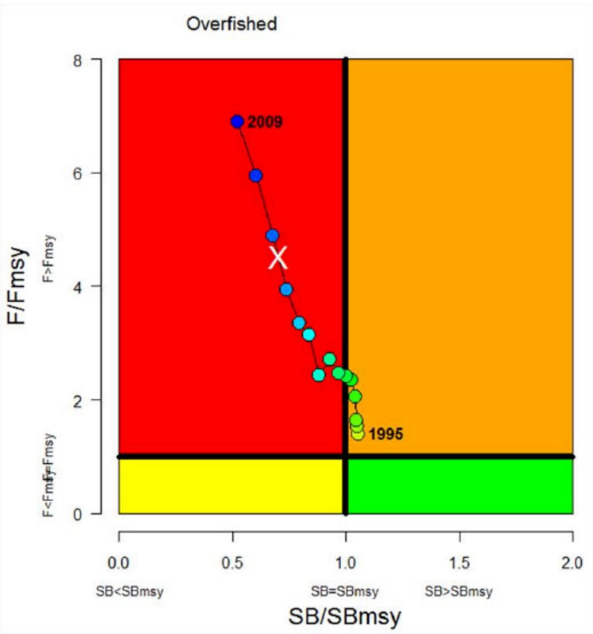
2. What is the current condition of the stock? (STATUS)

(What plots would you choose?)

2. What is the current condition of the stock?

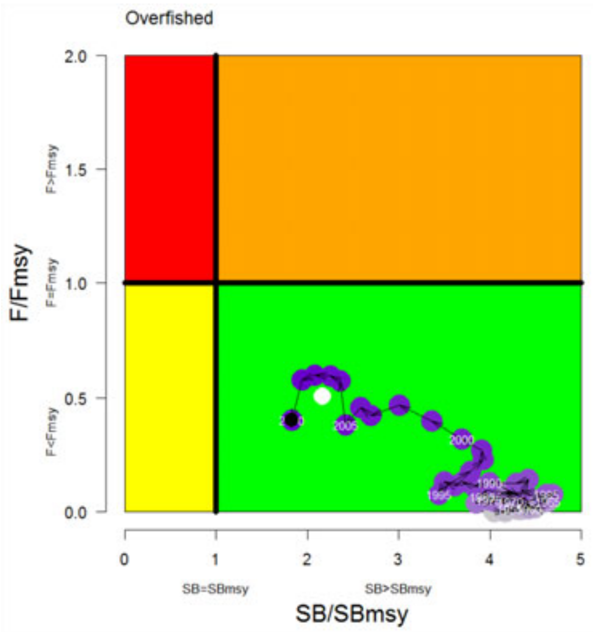
- Overfishing IS occurring

2013 Silky shark



- Overfishing is NOT occurring

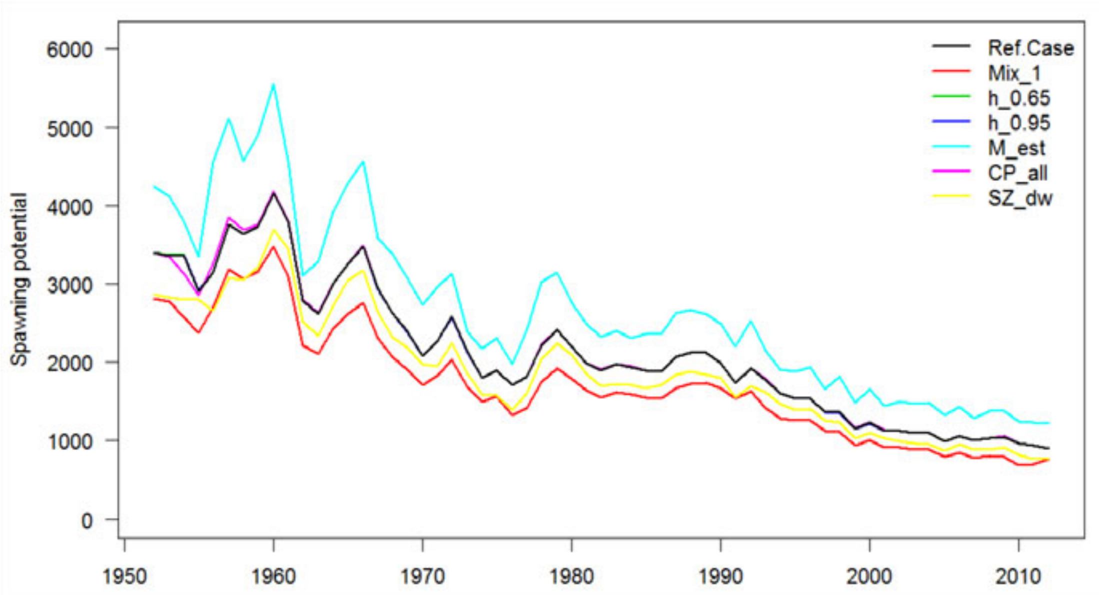
2013 Swordfish



2. What is the current condition of the stock?

Be aware of the uncertainties identified by sensitivity analyses

2014 Yellowfin

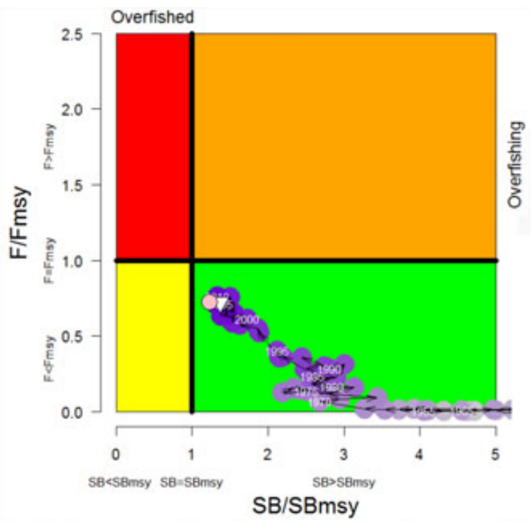


2. What is the current condition of the stock?

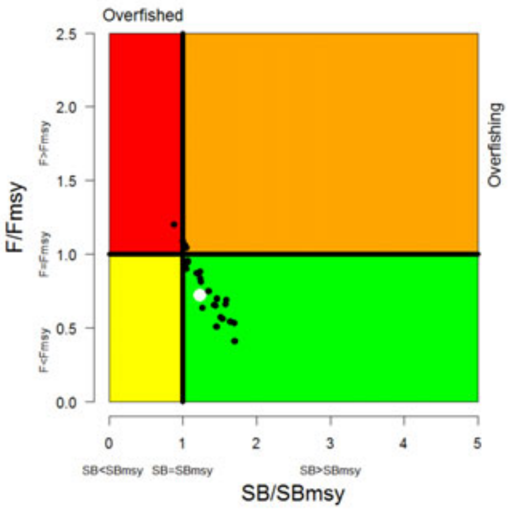
Be aware of the uncertainties identified by sensitivity analyses.

For YFT, these suggest that the adult stock could plausibly be overfished or will be in the near future.

2014 Yellowfin Ref. model



2014 Yellowfin uncertainty grid



3. Are measures required to ensure sustainability objectives are met?

(What was the advice from the Scientific Committee to the Commission?)

Are measures required to ensure sustainability objectives are met?

In reality there are 3 questions worth considering at this point:

1. What action, if any, is required to achieve sustainability objectives?
2. Has action already been taken?
3. Is that action likely to ensure the management objectives are met, or is further management action required?

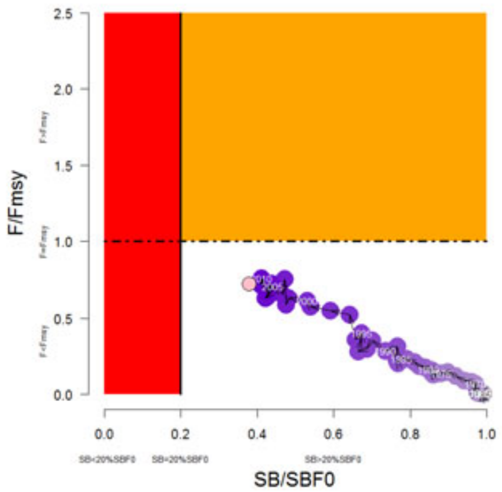
With respect to your fishery and country, what are the implications for your fishery if management action is not taken? If it has been taken but is not successful? If it has been taken and is successful?

Are measures required to ensure sustainability objectives are met?

<u>SC-6 Conclusions</u>

The WCPO yellowfin spawning biomass is above the biomass-based LRP WCPFC adopted, $0.2SB_{F=0}$, and overall fishing mortality appears to be below F_{MSY}. It is highly likely that stock is not experiencing overfishing and is not in an overfished state.

<u>SC-6 recommendation</u>: The SC recommend that the catch of WCPO yellowfin should not be increased from 2012 levels which exceeded MSY and measures should be implemented to maintain current spawning biomass levels until the Commission can agree an appropriate TRP.

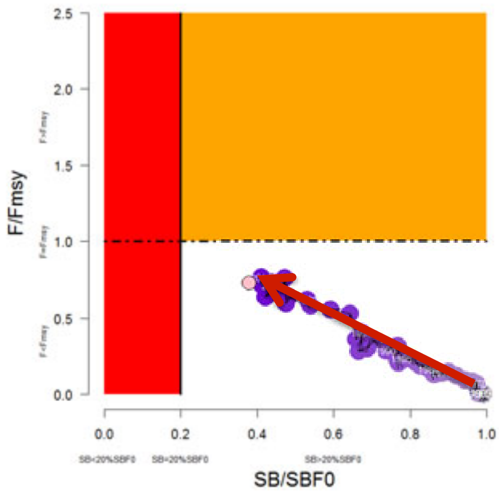


That recommendation is quite conservative given the stock status.

Why do you think the Scientific Committee would provide advice to the Commission that is seemingly more precautionary than one may feel is necessary?

Reasons to provide conservative advice

- The stock spawner biomass decline is not stabilising.
- Latest (2012) catch (612,797t of WCPO yellowfin tuna exceed the MSY (586,400t).
- Model uncertainty?
- The ability to control fishing mortality on a stock with multiple fisheries from many countries.



Summary

This presentation has hopefully provided a useful guide for how you might go about summarising and extracting the key information of relevance to fisheries managers from the WCPFC tuna stock assessment papers. The key elements are plots relating to:

1. Fishery structure and catches
2. Fishing impacts (mortality and biomass impacts)
3. Stock status (and uncertainty around that)

And then a summary of any management advice and recommendations from the Scientific Committee to the WCPFC.

Discussion – If you were asked to give a 5 slide presentation on stock status, which plots would you choose?

Chapter 11

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?

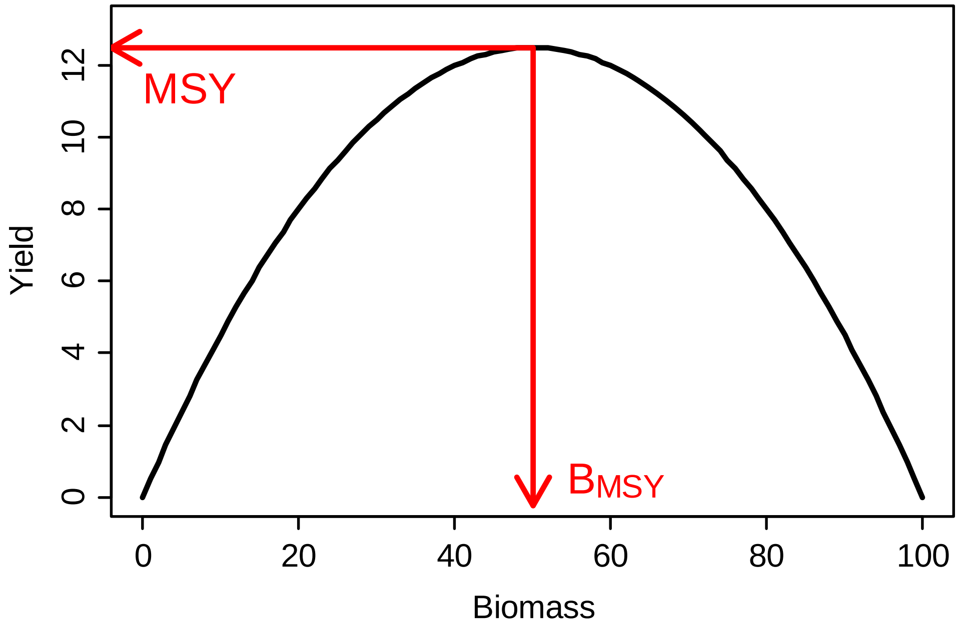
1. **Reference Point** – the pre-determined level of a given *indicator* that corresponds to a particular state of the stock that management either seeks to achieve or avoid. e.g. $B_{current}/B_{MSY} = 1$

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

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

Traditional Reference Points: MSY and B_{MSY}

- B_{MSY} – the biomass at which Maximum Sustainable Yield, *MSY*, is achieved.



What are the different types of reference points?

The three main types of reference point are:

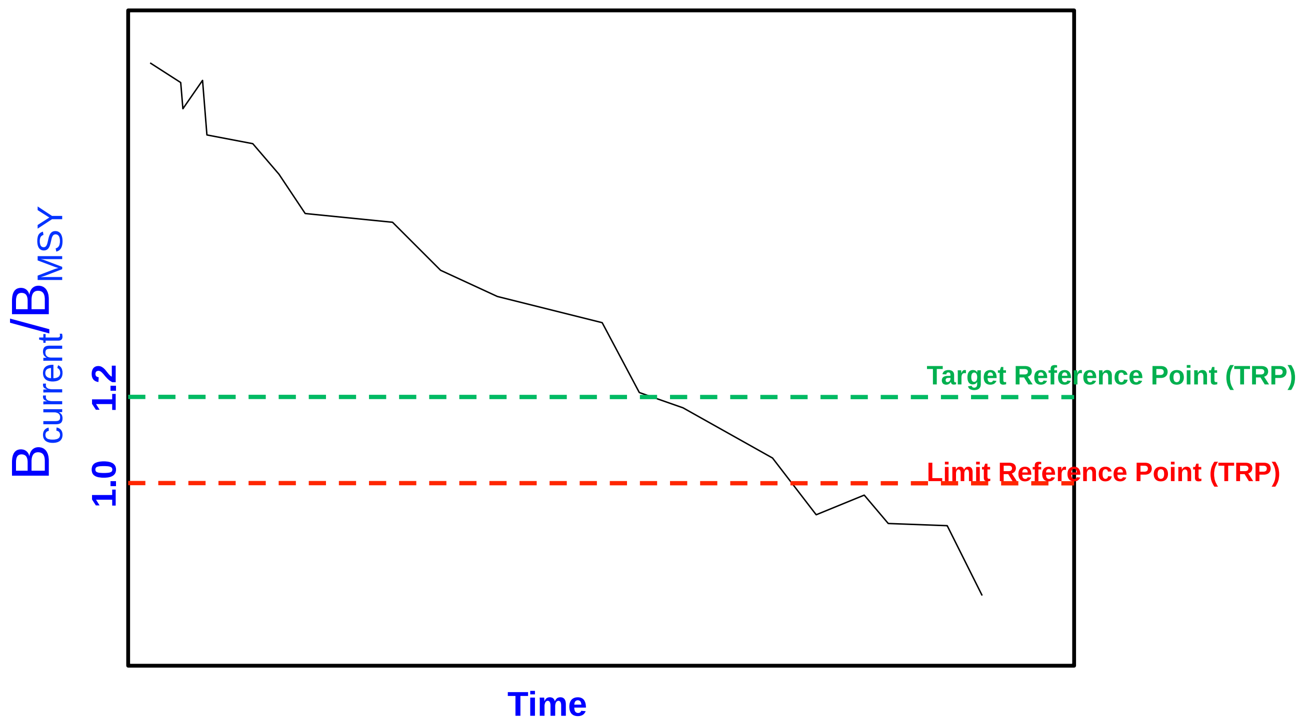
· **Target Reference Points (TRPs)** - describe the intended outcome for the stock and are generally associated with management objectives. (e.g. currently Fc/Fmsy=1; Bc/Bmsy=1, in the WCPFC)

· **Limit Reference Points (LRPs)** - describe an undesirable state of the indicator that should be avoided with high probability. These are intended to constrain harvesting within safe biological limits. Fishery management strategies should ensure that the risk of exceeding limit reference points is very low.

· **Trigger Reference Points (TrRPs)** - identify a predefined management response. The set of trigger reference points may include the target and limit reference points, but could also be reference points between the two.

What are the different types of reference points?

For example:



What are biological reference points?

To get an understanding of how this all works in more detail, lets consider as examples the key biological reference points used by the WCPFC.

These are known as **MSY based reference points**

Which BRPs are used by the WCPFC?

The Commission uses a number of MSY based reference points to assist its decision making processes. To understand this lets get our definitions clear:

1. **What is MSY**?

   The maximum sustainable yield (MSY) is the maximum yield (catch) that can be taken on average from the fishery in the long term without impacting the reproductive potential of the stock.

2. **What is B_{MSY}**?

   The stock biomass level at which the fishery is able to achieve the maximum sustainable yield

3. **What is F_{MSY}**?

   The fishing mortality rate which provides the maximum sustainable yield.

Which BRPs are used by the WCPFC?

The key MSY based reference points used by the WCPFC are in fact ratios of quantities. For example:

$$F_{current}/F_{MSY} = 1$$

...is a key **reference point** used by the WCPFC.

It is a specific value of the **indicator** $F_{current}/F_{MSY}$ which is the current (or recent average) fishing mortality rate divided by the fishing mortality rate which will provide the maximum sustainable yield.

Values ***greater*** than 1 indicate that overfishing is occuring, and if effort level are not reduced, an overfished fishery will develop.

Which BRPs are used by the WCPFC?

Another example:

$B_{current}/B_{MSY} = 1$

...is the other key **reference point** used by the WCPFC.

It is a specific value of the **indicator** $B_{current}/B_{MSY}$ which is the current (or recent average) biomass divided by the biomass which will provide the maximum sustainable yield.

Values ***less*** than 1 indicate that the fishery is overfished, and very significant reductions in fishing effort are required for recovery to occur

There are some significant risks associated with managing fisheries based on these reference points which will be discussed later.

Which BRPs are used by the WCPFC?

SPC also provides a number of other reference points in the assessment papers, in addition to the F_{MSY} and B_{MSY} reference points currently focused on.

Symbol	Description
$F_{current}$	Average fishing mortality-at-age for 2001–2003
F_{MSY}	Fishing mortality-at-age producing the maximum sustainable yield (MSY)
$\tilde{Y}_{F_{current}}$	Equilibrium yield at $F_{current}$
$\tilde{Y}_{F_{MSY}}$ (or MSY)	Equilibrium yield at F_{MSY}, or maximum sustainable yield
$\tilde{B}_0$	Equilibrium unexploited total biomass
$\tilde{B}_{F_{current}}$	Equilibrium total biomass at $F_{current}$
$\tilde{B}_{MSY}$	Equilibrium total biomass at MSY
$S\tilde{B}_0$	Equilibrium unexploited adult biomass
$S\tilde{B}_{F_{current}}$	Equilibrium adult biomass at $F_{current}$
$S\tilde{B}_{MSY}$	Equilibrium adult biomass at MSY
$B_{current}$	Average current (2001–2003) total biomass
$SB_{current}$	Average current (2001–2003) adult biomass
$B_{current,F=0}$	Average current (2001–2003) total biomass in the absence of fishing.

Why is the WCPFC using these MSY based reference points?

SPC CPS

The WCPFC convention makes reference to a number of reference points, most importantly:

- *Maintain or restore stocks at* [biomass] *levels capable of producing MSY* [Article 5(b)]:

i.e. Maintain $B_{current} \geq B_{MSY}$

- *Eliminate overfishing and excess fishing capacity* [Article 5(g)]:

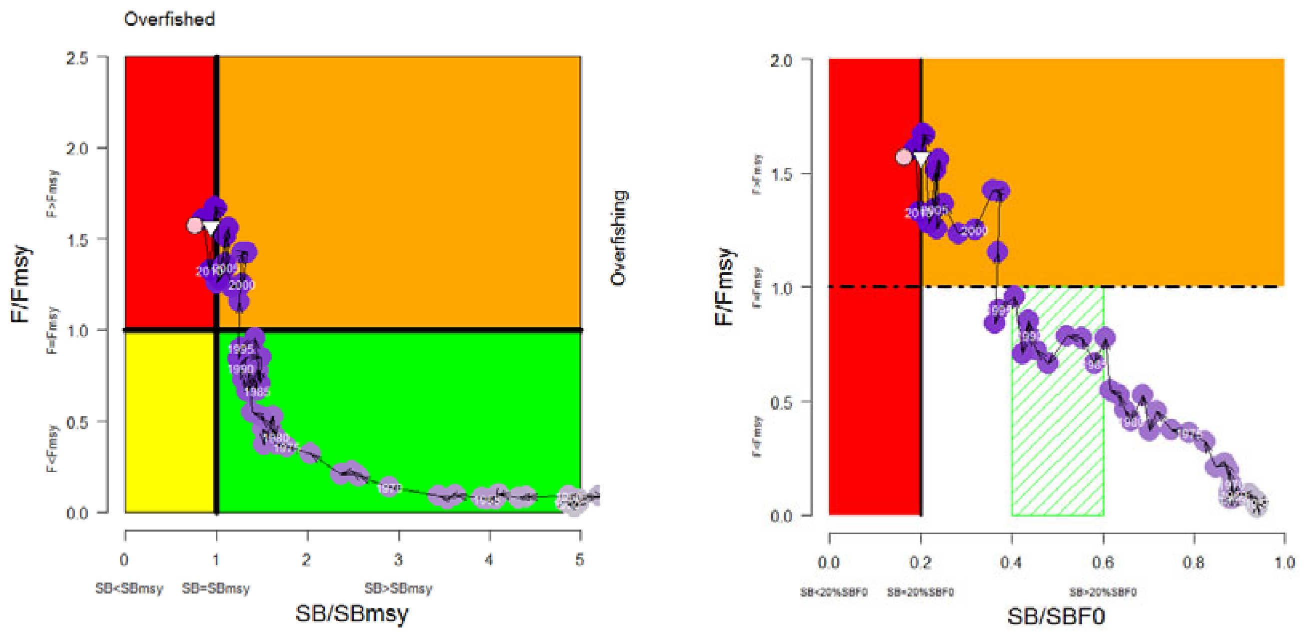
i.e. Maintain $F_{current} \leq F_{MSY}$

These references flow originally from the UN Fish Stocks Agreement.

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

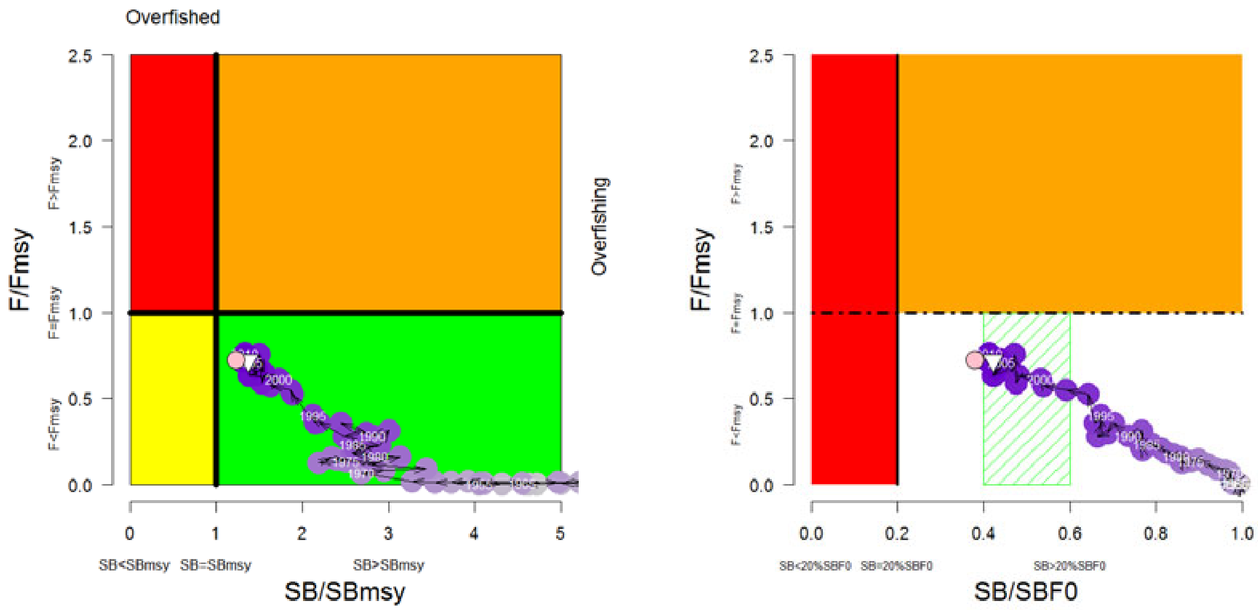
SPC CPS

Bigeye tuna 2013 - (overfishing, approaching overfished)



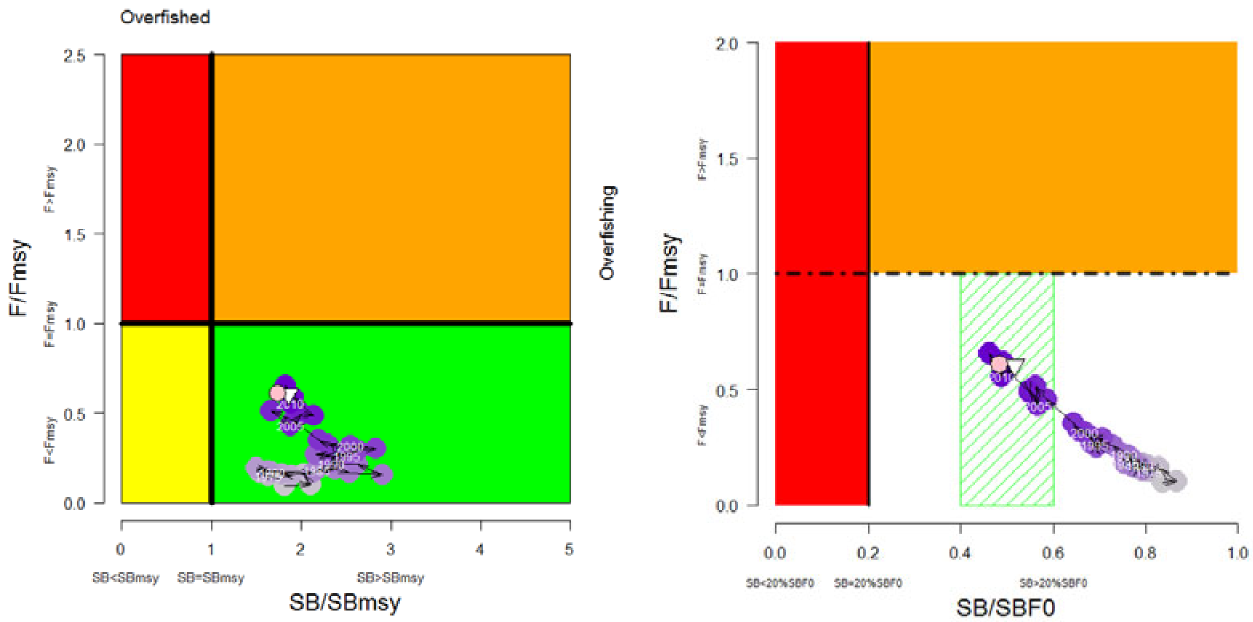
What do BRPs indicate about status of stocks (in Convention Area)

Yellowfin tuna 2009 - (no overfishing, not overfishing)



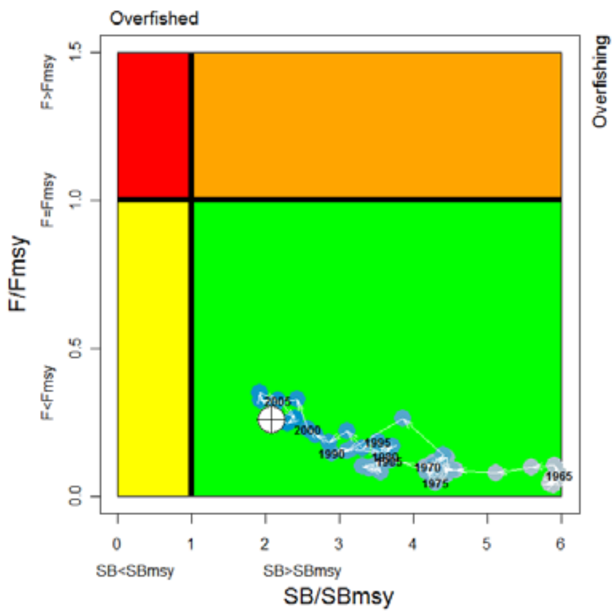
What do BRPs indicate about status of stocks (in Convention Area)

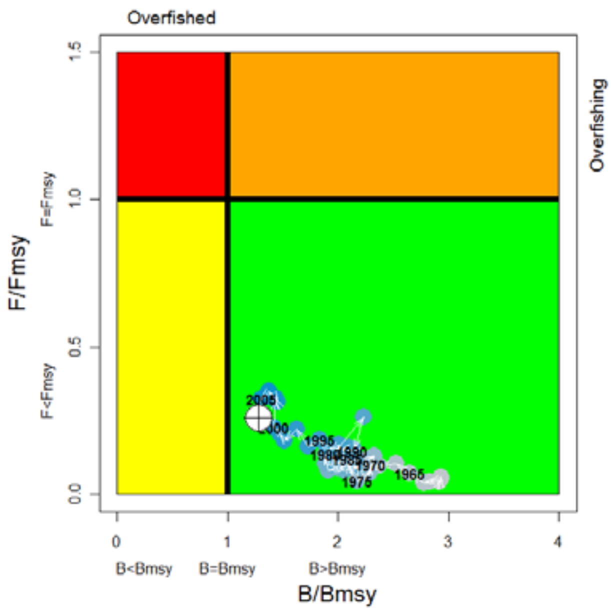
Skipjack tuna 2013 (no overfishing, not overfished)



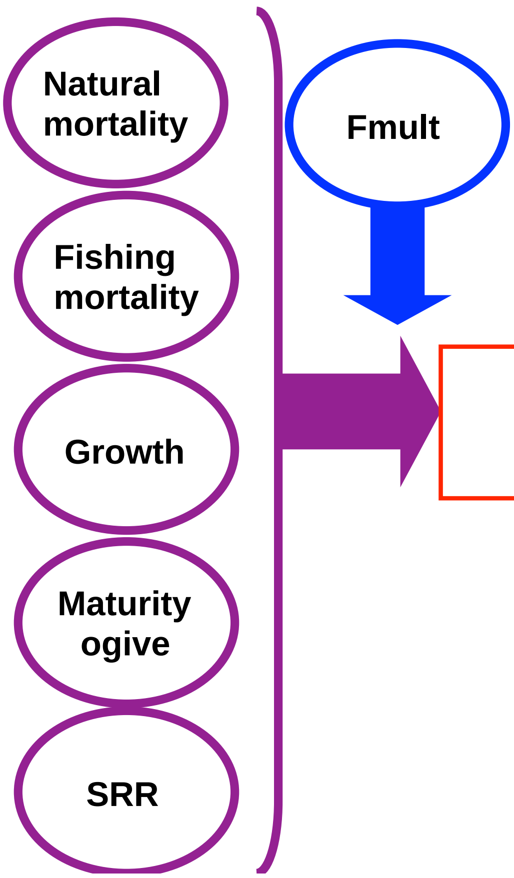
What do BRPs indicate about status of stocks (in Convention Area)

Albacore tuna 2011 (no overfishing, not overfished)



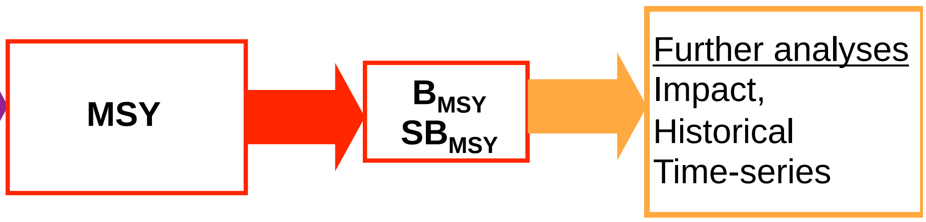


How are reference points calculated?



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 equilibrium yields across many fishing effort levels.

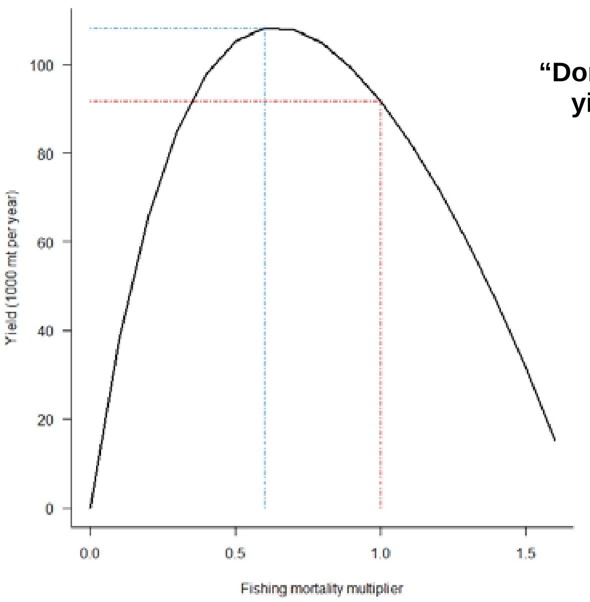


The model parameters are used to estimate the equilibrium yield that would be derived by the fishery at many different effort (or fishing mortality) levels, relative to the current effort level (="1").

How are reference points calculated?

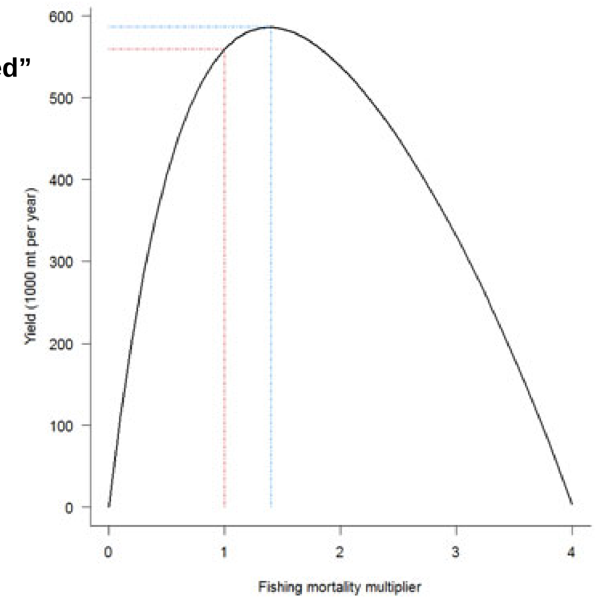
The highest **equilibrium yield** level estimated is the **maximum sustainable yield**, with the fishing mortality rate that provides that yield equivalent to **Fmsy**. The graph below indicates whether that F level is greater than or less than the ***current*** F level (denoted by "1")…..which tells us whether overfishing is occurring or not.

Bigeye tuna



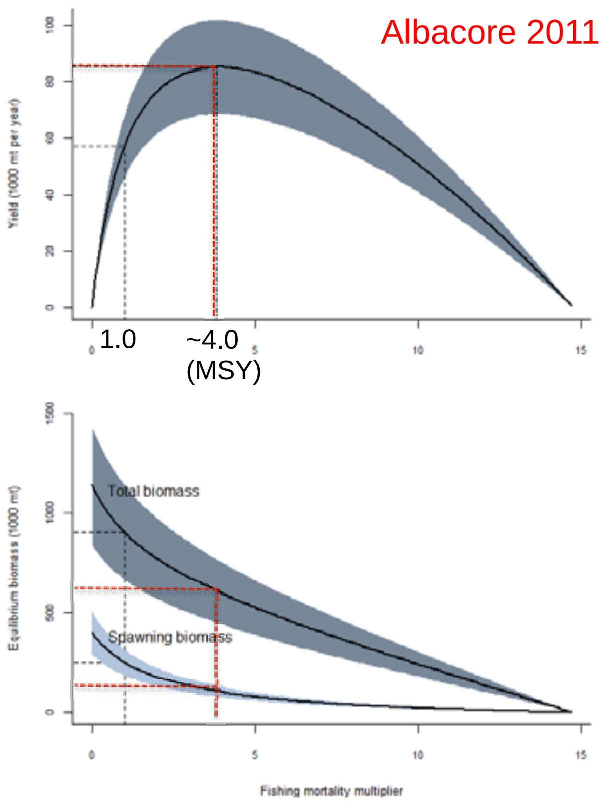
"Dome-shaped" yield curve

Yellowfin tuna



How are reference points calculated?

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



A caution about MSY based reference points

SPC CPS

- MSY based reference points are often used as ***target*** reference points (e.g. by the WCPFC). This is widely recognised as a **high risk** strategy in fisheries, because stock assessments can not predict with high certainty where MSY lies (it is difficult to determine where it is exactly without fishing the stock below B_{MSY}).
- Thus aiming for MSY carries a high risk of fishing the stock down past Bmsy, effecting recruitment levels and lowering sustainable yield levels.
- Hence it is often recommended by scientists that, if you wish to reduce the risk of fishing past MSY, managers set a more ***precautionary*** reference point as the target and use MSY as the ***limit*** reference point (the reference point to be avoided).

SPC CPS

SENSITIVITY ANALYSES

Sensitivity analyses

Background

On Day 1 of the workshop we discussed how stock assessment models comprise numerous equations made up of parameters, and how the value of many of the parameters may be **known** (through data collection) but that the value of other parameters may be **unknown**.

The **model fitting** process is typically used to **estimate** the value of the unknown parameters (usually with some upper/lower limits and starting values specified to ensure the estimated value is within a biologically realistic range).

However, the fact remains that for those estimated values, until such time as data/evidence can be collected to verify them, some **uncertainty** remains.

It is very important that scientists do not ignore the potential effect of highly uncertain parameters upon stock assessment model outputs, and identify, explore and communicate the potential implications of such uncertainty to fisheries managers. Why is this?

Sensitivity analyses

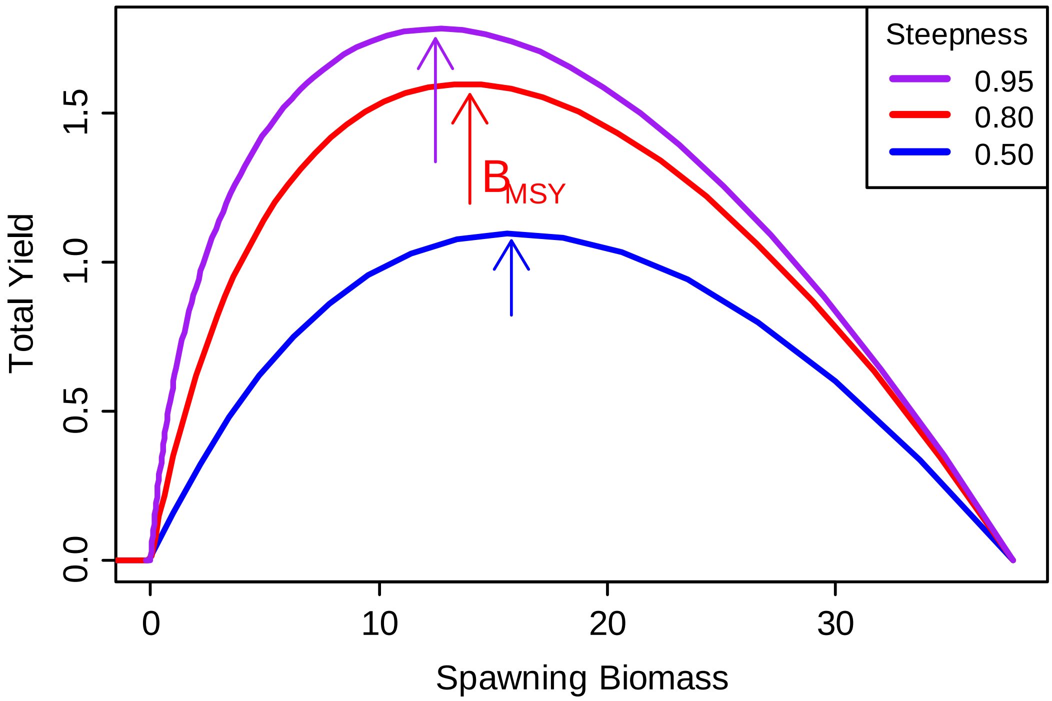
Background

Hypothetical: An assessment is run for species A, and steepness of the SRR is unknown. The models estimates this value to be 0.9 during fitting. The model estimated that Fc/Fmsy = 0.9 and Bc/Bmsy = 1.2. The scientists told the managers that the stock was healthy and that current fishing effort levels were fine.

Unbeknown to the scientists the true value of steepness was 0.6. Had they known this, the model might have indicated a far less productive stock upon which a significant level of overfishing was occurring. The scientists had not explored the potential effect of other possible values of steepness on the model outputs and had subsequently given the fishing managers misleading information. Inaction by managers could result in an overfished fishery, recruitment failure and economic hardship for the fishermen and fishing communities due to a lack of fish to catch.

The scientists mistake was their failure to carry out a **sensitivity analysis!**

Sensitivity of yield curve to steepness



Sensitivity analyses

What is a sensitivity analysis?

In stock assessment modelling, if there is either:

a) some uncertainty pertaining to a particular parameter value which has been specified or estimated within the model, or pertaining to an assumption made in the model, or,

b) a structural change to the model (e.g. due to new fishery data becoming available, or fisheries being split, or new estimates of biological parameters or relationships etc)..

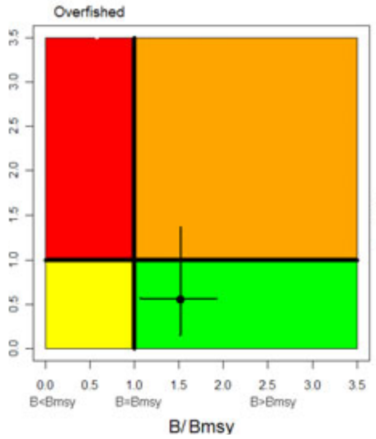
.....then scientists will typically undertake what is called a "sensitivity analyses".

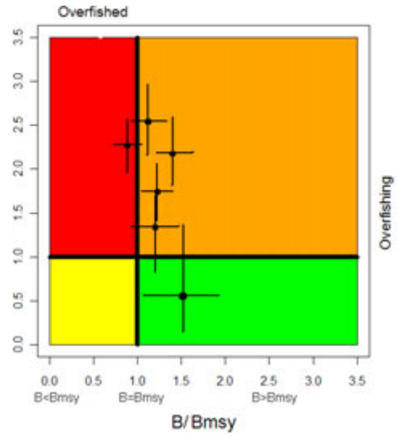
Sensitivity analyses

In case a) the sensitivity analyses might involve **re-running the assessment** with both a higher and lower values of the uncertain parameter, or re-running using a slightly different assumption.

In case b) the sensitivity analyses might involve running the model both with and without the structural change.

The scientists and managers can then look at the difference in the model fit (between the old and new model), and also the impact of the changes upon the biological reference points BRPs and scientific advice provided to the fisheries managers.





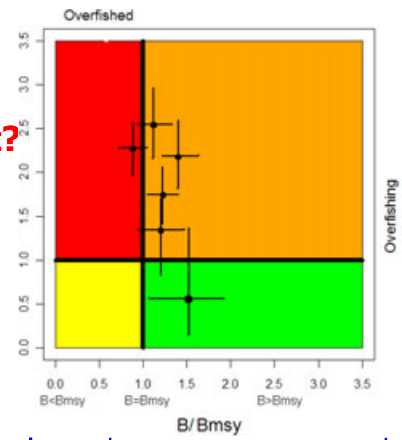
Sensitivity analyses

If there are not significant changes to model fit or BRPs, it might be deduced that the while there is uncertainty around a parameter value or assumption, these may not influence the end advice to fisheries managers.

That is, the outputs and conclusions of the stock assessment are not greatly impacted by uncertainty in the level of this variable.

However, in some instances the reference points and management advice **are** impacted by such changes.

How would you interpret stock status from this plot?



This is critical information for managers when considering how to use assessment outputs in their decision making.

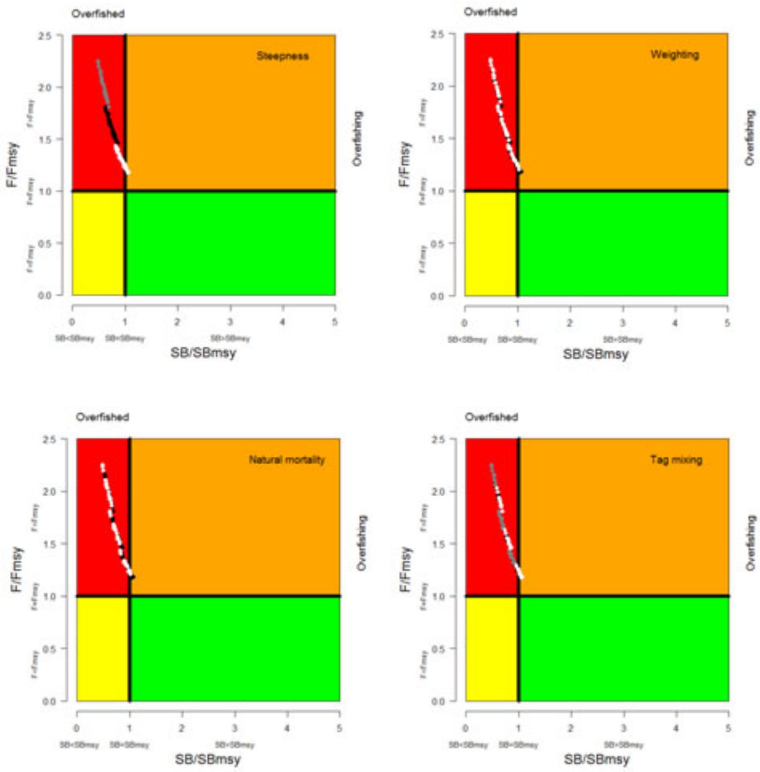
Sensitivity analyses

BET 2014

Scientists were uncertain about the true value a number of parameters, e.g.:

- SR steepness
- Weighting of size data
- Age-specific natural mortality
- Duration of tag mixing period

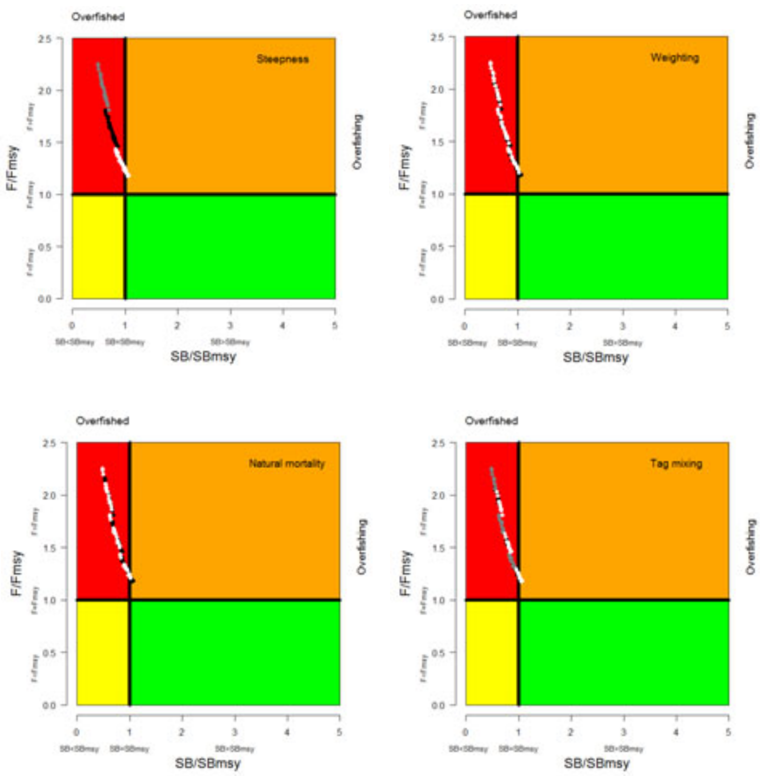
So they tested across the range of plausible values to determine what effect these had upon reference points estimates (and subsequently advice regarding stock status)



Sensitivity analyses

BET 2014

- What do the results of all these sensitivity analyses tell us about the status of the stock??
- How do we interpret plots like this?
- Which factor appears to have the greatest effect upon the estimates of stock status?



Summary

- BRPs are a way of summarising the outputs of a stock assessment
- They allow;
  - the status of a stock to be assessed
  - The impacts of fishing on a stock to be estimated
  - The performance of the stock against management objectives to be assessed
- BRPs vary through time due to changes in fisheries, catches and the incorporation of new information
- MSY based reference points are currently used by the WCPFC.
- MSY based reference points carry significant risk, due to difficulties in estimating MSY.
- The impact of uncertainty in parameter values or estimates upon model outputs, in particular reference points, should be fully explored by scientists via the use of sensitivity analyses, and the results and implications of these communicated to fishery managers so that they too are aware of uncertainty in the assessment results.

Chapter 12

Assessing the assessment: Model fit

So, how do you assess a stock assessment model?

There are five key questions you should ask yourself:

1. **Assumptions**
   What are the assumptions made by the assessment model?

2. **Model structure**
   What structural changes have been made since the last stock assessment?

3. **Sensitivity analysis**
   Has a sensitivity analysis been undertaken to test the importance and effect of each assumption or structural change?

4. **Goodness of fit**
   How well does the model fit the data?

5. **Uncertainty**
   How well has uncertainty been incorporated, represented or discussed within the stock assessment?

Model fitting

Review: How does a stock assessment model work?

To gain an understanding of how model fitting works and its importance to understanding uncertainty in an assessment, it is worth refreshing our memory of what a stock assessment model is and its key components.

A **stock assessment model** provides a mathematical and statistical simplification of a very complex system (fish population and fishery), to help us estimate population changes over time in response to fishing.

As such they can be considered to comprise two key components, these being:

a. A **mathematical model** of population processes

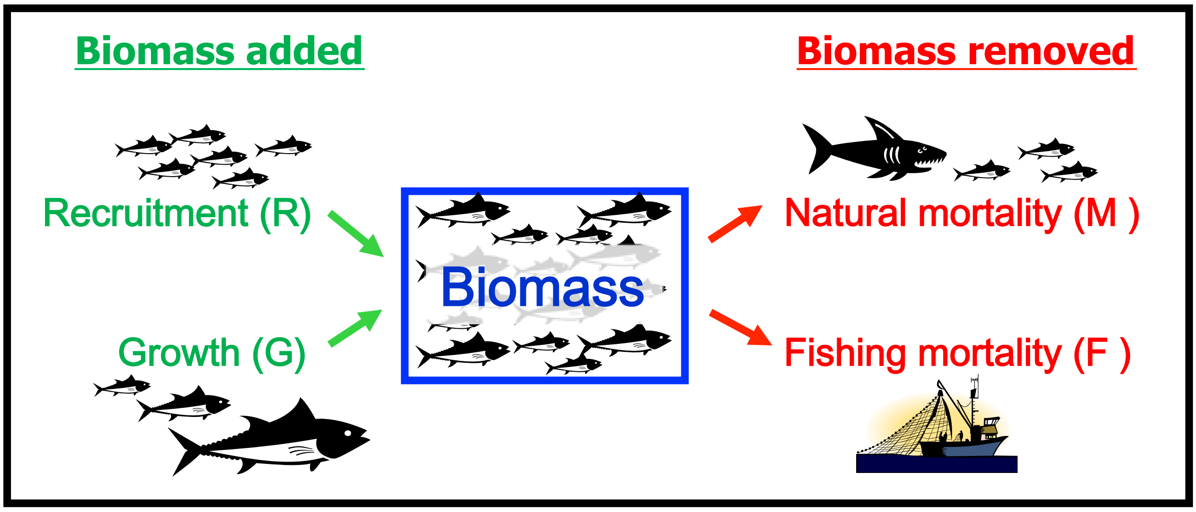
b. A **statistical model** used to fit the mathematical model to data collected from the fishery

Model fitting

Review: How does a stock assessment model work?

The mathematical model of the exploited fish population dynamics: To estimate abundance (biomass) over time, the model must take into account (at the very least) four key processes: **Recruitment**, **Growth**, **Natural Mortality** and **Fishing Mortality,** conceptually expressed as:

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



Of course, this is just a conceptual model. A real model looks more like.........

Model fitting

Review: How does a stock assessment model work?

Age Structured Model

$N_{t+1,a+1} = N_{t,a}e^{-(M_a + F_{t,a})}$

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

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

$R_t = (AS_t)/(b+S_t)$

$N_{t+1,1} = R_t$

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

$S_t = \Sigma N_{t,a} w_a o_a$

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

$N_{t+1,a+1}$ = Number of fish of age+1 at time +1
M_a = natural mortality rate at age *a*
F_a = fishing mortality rate at age *a*
q = catchability
E = fishing effort (units)
s = age specific vulnerability to the gear (selectivity of the gear)
$C_{t,a}$ = Catch at time t and age *a*
w_a = Mean weight at age *a* << *(Growth)*
R_t = Recruitment at time t
A = maximum recruitment
b = Stock size when recruitment is half the maximum recruitment
w_a = weight at age a
o_a = proportion mature at age a
B_t = population biomass at time t
S_t = spawning stock biomass at time t
VB = vulnerable biomass at time t

Model fitting

Review: How does a stock assessment model work?

"Counting fish is just like counting trees...except we cant see them and they move!!"

Age Structured Model

$N_{t+1,a+1} = N_{t,a}e^{-(M_a + F_{t,a})}$

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

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

$R_t = (AS_t)/(b+S_t)$

$N_{t+1,1} = R_t$

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

$S_t = \Sigma N_{t,a} w_a o_a$

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

The mathematical component of the model comprises equations describing each of these processes and how they interact with each other to determine the population biomass (and other parameters) over time.

We build a model because we cant directly "count" the exact numbers of recruits and deaths nor measure the growth of each fish in the population ...

...instead of direct counts and measures, our model (via a series of equations) allows us to "estimate" these processes and the populations dynamics.

Model fitting

Review: How does a stock assessment model work?

Age Structured Model

$$N_{t+1,a+1} = N_{t,a} e^{-(M_a + F_{t,a})}$$
$$F_{t,a} = q_t E_t s_a$$
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$$B_t = \Sigma N_{t,a} w_a$$
$$S_t = \Sigma N_{t,a} w_a o_a$$
$$VB_t = \Sigma N_{t,a} w_a s_a$$

These equations are of little use unless we have data or information which can accurately inform the model of the value of most of the key parameters:

- How much fishing effort?
- How much catch?
- What's the average weight of fish in each age class?
- What proportion of the fish in each age class are mature?

Etc, etc

We have to collect the data required to inform the model regarding the value of of these parameters

Model fitting

Review: How does a stock assessment model work?

Age Structured Model

$$N_{t+1,a+1} = N_{t,a} e^{-(M_a + F_{t,a})}$$
$$F_{t,a} = q_t E_t s_a$$
$$C_{t,a} = N_{t,a} F_{t,a} w_a$$
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$$B_t = \Sigma N_{t,a} w_a$$
$$S_t = \Sigma N_{t,a} w_a o_a$$
$$VB_t = \Sigma N_{t,a} w_a s_a$$

However, the reality is that we have variable levels of information or data pertaining to the different parameters:

Some parameters we have very good estimates for (e.g. maybe catch, average size at age) derived from biological research or fishery data collection

Some parameters we have limited data for and some uncertainty

Some parameters we have no data for and high uncertainty (unknown parameter values)

Model fitting

Review: How does a stock assessment model work?

Age Structured Model

$$N_{t+1,a+1} = N_{t,a}e^{-(M_a + F_{t,a})}$$

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

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

$$R_t = (AS_t)/(b+S_t)$$

$$N_{t+1,1} = R_t$$

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

$$S_t = \Sigma N_{t,a} w_a o_a$$

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

Given that we have moderate or large uncertainty regarding the value of some parameters, **how do we determine their value in an assessment model?**

How do we determine that the model overall can accurately predict the population dynamics and status of the fish population? (i.e. is an accurate model of "reality")

We do this by a process called **"fitting" the model to fishery data using the second component of the model, the statistical component.**

How does this work?

Model fitting

How does model "fitting" work?

Firstly, we need an index of abundance!

To make sure our model can accurately predict how the population size changes over time, we need to collect and provide the model with data from the fishery itself which acts as an indicator of those changes in population size:

i.e.; data which can act as an index of abundance (or an index of relative population size) over time.

Typically the index used is catch rate or catch per unit effort (CPUE) data, generally using data collected from fishers logsheets:

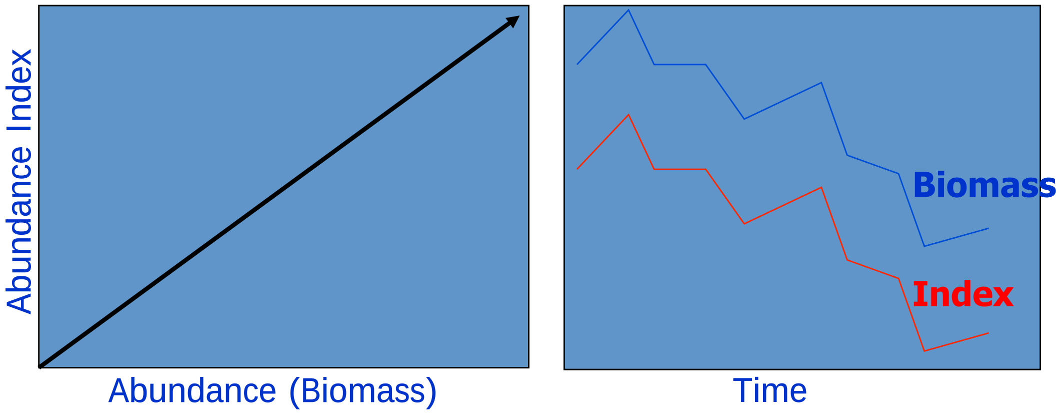
CPUE = catch/effort (e.g. 6 fish/100 hooks; 2mt/set)

Model fitting

How does model "fitting" work?

The use of CPUE as an "index of abundance" relies on the assumption that the relationship between the index (CPUE) and abundance is linear (proportional), so if CPUE goes up, the population has gotten bigger; if it goes down, it has gotten smaller. In this way CPUE is assumed to be an accurate index of population change over time.

*(**In fact, this is not always true, but we will discuss this further later)*

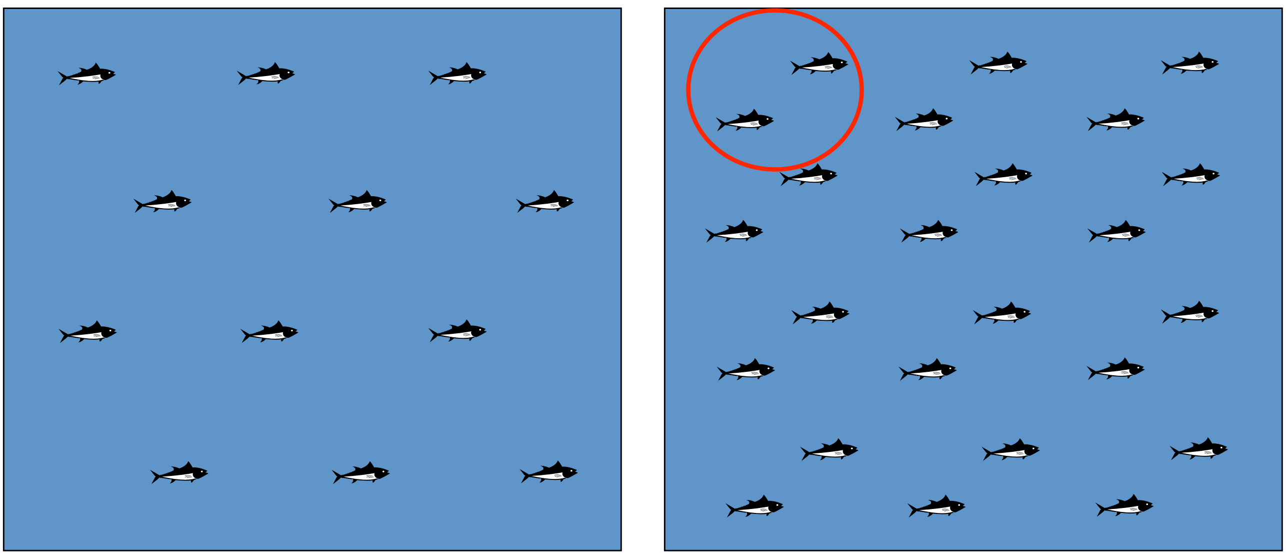


Model fitting

How does model "fitting" work?

Consider the following example. To fish populations in equally sized habitats, with one population exactly twice the size as the other.

pond with 12 fish | pond with 24 fish



Mean CPUE ~ 1.2/set | *Mean CPUE ~ 2.4/set*

Model fitting

How does "model fitting" work?

- So we have our observed CPUE series
- Our model also has an equation to predict CPUE.
- We can now employ the statistical component of the model to search for and select the "best" combination of parameter values (for the "unknown" parameters) which maximises the models ability to accurately predict the observed CPUE data (i.e.; pick the values which maximise the fit of the model predictions to the observed data).
- Note that the tuna assessments also fit to other data types:
  - Tagging data (to ensure realistic modelling of movement)
  - Size data (to ensure realistic modelling of population structure)

Model fitting

What are the different approaches to model fitting?

There are (at least) three general approaches to how we might go about doing this that you should be aware of (or at least know exist!):

- **Least-squares (LS) estimation**
- **Maximum likelihood (ML) estimation**
- **Bayesian estimation**

We use maximum-likelihood estimation (MLE)

In our tropical tuna assessments, method (ii) (MLE) is used to fit our assessment models to our data, with that data typically being the CPUE data (an index of population size), the size data (an index of population structure) and the tagging data (an index of population movement)

Model fitting

Brief summary of three main methods

1. Least Squares estimation (or Minimisation of Sum of Squared Errors (SSE))

Basically, this approach asks "What combination of values result in there being the smallest difference (degree of error) between the model estimated CPUE series and the real CPUE series?"

2. Maximum likelihood estimation

This approach asks "What combination of values for all of these parameters would most likely result in the observed CPUE values occurring?"

3. Bayes estimation

An extension of ML estimation that incorporates prior knowledge and better quantifies uncertainty

We will examine LS and ML in some detail, but note that bayeasian methods are increasingly utilized

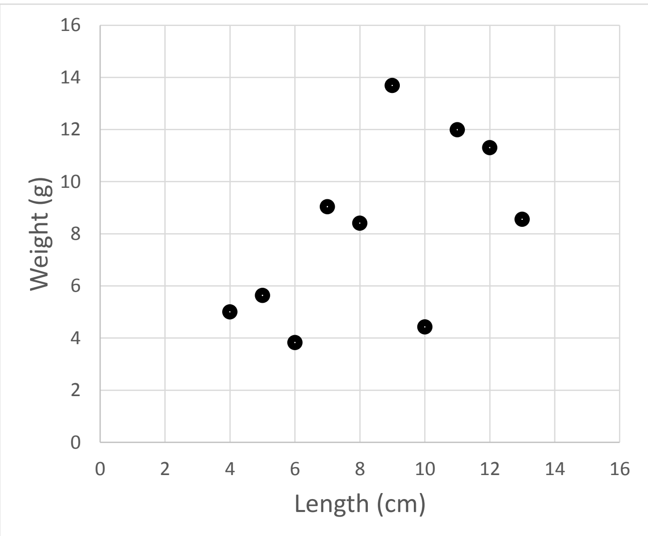
Model fitting: LS approach

Model fitting: LS approach

- This approach involves a search for the parameter values which minimizes the sums of squared differences – i.e., the "least squares" solution - between the observed data and the data as predicted by the model and parameters.
- It is almost impossible in any even slightly complex system to create a model that exactly fits the real data....there is always some error. The objective of the LS approach is to find parameter values that minimize the total error.

Model fitting: LS approach

An example using fish length and weight



y is fish weight

x is fish length

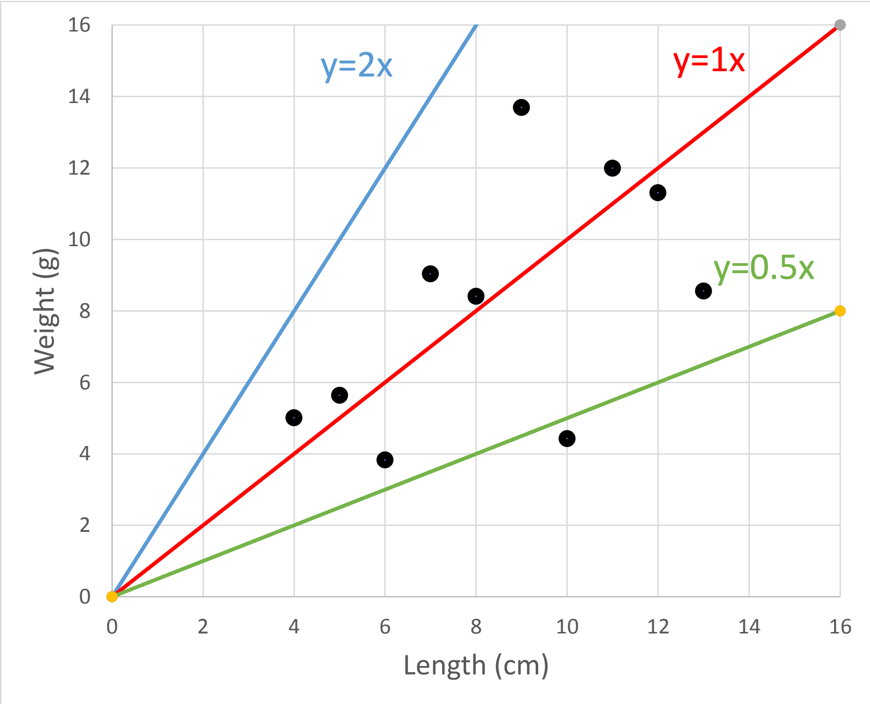
These are data to which we will fit a model. We want to determine how fish weight is related to fish length

y=mx **This is our simple (linear) model**

m is a parameter linking the two, which is to be estimated

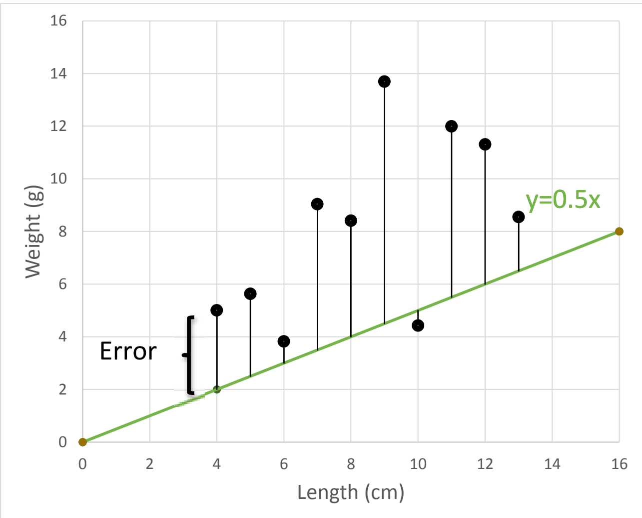
Model fitting: LS approach

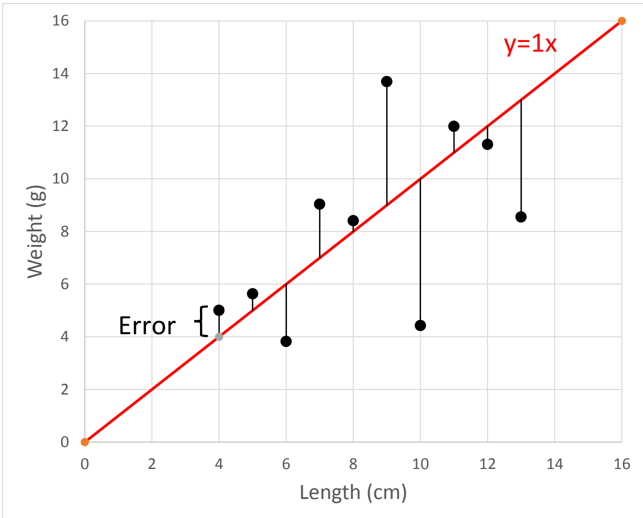
An example using fish length and weight: **y=mx**



Model fitting: LS approach

Models used to deduce relationship and find best fit





Error = Observed Value – Predicted Value = (O – E)
Squared Error = $(O – E)^2$
Least Squares = Minimum of Sum of Squared Errors

Model fitting: LS approach

SPC CPS

Models fitting results

x variable	y variable	Model: y = 0.5x			Model: y = 1.0x			Model: y = 2.0x		
Length	Observed	Predicted	(O - E)	$(O - E)^2$	Predicted	(O - E)	$(O - E)^2$	Predicted	(O - E)	$(O - E)^2$
4	5.0	2.0	3.0	9.0	4.0	1.0	1.0	8.0	-3.0	9.0
5	5.6	2.5	3.1	9.8	5.0	0.6	0.4	10.0	-4.4	19.1
6	3.8	3.0	0.8	0.7	6.0	-2.2	4.7	12.0	-8.2	66.8
7	9.0	3.5	5.5	30.6	7.0	2.0	4.1	14.0	-5.0	24.7
8	8.4	4.0	4.4	19.4	8.0	0.4	0.2	16.0	-7.6	57.7
9	13.7	4.5	9.2	84.4	9.0	4.7	22.0	18.0	-4.3	18.6
10	4.4	5.0	-0.6	0.3	10.0	-5.6	31.1	20.0	-15.6	242.6
11	12.0	5.5	6.5	42.2	11.0	1.0	1.0	22.0	-10.0	100.1
12	11.3	6.0	5.3	28.2	12.0	-0.7	0.5	24.0	-12.7	161.1
13	8.6	6.5	2.1	4.2	13.0	-4.4	19.8	26.0	-17.4	304.4
			SSE	**228.9**		**SSE**	**84.8**		**SSE**	**1004.1**

Winner!

Model fitting: LS approach

SPC CPS

Age Structured Model

$$N_{t+1,a+1} = N_{t,a}e^{-(M_a + F_{t,a})}$$

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

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

$$R_t = (AS_t)/(b+S_t)$$

$$N_{t+1,1} = R_t$$

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

$$S_t = \Sigma N_{t,a} w_a o_a$$

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

- Here are the equations that described the population processes….we believe these are correct based on past research etc.
- And we have data collected from the fishery or science research for many of the parameters.
- But we don't have any data for some parameters.
- Model fitting is the process by which our computer programme searches amongst all the possible "unknown" parameter values until it finds and selects the "best" combination of parameter values which maximise the fit of the model predictions to the observed data (e.g. CPUE).
- In other words it selects values for the unknown parameters which maximise the models ability to accurately predict the observed CPUE (in this example) data.

Model fitting: Maximum Likelihood

Model fitting: ML approach

Maximum Likelihood Method

For this approach, parameters are selected which maximise the probability or likelihood that the observed values (the data) would have occurred given the particular model and the set of parameters selected (the hypothesis being tested)

The set of parameter values which generate the largest likelihood are the maximum likelihood estimates:

So..

Likelihood = P{data|hypothesis}

Which means "the probability of the data (the observed values) given the hypothesis (the model plus the parameter values selected)".

E.g. Think of the flip of a coin

What's the probability of getting heads? Of getting tails?

Stock assessment models can use fairly complex mathematics to determine the probability of, for example, the observed CPUE series occurring, given a particular model.

Model fitting: ML approach

Maximum Likelihood Method

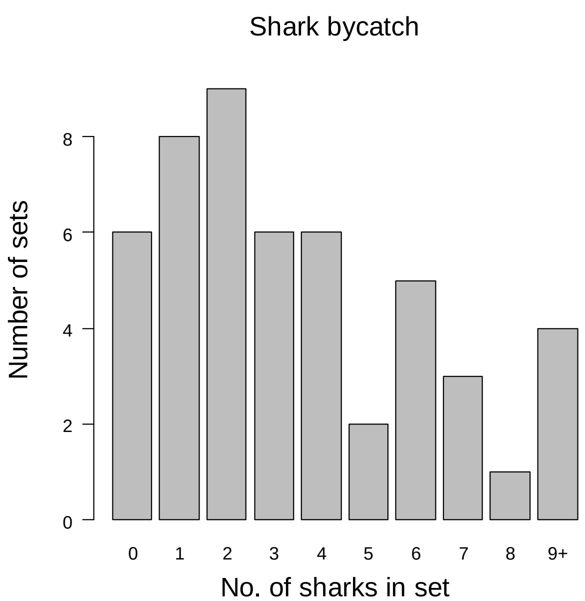
ML estimation is far more elegant and general purpose than LS estimation

- Allows for many different distributions (note that LS and ML are equivalent in the case of normally distributed data)
- Finds best fit to the data for a given model (the ML estimate) and computes likelihood for all parameter values
- Allows for calculation of confidence bounds (with likelihood profile) on parameters
- Allows for comparison of alternative hypotheses (Likelihood ratio test or AIC)

Model fitting: ML approach

Maximum Likelihood: An example

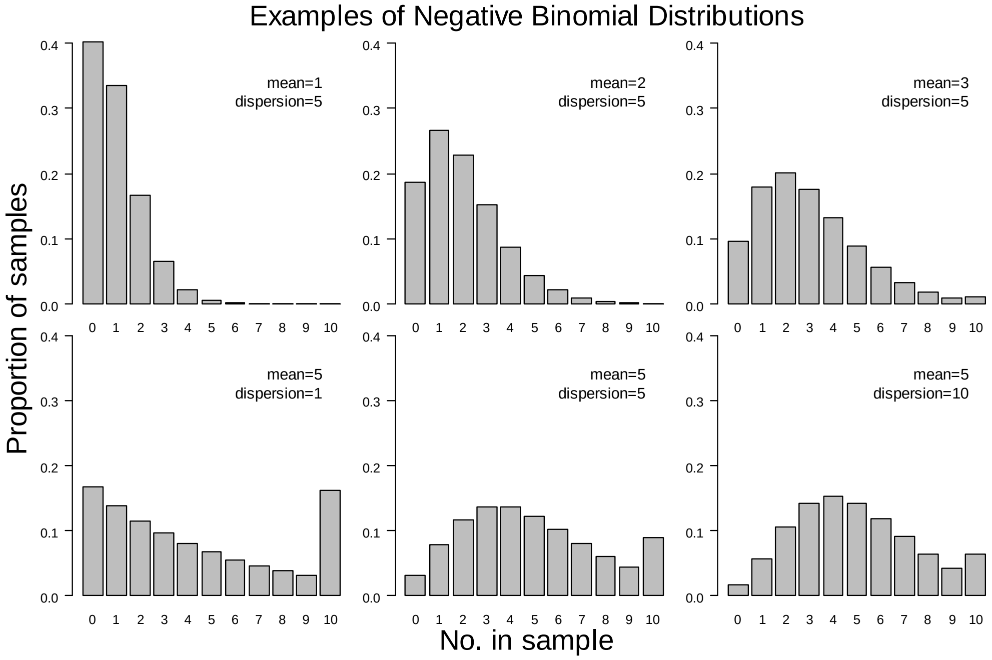
We are interested in modeling the catch of hammerhead sharks in purse seine sets in a given region. The data we have are number of hammerheads caught in 50 different sets.



- The data are "discrete"
- Cannot fit a Normal distribution
- We have a variety of distributions (models) to chose from
  - Poisson
  - Binomial
  - Negative binomial
- We will fit a Negative binomial model to illustrate the ML fitting process
  - Will compare to Poisson model fit at the end

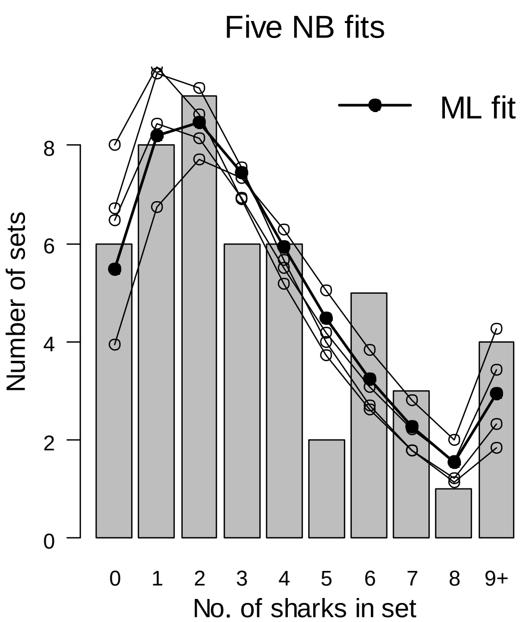
Model fitting: ML approach

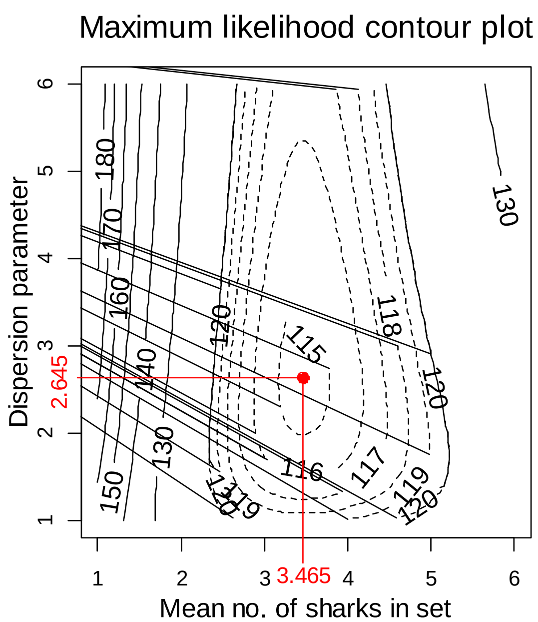
- In Ecology, the Negative Binomial distribution is used to model No. of counts in a sample. The parameters are
  - Mu, or the **mean** number in the sample
  - Theta, or the “**overdispersion**” parameter (~ variance)



Model fitting: ML approach

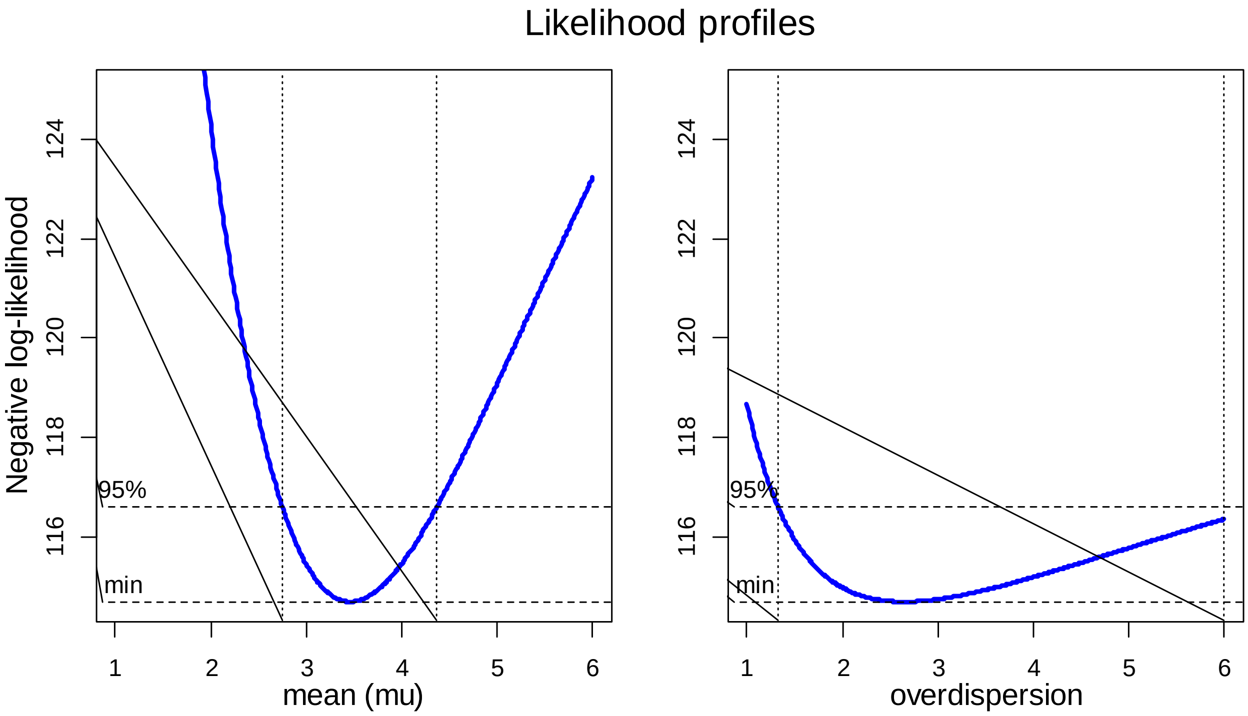
- Given a distribution, a computer algorithm than searches across all combinations of parameter values and computes the “negative log likelihood” value
  - Minimum log likelihood = Maximum likelihood, but much easier/reliable to find





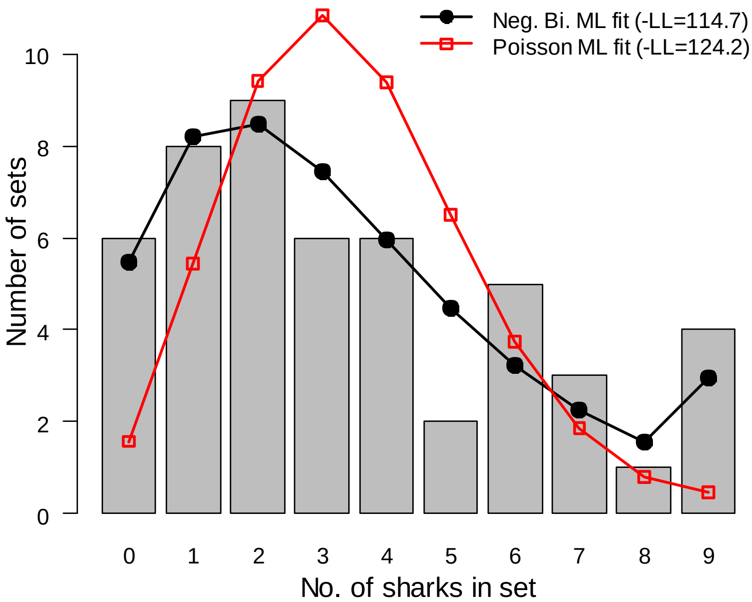
Model fitting: ML approach

- The "confidence" in the parameter estimates is computed from the likelihood profiles



Model fitting: ML approach

- Comparison of competing "hypotheses"



$$AIC = -2LL + 2k$$

Where k = no. parameters thus penalizing a model for more parameters.

Lowest AIC is considered better model

Model	No. params	-LL	AIC
Neg. Bin.	2	114.7	233.7
Poisson	1	124.2	250.2

Winner!

Model fitting: ML approach

- The likelihoods, priors and penalties for a North Pacific stock assessment

Posterior distribution components	**Model Description** (continued)
$L_C = \lambda_c \sum_{1}^{g} \sum_{y} \left(\ln C_{g,y} - \ln \hat{C}_{g,y}\right)^2 / \left(2\sigma_C^2\right)$	Catch likelihood
$L_I = \lambda_I \sum_{1}^{g} \sum_{y} \left(\ln I_{g,y} - \ln \hat{I}_{g,y}\right)^2 / \left(2\sigma_I^2\right)$	Survey biomass index likelihood
$L_{age} = \lambda_{age} \sum_{i=1}^{n_g} -\psi_y^g \sum_{a_0}^{a_+} \left(P_{i,a}^g + v\right) \ln\left(\hat{P}_{i,a}^g + v\right)$	Age composition likelihood
$L_{length} = \lambda_{length} \sum_{1}^{s} \sum_{i=1}^{n_g} -\psi_y^g \sum_{l=1}^{\Omega} \left(P_{i,l,s}^g + v\right) \ln\left(\hat{P}_{i,l,s}^g + v\right)$	Length composition likelihood (ψ_y^g =sample size, n_g = number of years of data for gear g, i = year of data availability, v is a constant set at 0.001)
$L_q = \left(\ln \hat{q}^g - \ln q_\mu^g\right)^2 / 2\sigma_q^2$	Prior on survey catchability coefficient for gear g
$L_M = \left(\ln \hat{M} - \ln M_\mu\right)^2 / 2\sigma_M^2$	Prior for natural mortality
$L_{\sigma_r} = \left(\ln \hat{\sigma}_r - \ln \sigma_{r_\mu}\right)^2 / 2\sigma_{\sigma_r}^2$	Prior distribution for σ_r
$L_r = 0.1 \sum_{y=1}^{T} \frac{\tau_y^2}{2\hat{\sigma}_r^2} + n \ln \hat{\sigma}_r$	Prior on recruitment deviations
$L_f = \lambda_f \sum_{1}^{g} \sum_{y=1}^{T} \phi_{y,g}^2$	Regularity penalty on fishing mortality
$L_{Total} = \sum_{x} L_x$	Total objective function value

Model Likelihood Components (Data)	2013	2014
Catch	8	7
Domestic LL survey RPN	46	47
Japanese LL survey RPN	18	18
Domestic LL fishery RPW	7	10
Japanese LL fishery RPW	12	13
NMFS GOA trawl survey	19	19
Domestic LL survey ages	169	180
Domestic LL fishery ages	192	238
Domestic LL survey lengths	55	59
Japanese LL survey ages	144	144
Japanese LL survey lengths	46	46
NMFS trawl survey lengths	290	286
Domestic LL fishery lengths	198	207
Domestic trawl fishery lengths	186	194
Data likelihood	1391	1469
Total objective function value	1415	1489

Evaluating the model fit

Evaluating goodness of fit:

1. So, how does one go about determining if a model has a reasonable fit to the observed fishery data offered to it? There are three basic parts of the assessment you should look at:

- **The narrative**
  What does the modeller(s) say in the text about the fit?

- **Graphical summaries**
  The plots showing: (i) residual plots; (ii) effort deviations; (iii) observed versus predicted sizes (lengths and weights); and (iv) observed versus predicted tag returns.

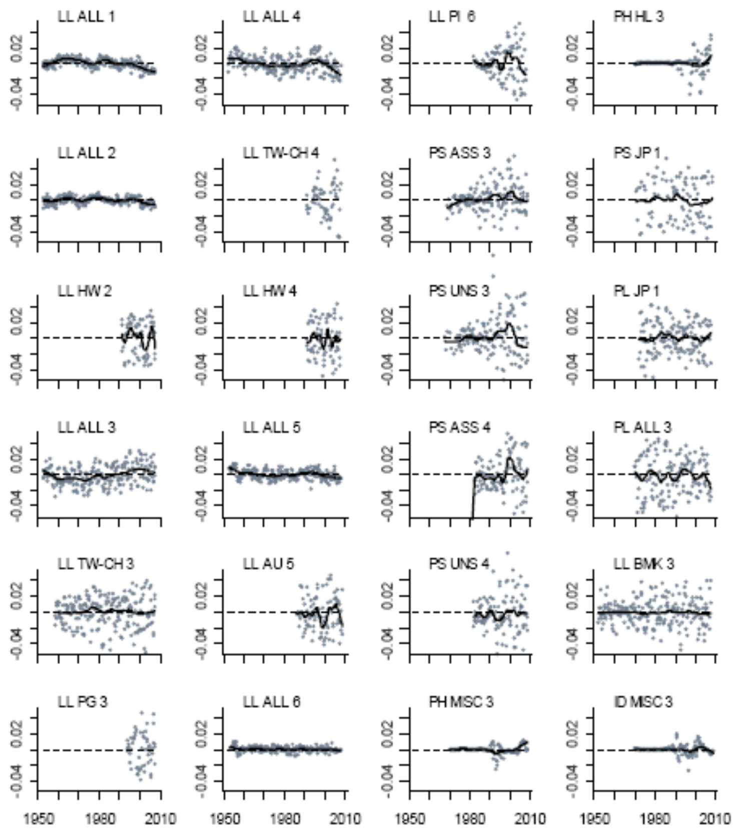
- **Likelihood contributions**
  The table(s) of the model total and observation likelihoods

Evaluating the model fit

Example: ln(total catch) SC-5 2009 YFT

Residuals of ln (total catch) for each fishery. The solid line represents a lowess fit to the residuals.

If the model fits the data well, the residuals should be evenly distributed around zero, instances where the residuals are not evenly distributed may indicate poor fit. In those instances you might then ask the question "why"?



Evaluating the model fit

Example: Effort deviates SC-5 2009 YFT

Effort deviations by time period for each fishery. The solid line represents a Loess fit to the data.

If the model is fitting the data well, the effort deviations should be evenly distributed around zero, instances where the effort deviations are not evenly distributed over time may indicate poor fit and again you may choose to ask "why"?

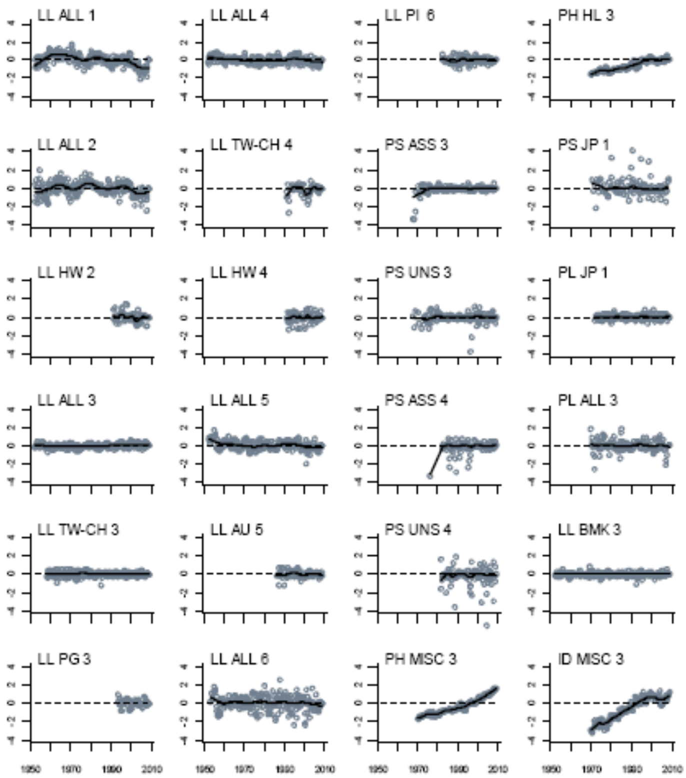
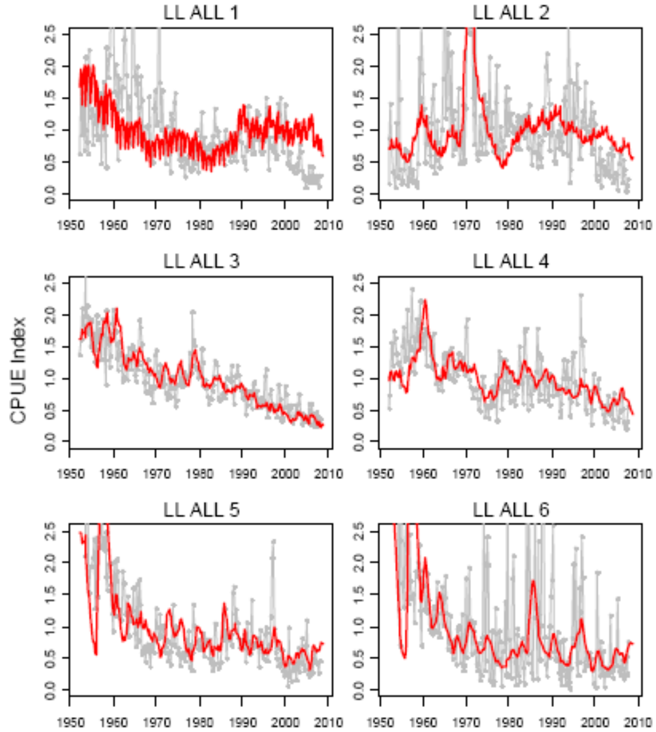


Figure 28. Effort deviations by time period for each fishery. The solid black line represents the lowess smoothed trend of the data.

Evaluating the model fit

Example: LL CPUE SC-5 2009 YFT

Adequate goodness of fit in the standardised CPUE indices is extremely important, given the role of these data within the assessment.



e 40. A comparison of longline exploitable biomass by quarter and region (red line) and the quarterly ardised CPUE indices for the fisheries. For comparison, both series are scaled to the average of the series.

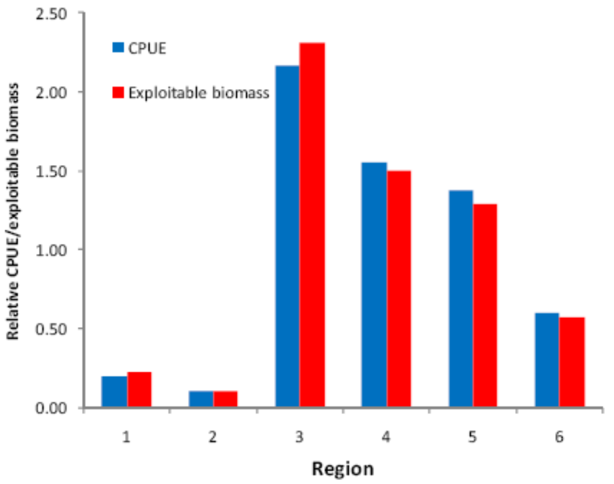
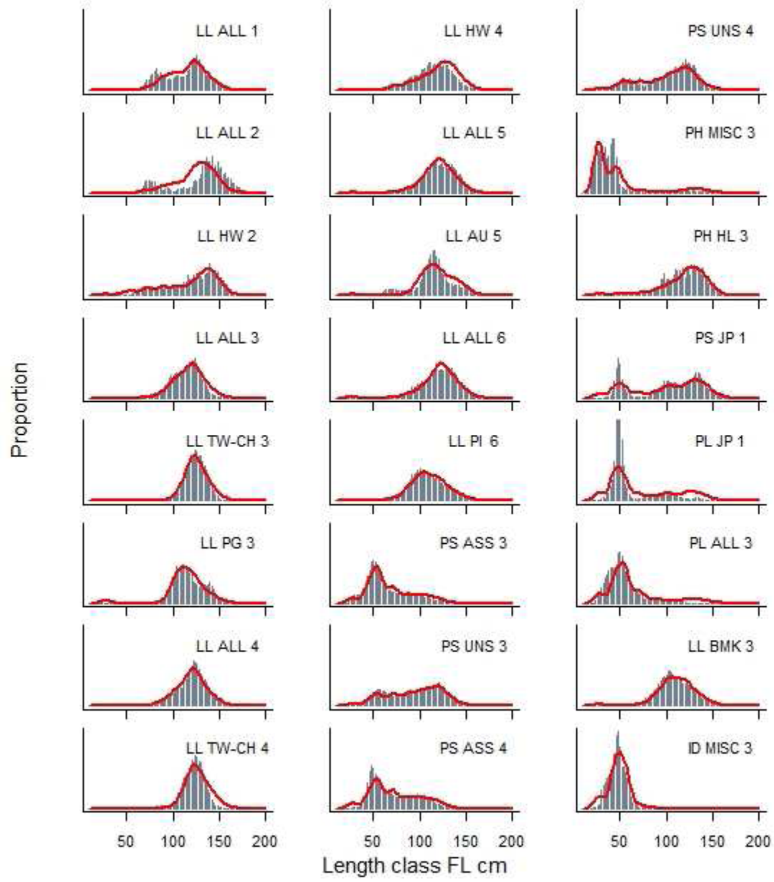


Figure 41. CPUE and exploitable abundance for LL ALL 1–6 averaged over all time periods. Values for each region are scaled relative to their averages across all regions.

Evaluating the model fit

Example: LF data SC-5 2009 YFT

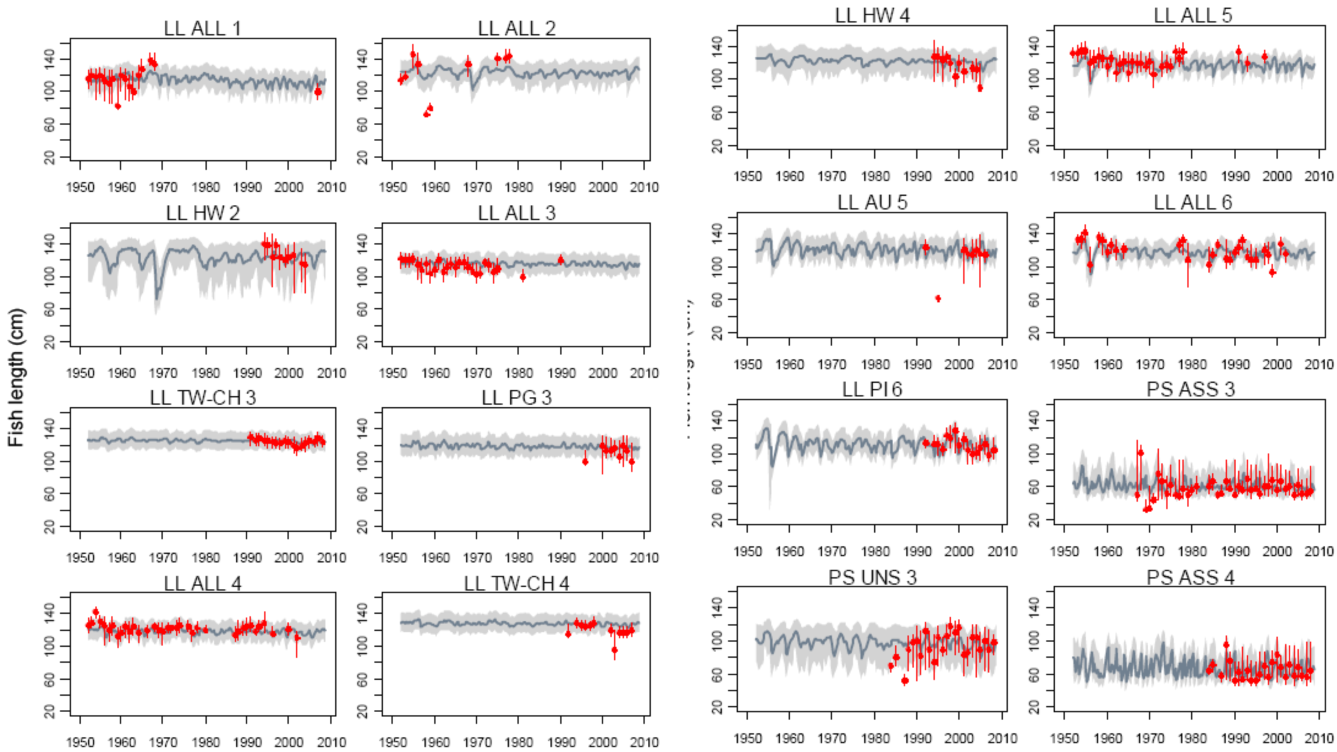
Again, we are looking for good consistency between the observed and predicted values. The kinds of things we should look for are similar trends in the length-range and structure (i.e., the number of modes, etc.) in the data and the model predicted results. It can also be useful to look directly at the residuals (i.e., plots of residuals versus expected values) themselves. Similar results are useful for the WF data.



Evaluating the model fit

Example: LF data SC-5 2009 YFT

Here is another way of looking at trends in the observed and predicted LF data over time.



Evaluating the model fit

Example: Tagging data SC-5 2009 YFT

Two very common tagging data diagnostics are various plots of the observed and predicted numbers of tag returns over time and by other factors.

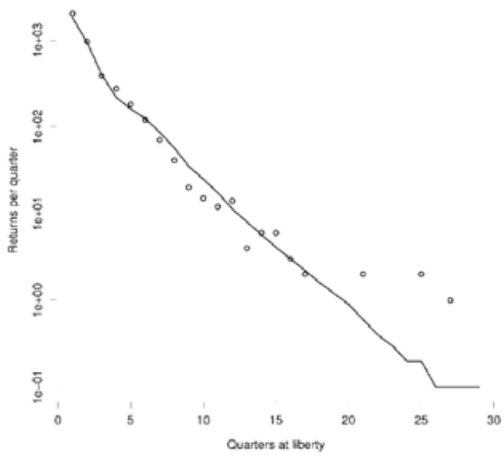


Figure 20. Number of observed (points) and predicted (line) tag returns by periods at liberty (quarters).

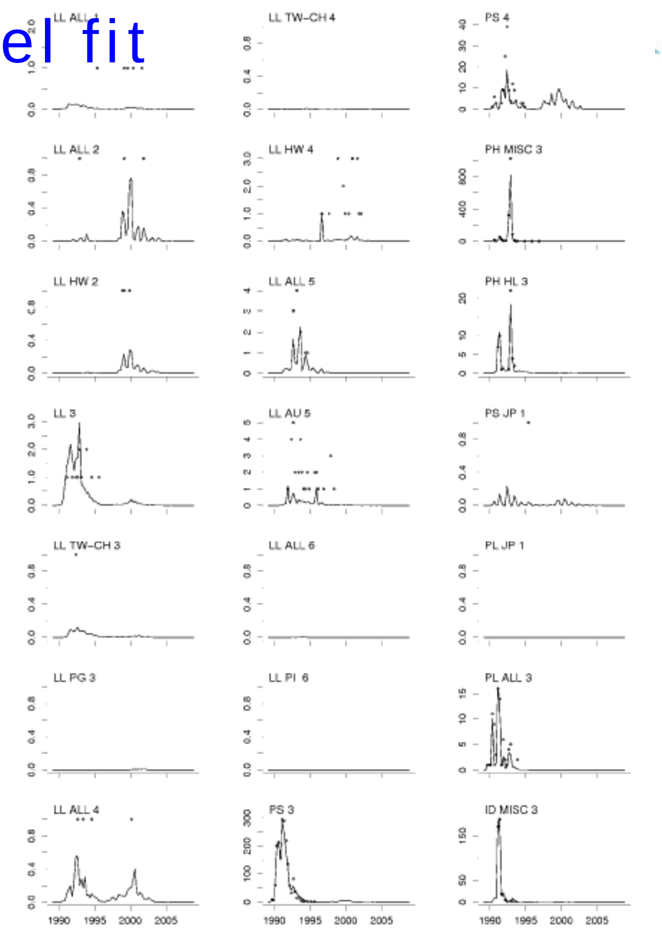


Figure 21. Number of observed (points) and predicted (line) tag returns by recapture period (quarter) for the various fisheries (or groups of fisheries) defined in the model.

Evaluating the model fit

Example: Likelihood table SC-4 2009 YFT

Assuming that each run was fitted to exactly the same observations, which run, given only the data provided in the table, has the best fit?

Objective function component	CPUE low, LL sample high, LL q incr	CPUE high, LL sample low, LL q incr	CPUE low, LL sample high	CPUE high, LL sample low	Base 2007	Base 2007, steepness 0.75
Length frequency log-likelihood	-372,200.20	-344,431.70	-372,206.00	-344,424.90	-410,082.70	-410,082.20
Principal LL fisheries	-89,221.58	-61,168.68	-89,220.20	-61,165.51	-97,652.02	-97,652.35
Other fisheries	-282,978.60	-283,263.00	-282,985.80	-283,259.40	-312,430.70	-312,429.80
Weight frequency log-likelihood	-670,570.30	-592,920.70	-670,564.10	-592,909.40	-735,160.80	-735,160.40
Principal LL fisheries	-402,445.10	-324,736.20	-402,442.00	-324,735.70	-440,745.90	-440,745.90
Other fisheries	-268,125.30	-268,184.50	-268,122.20	-268,173.70	-294,414.90	-294,414.60
Tag log-likelihood	2,598.64	2,608.71	2,594.68	2,600.83	2,640.06	2,639.57
Total catch log-likelihood	89.65	172.80	89.61	172.15	486.18	486.24
Penalties	2,485.21	3,641.19	2,485.81	3,627.23	5,953.26	5,949.79
Total function value	-1,037,597.00	-930,929.70	-1,037,600.00	-930,934.10	-1,136,164.00	-1,136,167.00
gradient	0.00081	0.02958	0.07894	0.01785	0.00092	0.00084

It can be useful to compare the relative fits of each run to each different set of observations to which the models were fitted.

Maximum-likelihood estimation in brief

Older example

Note!

- Typically, to find the MLEs we actually search for parameter values that minimise the model's negative log-likelihood function, logL,
- So, in an assessment using MLE, to determine the model with the best fit, find the model with the lowest negative log-likelihood score. A table is usually produced which provides the negative log-likelihood estimates for each data set offered to the model (e.g., catch, size, tagging data) and the combined total for all of these.

Table 1. Details of objective function components for the base-case model and three of the sensitivity analyses.

Objective function component	base-case	ID-low-catch	ID-high-catch	region3-growth
Total catch log-likelihood	598.80	595.90	600.18	638.50
Length frequency log-likelihood	-349,920.62	-349,876.45	-349,936.53	-350,030.85
Weight frequency log-likelihood	-760,710.15	-760,709.29	-760,713.94	-759,670.09
Tag log-likelihood	2,618.91	2,606.04	2,632.90	3,118.94
Penalties	7,152.87	7,148.73	7,157.87	7,331.48
Total function value	-1,100,260.19	-1,100,235.07	-1,100,259.52	-1,098,612.02

Chapter 13

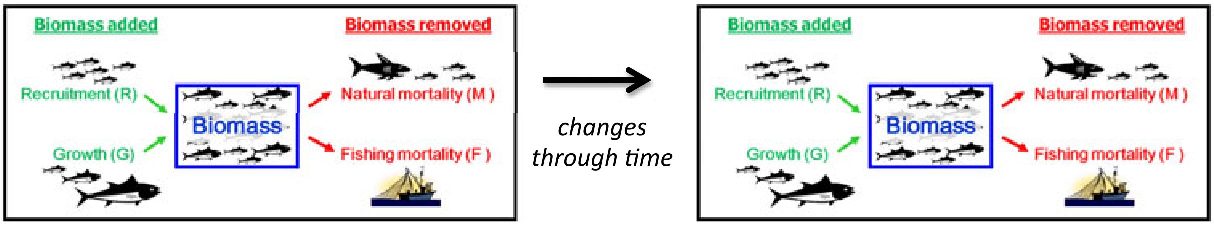
Use and Interpretation of MFCL Projections

Overview

- What are projections?
- Types of projections
- Approaches to conducting projections
- Structured decision-making
- Current WCPFC examples
- Exercises (inc. TUMAS)

SPC CPS

Stock assessment



1. Identify historical trends and current stock status (retrospective analysis)
2. Predict future trends and population reaction to proposed management (prospective analysis)

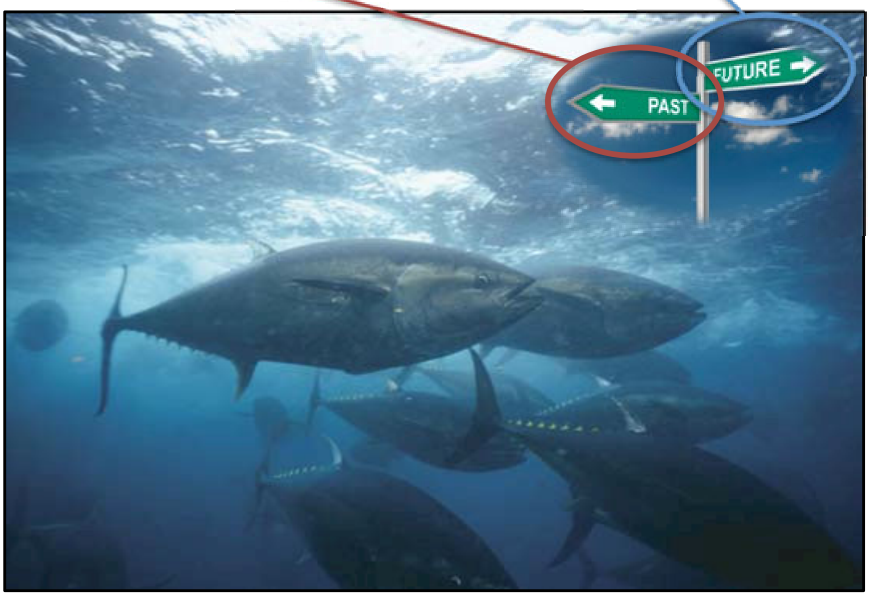
SPC CPS

Prospective analyses

e.g., implication of moving to a 6-month FAD closure

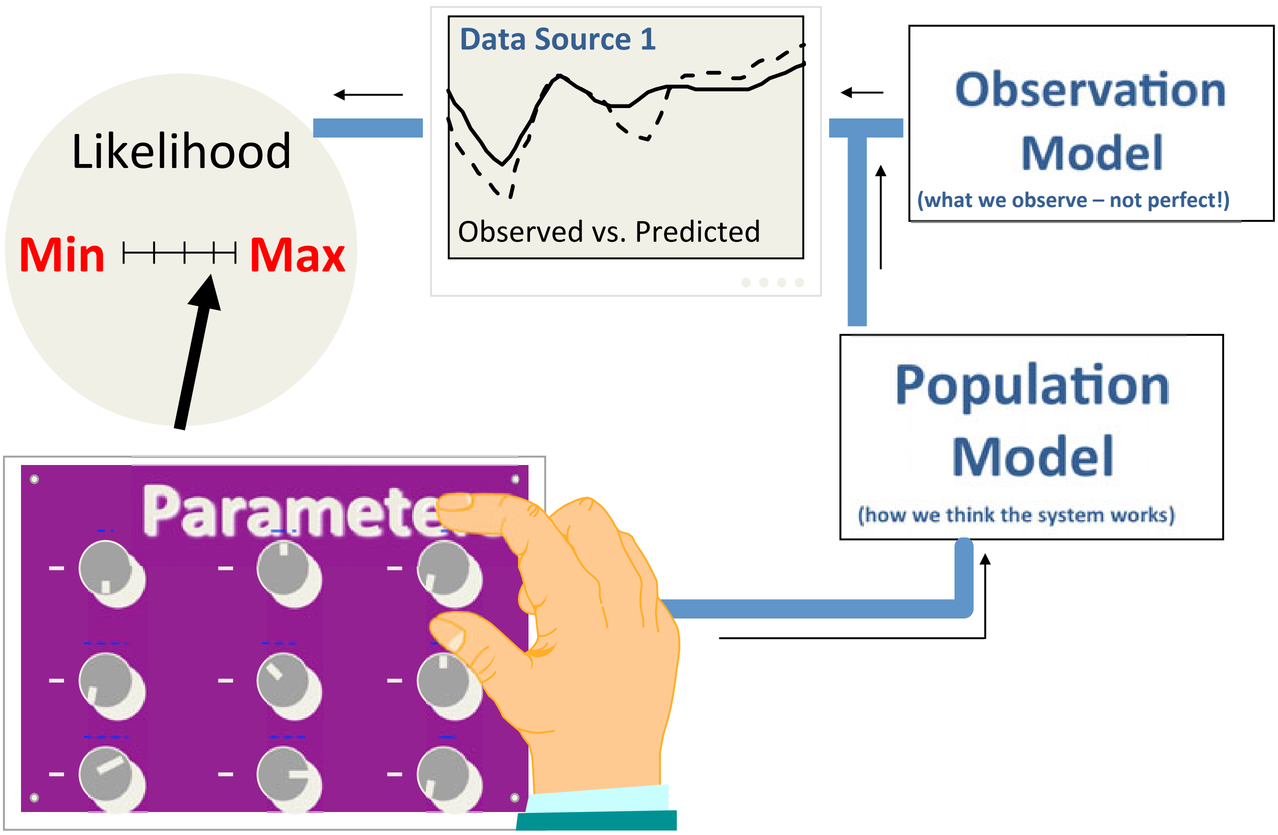
Retrospective analyses

e.g., current BET stock status



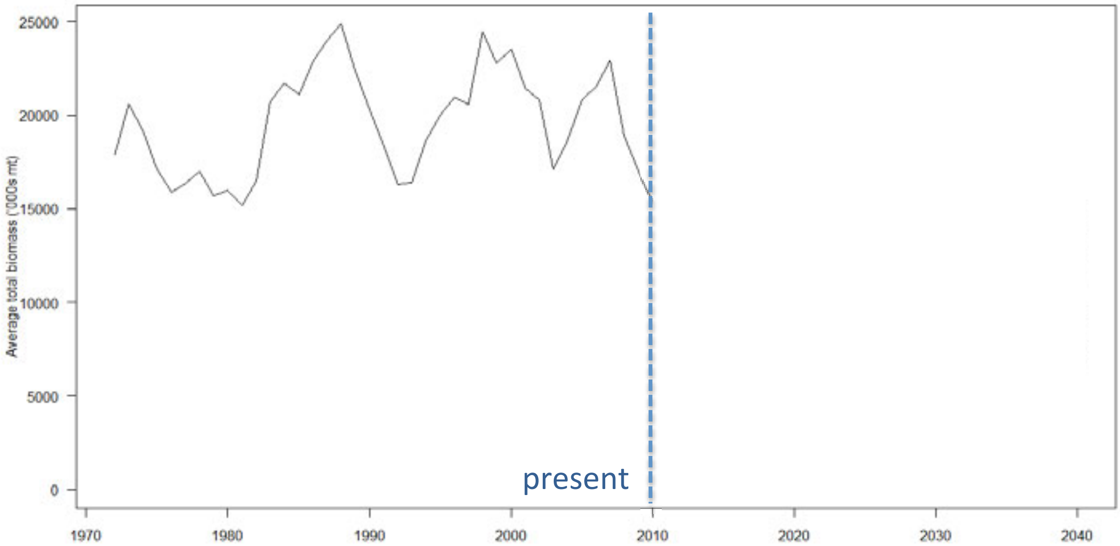
Projections are the tool used to implement prospective stock assessment analyses

Recall fitting an assessment model to data.....



Retrospective assessment model

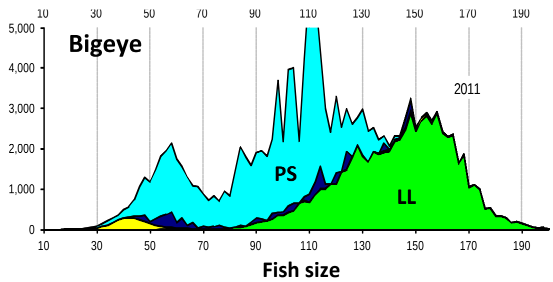
- Model that predicts what has happened from the past to the present using observed data



- Resulting population parameters are typically used as inputs into how the population will 'operate' into the future

$N_{t+1,a+1}$ = Number of fish of age+1 at time+1
M_a = natural mortality rate at age *a*
F_a = fishing mortality rate at age *a*
q = catchability
E = fishing effort (units)
s = age specific vulnerability to the gear (selectivity of the gear)
$C_{t,a}$ = Catch at time t and age *a*
w_a = Mean weight at age *a* << *(Growth)*
R_t = Recruitment at time t
A = maximum recruitment
b = Stock size when recruitment is half the maximum recruitment
w_a = weight at age a
o_a = proportion mature at age a
B_t = population biomass at time t
S_t = spawning stock biomass at time t
VB = vulnerable biomass at time t

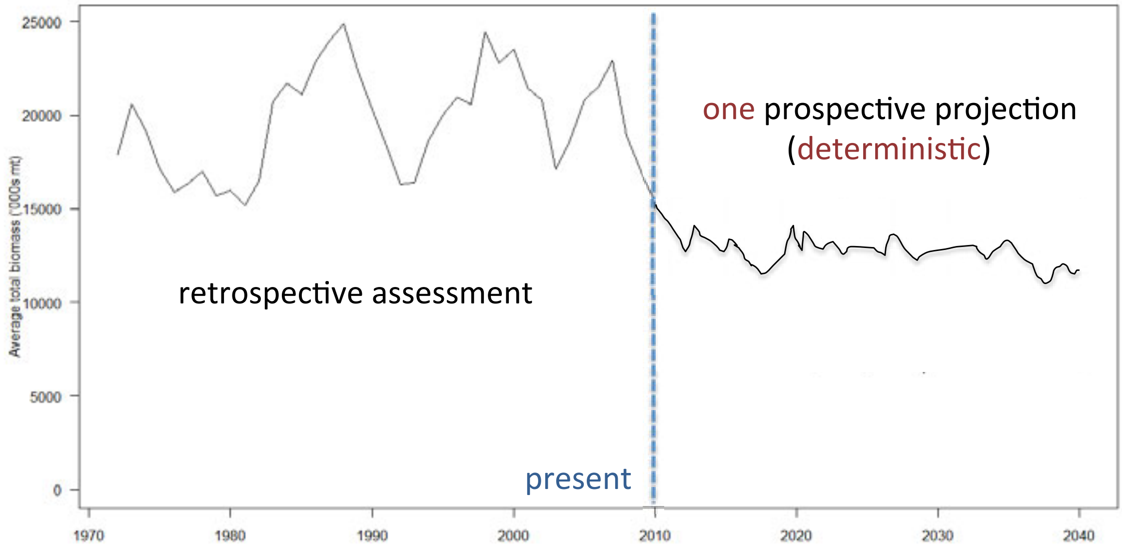
-e.g., purse seiners tend to catch smaller fish than longliners (parameter ***s***)



-e.g., how recruitment is determined by the size of the adult population (parameters ***A*** and ***b***)

Prospective assessment model

- Model that forecasts or projects outcomes from the <u>present to some future time</u> using parameters from the retrospective model



Uncertainty

- However, future conditions are highly uncertain due to several sources of error.

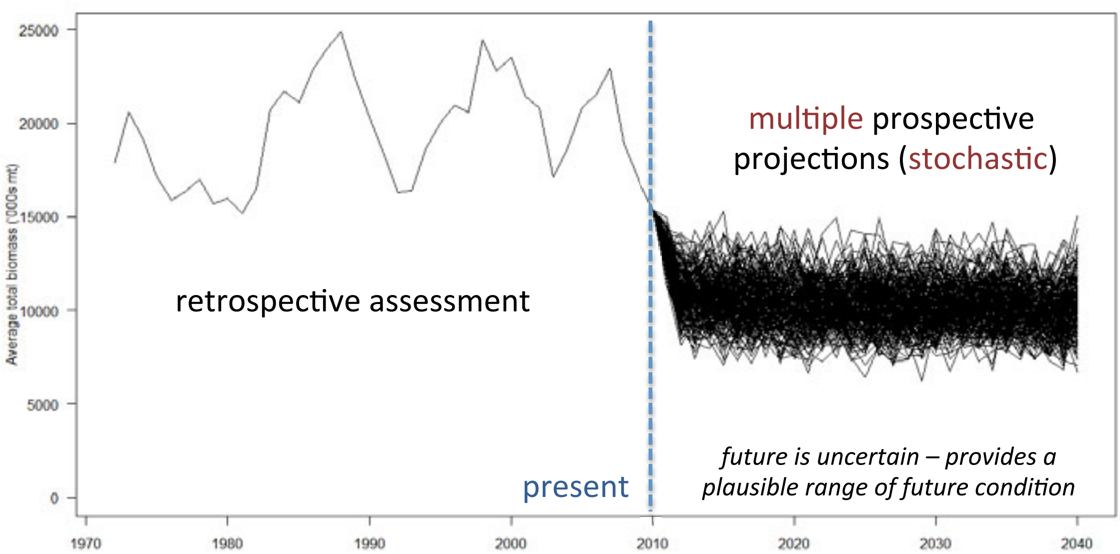
Uncertainty	**Description**	**WCPFC example**
Process error	Natural variation	Year-on-year variation in number of young tuna produced
Measurement error	When collecting information	Species composition in purse seine catch
Estimation error	When modelling natural processes	Fitting movement models based upon tagging information
Model error	When assuming that an assessment model mimics real life	The MULTIFAN-CL model and assumptions on spatial structure
Implementation error	Management decisions are never implemented perfectly	CMM-2008-01

"To know one's ignorance is the best part of knowledge"

Lao Tse, *The Tao*, No. 71

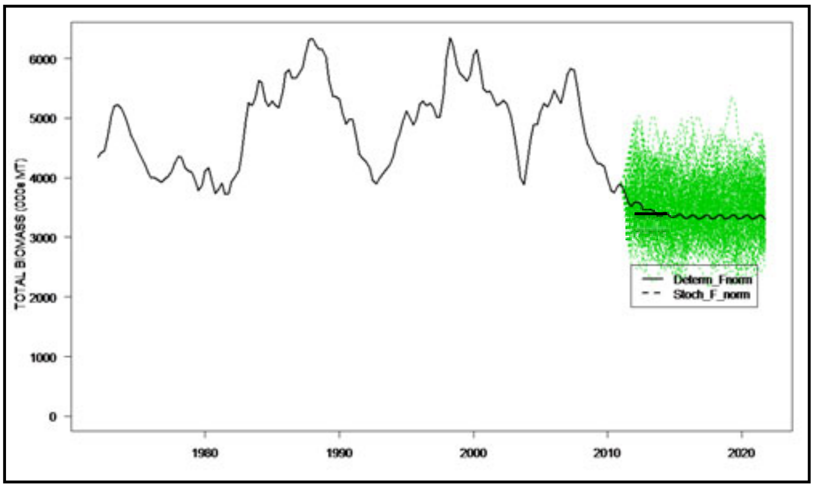
Prospective assessment model

- Model that forecasts from the <u>present to some future time</u> using a range of parameters from the retrospective model



Projection – key assumptions

- Deterministic - no uncertainty in key inputs (determined by one set of inputs)
- Stochastic – integrates uncertainty associated with the key inputs (more realistic variability)



SPC CPS

MFCL Projection - steps

1. get retrospective (past) model outputs
2. decide on a base catch / effort level from which to start projection
3. decide how catch / effort should be scaled in the future (relative to that in #2)
4. decide on the length of the projection (how many years?)

Example projection set-up

Base level: Average 2007-2010 catch

Projection catch: 1.2 times the base level

Time horizon: 10 years

scaled value is called the multiplier

SPC CPS

An example

(analyst decision points)

1. Retrospective assessment model outputs (parameters)

e.g., population trend, catch/effort trend

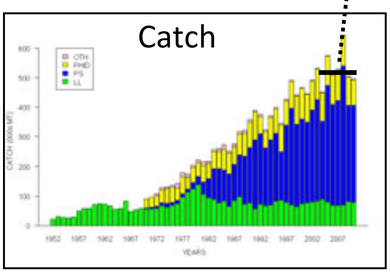
2. Base level *catch* = 510,000 mt (*average 2002-2010*)

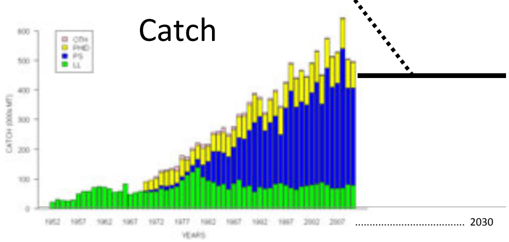
3. Projection multiplier = *0.9* (future catch held at 90% of 510,000 mt)

4. Project for *20* years

Project on specified conditions (MULTIFAN-CL)

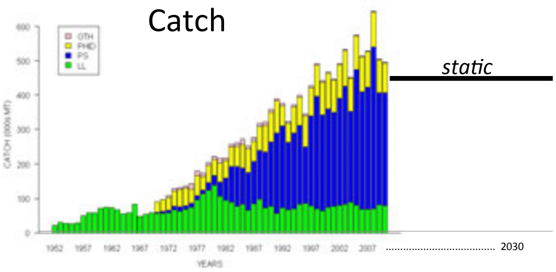
Evaluate, compare, and contrast results

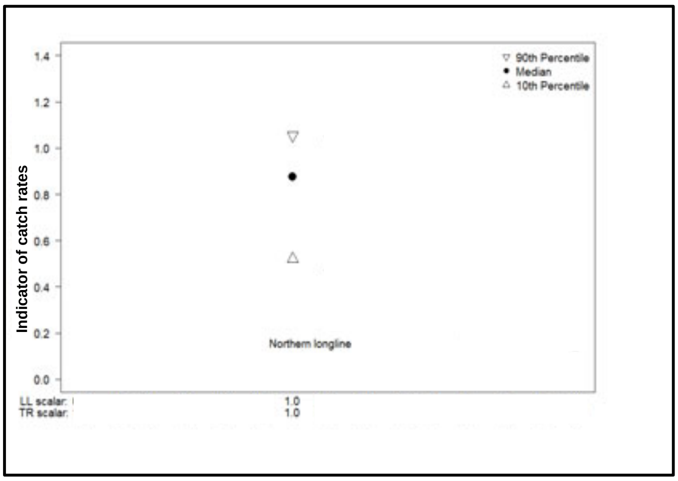




Projection - approach

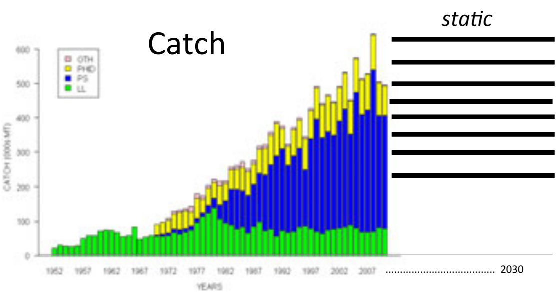
1. Static
   – Status quo - what will happen in *X* years if we continue fishing at the base level (multiplier = 1)

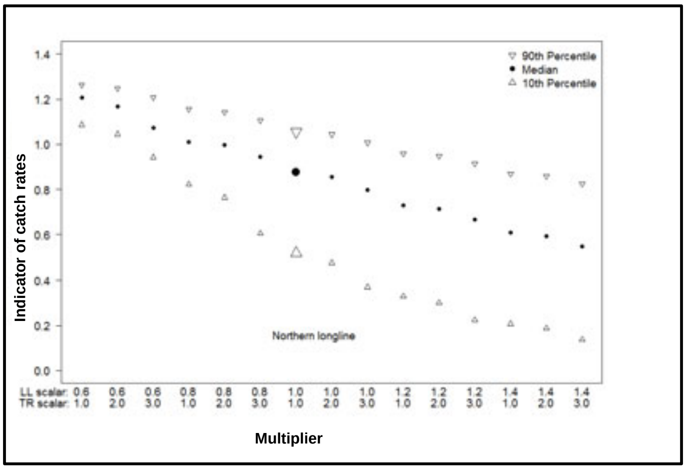




Projection - approach

1. Static
   – Alternative management scenarios - what will happen in *X* years if we fish at *Y* alternative catch/effort levels

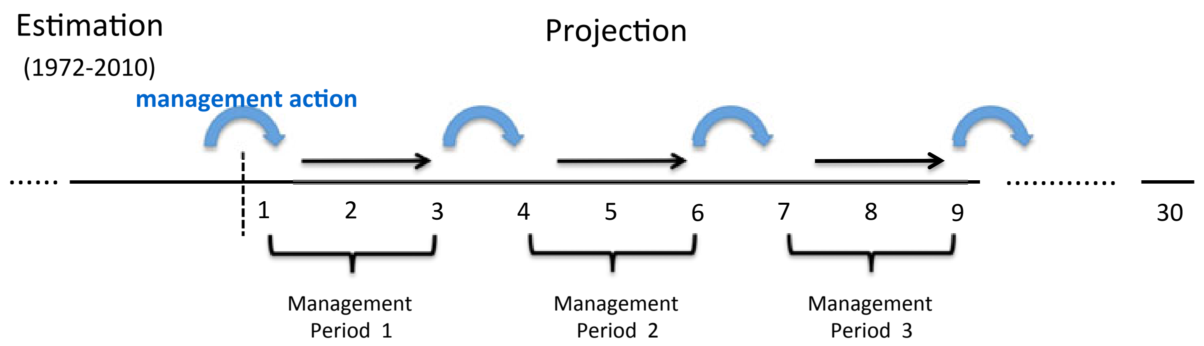




Projection - approach

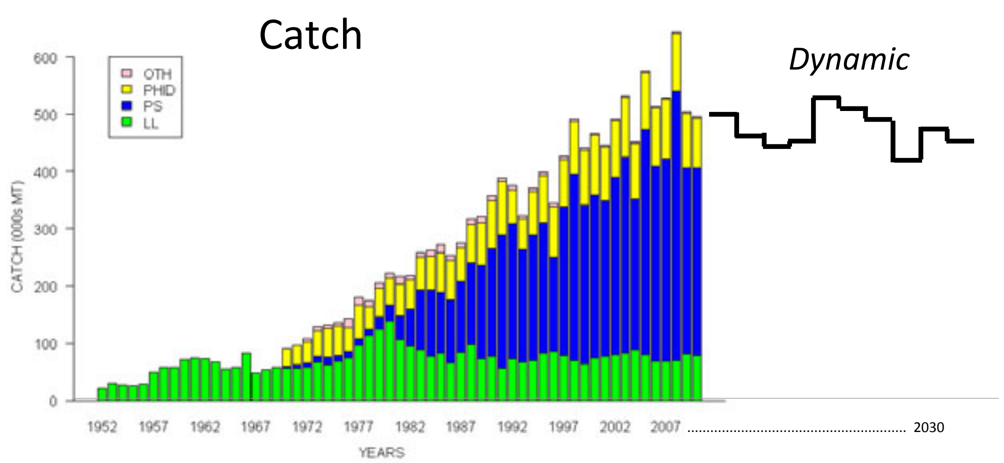
2. Dynamic
   - Management does not set fishing levels for long periods
   - Adjustment based on latest information
   - More realistic: adapt management decisions based on regular stock assessment

Example:



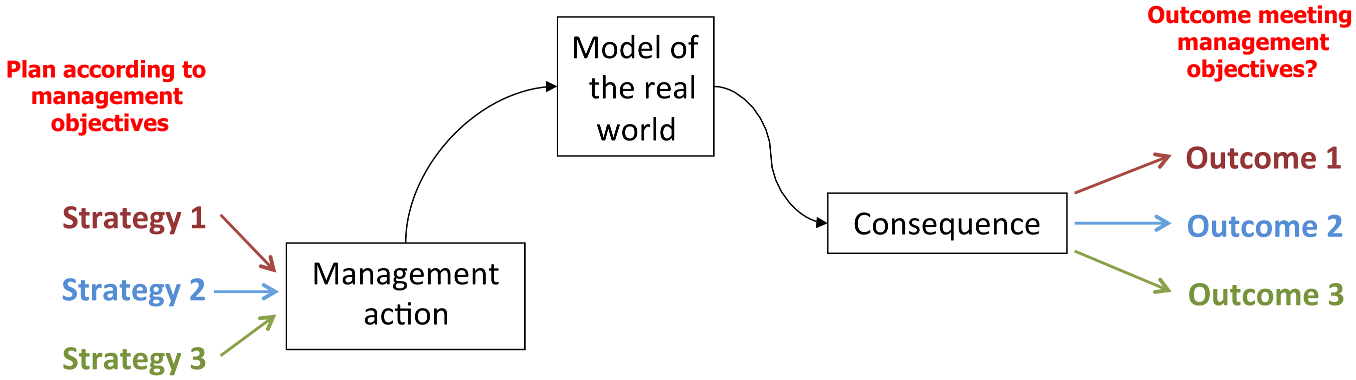
Projection - approach

2. Dynamic

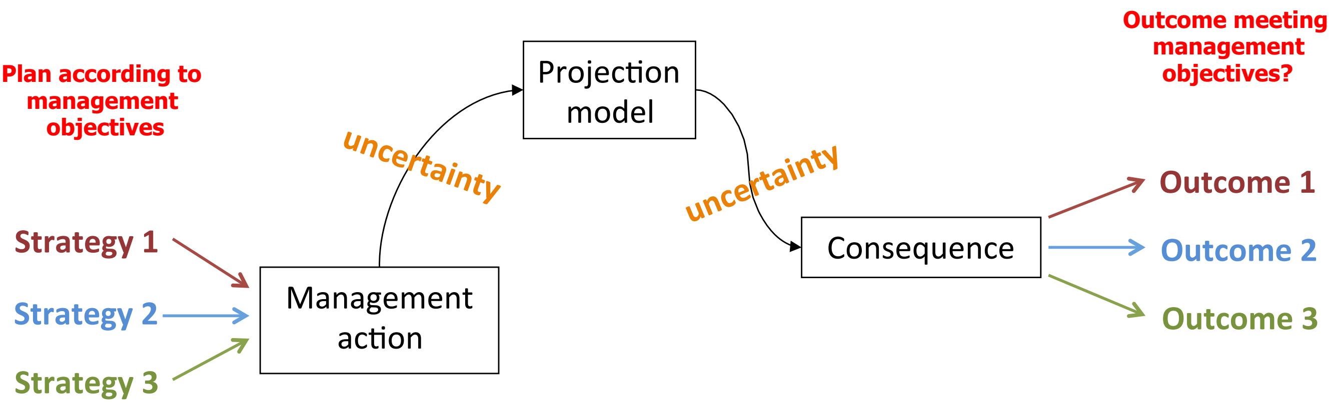


Structured decision making

- Science-based approach to making management decisions
- Projections are an excellent tool to compare and contrast the consequences from alternative potential management actions



Computer projections



<u>REPEAT each projection above many times</u> – each time a different plausible 'state of nature' is used for *uncertain processes* (arising from incomplete knowledge of the system) – to see which management strategy works best

e.g., future recruitment (some function of adult biomass?)

SPC use of MULTIFAN-CL projections

- Evaluate potential future consequences of current management decisions
- Compare and contrast different potential management options
- Assist with harvest management decision-making

Interpreting projections

Example 1 – CMM-2012-01

Run code[2]		Purse seine effort	Longline catch	Other effort	FAD closure	Comment
CMMa	101010102	New CMM	New CMM	2011	4 month FAD closure	Approximation of the draft measure (option a)
CMMb	101020102 (BY)	New CMM	New CMM minus 10% for 'large' fleets	2011	4 month FAD closure	Approximation of the draft measure (option b)
2011	102030101 (BY) 102010101 (S)	2011 effort	2011 catches	2011	3 month FAD closure	Approximation to the end of CMM2008-01

- 9-year projection for WCPFC9
- Relative to 2009 conditions

Species		F/Fmsy	$SB_{2012}/SB_{2012,F=0}$	$SB_{2018}/SB_{2018,F=0}$	$SPR_{2012}/SPR_{F=0}$	$SPR_{2018}/SPR_{F=0}$
Bigeye tuna	CMMa	1.33	0.25	0.24	0.21	0.24
	CMMb	1.30	0.25	0.25	0.21	0.24
	2011	1.38	0.25	0.23	0.21	0.22
Yellowfin tuna	CMMa	0.71	0.48	0.46	0.46	0.45
	CMMb	0.70	0.48	0.47	0.46	0.46
	2011	0.69	0.48	0.47	0.46	0.46
Skipjack tuna	CMMa	0.41	0.57	0.56	0.57	0.56
	CMMb					
	2011	0.42	0.57	0.55	0.57	0.54

(WCPFC9-2012-IP15 (Rev 1))

Interpreting projections

Example 2 – SP Albacore catch rate

- 10-year projection for WCPFC9
- Relative to 2010 conditions

(WCPFC9-2012-IP11)

LL	TROLL	LL Catch (2020)	TR Catch (2020)	SB/SBF0 (2020)	N_LL Catch rate (2020/2010)	S_LL Catch rate (2020/2010)	Troll Catch rate (2020/2010)	SB (2020/2010)
0.6	1	55,924	2,221	0.69	1.21	1.00	1.05	1.18
0.6	2	55,766	4,436	0.68	1.17	0.99	1.05	1.14
0.6	5	55,461	11,037	0.65	1.07	0.95	1.03	1.06
0.8	1	71,712	2,205	0.61	1.01	0.96	1.05	1.00
0.8	2	71,604	4,403	0.60	1.00	0.94	1.04	0.99
0.8	5	71,067	10,953	0.57	0.95	0.90	1.02	0.94
1	1	87,064	2,189	0.53	0.87	0.91	1.04	0.87
1	2	86,874	4,366	0.52	0.86	0.90	1.03	0.85
1	5	86,194	10,811	0.49	0.80	0.86	1.02	0.80
1.2	1	100,985	2,164	0.45	0.73	0.86	1.03	0.75
1.2	2	100,707	4,305	0.44	0.71	0.85	1.02	0.73
1.2	5	99,875	10,668	0.42	0.67	0.81	1.00	0.69
1.4	1	113,115	2,134	0.39	0.61	0.81	1.01	0.65
1.4	2	112,697	4,262	0.38	0.59	0.80	1.01	0.63
1.4	5	111,392	10,573	0.36	0.55	0.77	0.98	0.58

Summary

- Projections are a powerful tool for predicting future trends and population reaction to proposed management (i.e., prospective analyses)
- Open a pathway for the best available science to be incorporated into management decisions (e.g., structured decision-making)
- Some basic considerations when conducting projections:
  - type (deterministic or stochastic)
  - approach (static or dynamic)
  - time horizon
  - starting point
  - multiplier
- Fisheries science and management is fraught with uncertainty – advice stemming from scientific analyses that account for key sources of uncertainty will be more informative and robust on average

Understanding projections - exercises

- How to conceptually set up a projection to answer specific questions.
- How to evaluate alternative management options using TUMAS.

Supplementary material

- Using TUMAS -

What is TUMAS?

SPC CPS

- TUMAS is software that SPC has developed to support tuna fishery management through the WCPFC (and including SPC members).
- TUMAS enables its users to simulate what might happen to the size and health of the tuna stocks in the future, under different fishing conditions (e.g. different levels of increased or decreased fishing effort).
- As such, TUMAS is intended to assist the WCPFC, collectively, and its members, individually, to explore the possible benefits and costs of different potential management options

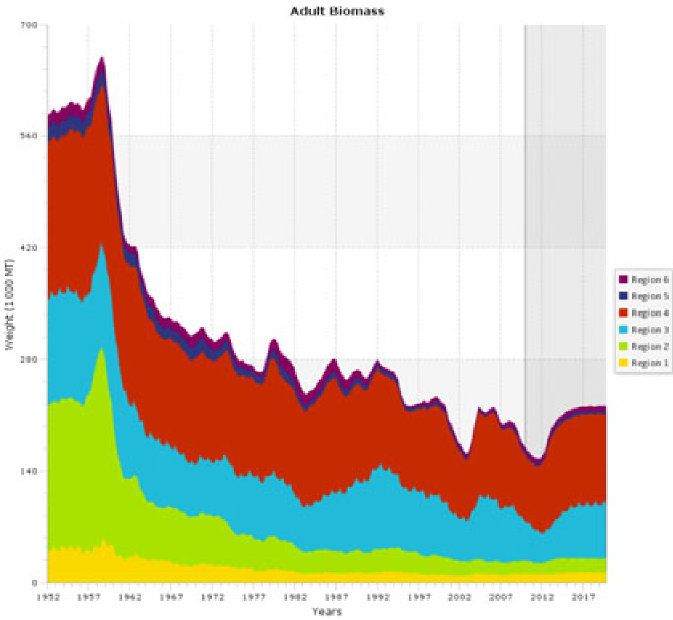
How does TUMAS "work"?

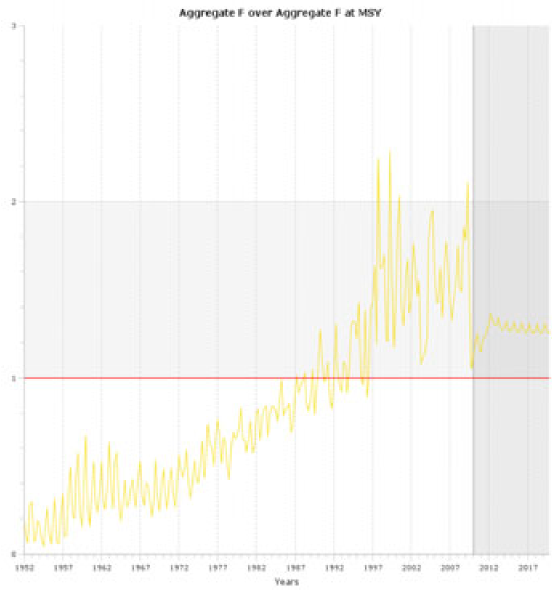
SPC CPS

- As you know, SPC scientists undertake stock assessments for the key tuna stocks in the WCPO using a modeling platform called MULTIFAN-CL. The outputs from these assessments provide an indication of the impact of past and current fishing upon the status (health) of the stocks.
- TUMAS is able to use the outputs from these assessments (e.g. MULTIFANs estimates of population biology, structure, fishery catchability and selectivity etc) to "project" forward into the future and predict/estimate what would happen to the status of the stocks if fishing effort in some/all fisheries was increased, decreased or remained the same.
- TUMAS provides the results of these predictions in a user friendly graphical format, showing how key parameters such as catches, biomass, and stock status might change over time.

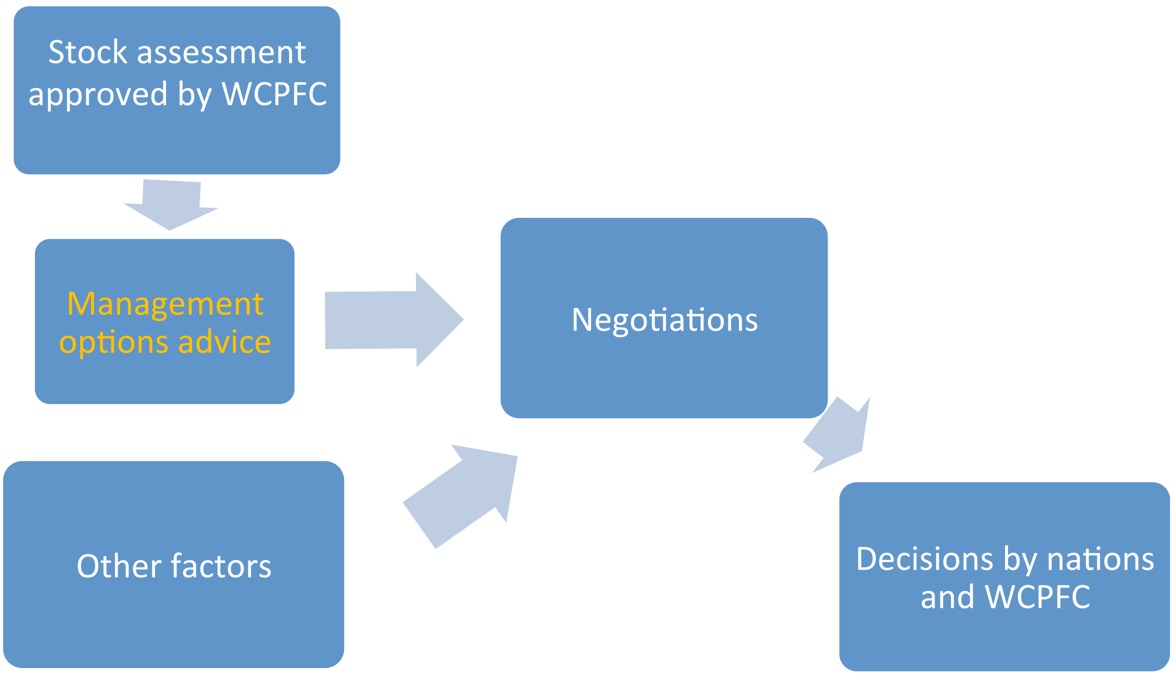
How does TUMAS "work"?

- TUMAS provides the results of these predictions in a user friendly graphical format, showing how key parameters such as catches, biomass, and stock status might change over time in response to different management actions.





How will it help fisheries managers?



How will it help fisheries managers?

- Until now, individual countries, sub-regional agencies (e.g. FFA, PNA) and the WCPFC itself have been dependant upon SPC scientists to run and present management options analyses at specific regional forums.
- Due to the highly varying nature of fisheries in different countries, such analyses may not always cover all the options that each country might wish to explore.
- Furthermore, understanding such analyses and why different options effect the stock and fishery in different ways is difficult for countries when they are quite removed from the analytical process
- This hinders the process of communication and negotiation between Commission members who ultimately must manage the tuna resources together and by consensus.

How will it help fisheries managers?

TUMAS represents a management tool which is:

- **Accessible**: You can run it on your computer
- **User friendly**: You don't need to be a scientist to use it (…although you do need some knowledge of stock assessment)

TUMAS should allow Commission members to:

- Explore and compare the results of different management options
  - What if longline effort decreases by 10%?
  - What if the region 3 FAD fishery closes for 3 months?*
  - How could these options affect stock status, your nation's interests, and other nations' interests?
- Improve within government and inter-government understanding via more informed communication and subsequently…
- Help fishery managers and advisers make decisions and negotiate with one another regarding how the fishery should be managed.

* once fully refined

How is it relevant to you specifically?

Despite the accessible and user friendly nature of the TUMAS software, the subject matter that it deals with (fishing impacts upon tuna stocks) still requires that the user has a good understanding of the basic principles of stock assessment, particularly as relates to tuna stocks in the WCPO.

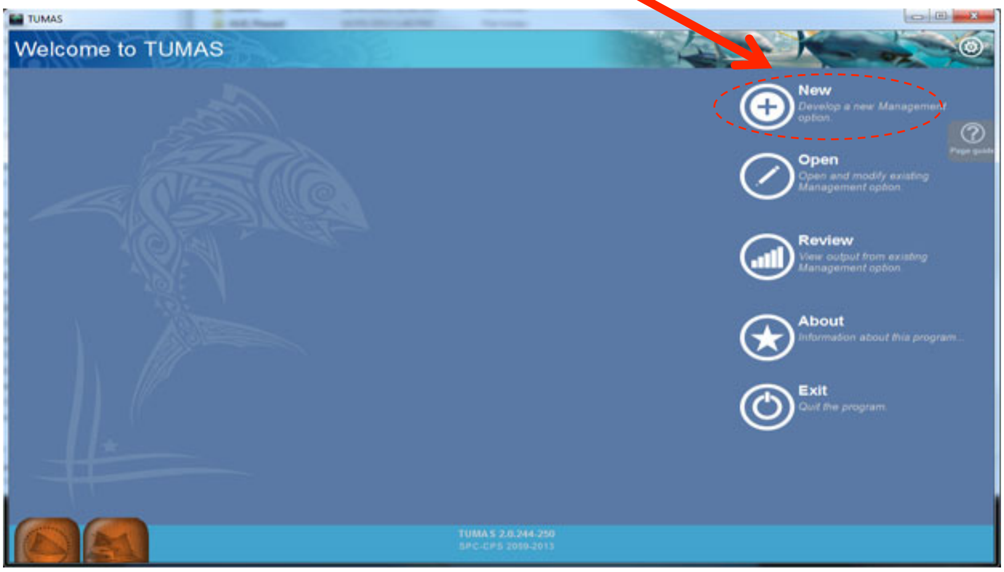
A fishery manager or policy maker with little understanding of stock assessment and reference points will struggle to use the software and correctly interpret its outputs, without the advice of someone who does hold such knowledge. There is significant risk to the achievement of management objectives when such key issues are misunderstood.

The purpose of this workshop is to help you to become your countries own “expert” in the use of TUMAS, so that, along with SPC scientists, you become an additional resource and technical advisor for your government when it wishes to explore and understand the potential risks and benefits of different management options that it or the Commission might consider imposing upon the fishery in future.

TUMAS in action: an example

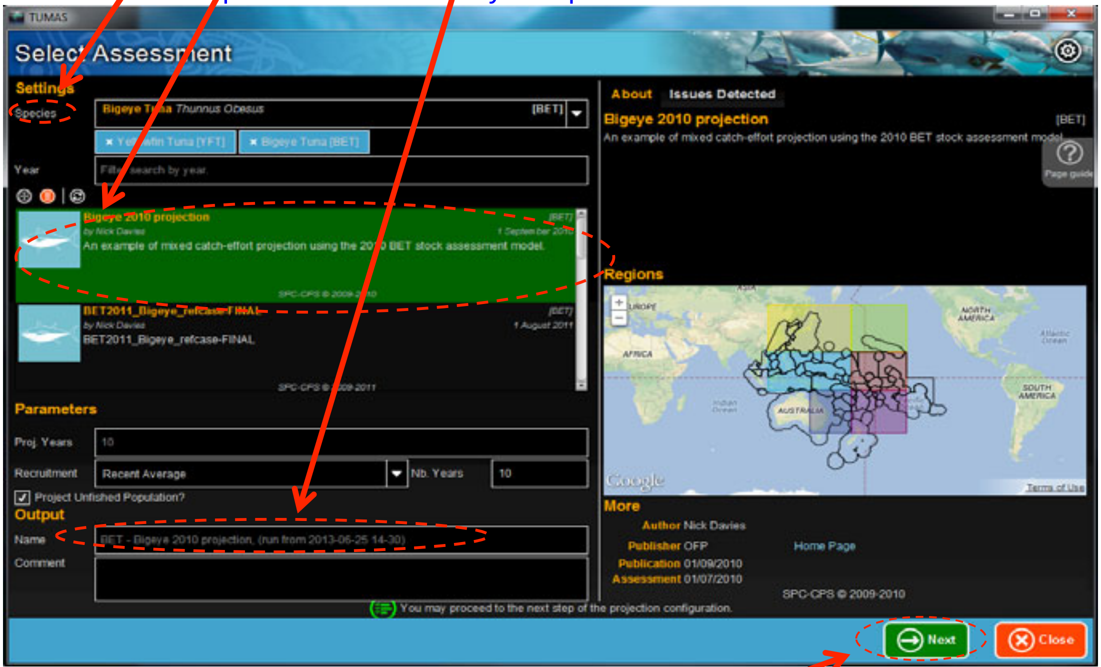
Please refer to your TUMAS manual for a more detailed understanding of how to use TUMAS. This **example** shows you how to define a management option with TUMAS, use MULTIFAN-CL to project the population forward under this management option, and review the resulting output.

1. Open TUMAS, and wait until the 'Welcome to TUMAS' screen appears.
2. Select 'New' and then select ‘Projections with Multifan-CL’ and select ‘Next’.



TUMAS in action: an example

3. Select a species (Bigeye in this case) from the drop-down “Species” list and select the assessment model year to use. Leave all the Parameters settings at their default values.
4. Type in a new output name (file identifier) for your management option. This will be saved and the outputs associated with your option can be viewed at later dates.

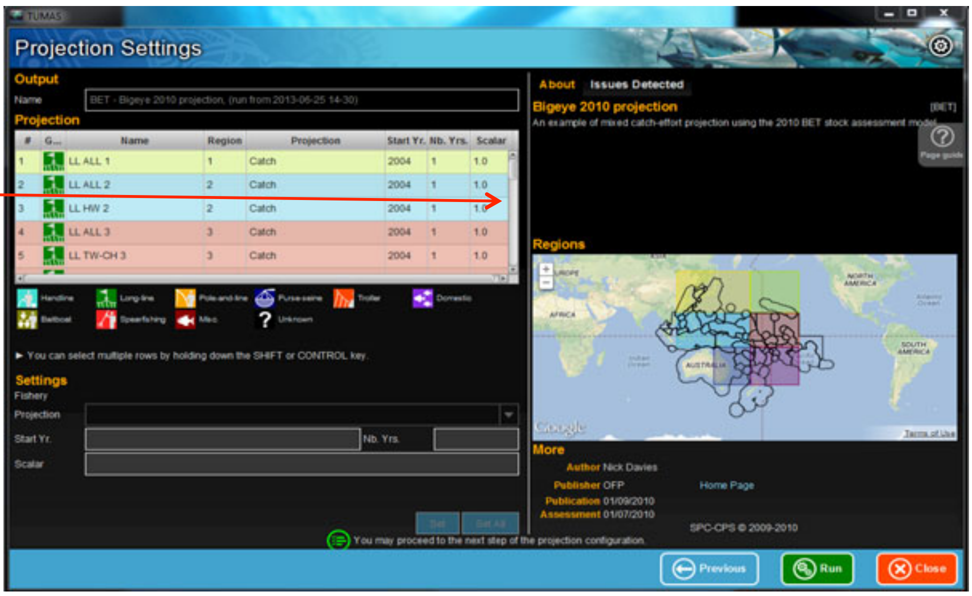


5. Select 'Next' to move to the 'Projection Settings' screen.

TUMAS in action: an example

5. The 'Projection Settings' screen lists the defined bigeye fisheries on the left and shows a map of the regions in the bigeye stock assessment on the right

Note the scroll bar…..there are in fact 26 fisheries, with these being the same fisheries defined in the bigeye tuna stock assessment paper.

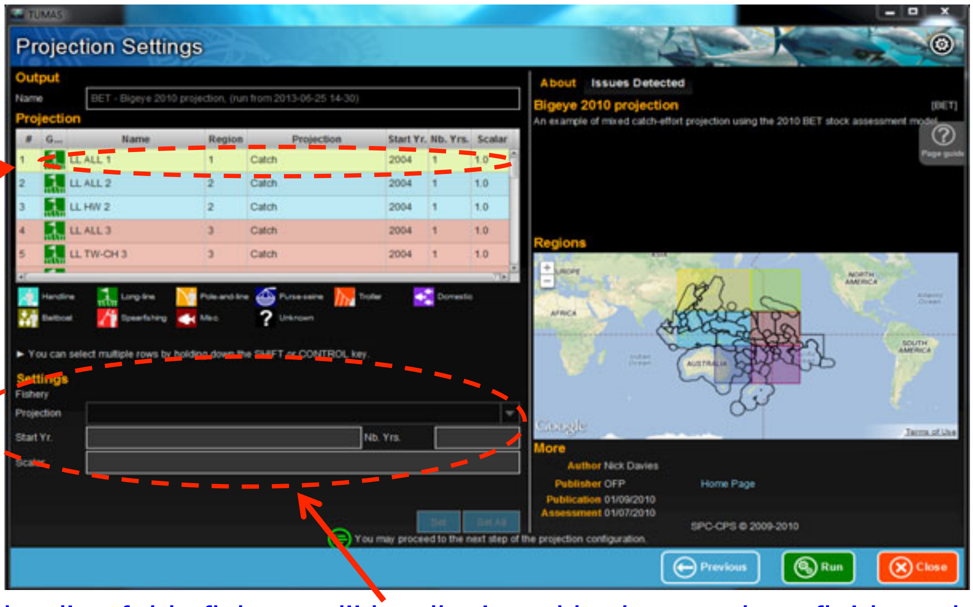


6. Your task here is to define the management option by defining future effort and/or catch for each fishery.

TUMAS in action: an example

7. In this example, you will reduce effort in all fisheries to 20% below the average level from 2006-2008. To do this, use your mouse to select one of the fisheries (any one will do).

Here, fishery #1 has been selected



The details of this fishery will be displayed in data settings fields at the bottom of the page on the left. You can modify the entries in these fields.

TUMAS in action: an example

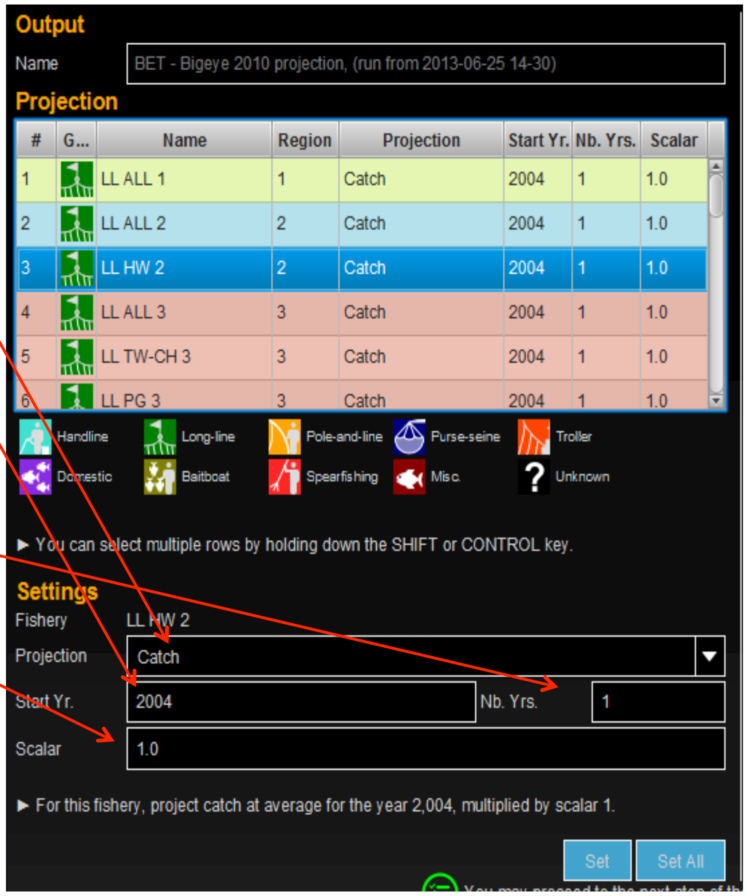
The options presented in the data entry fields are:

Type: this is the type of data which you wish to modify in the "future" fishery, with the options being **catch** or **effort**

Start Yr: this is the start year of the period for which average fishery and population parameters (e.g. fishing mortality etc) will be derived for use in the model projections**.** **Note that this is **NOT** the start year of the projection itself

N Years: this is the number of years (from the start year) over which average fishery and population parameters (e.g. fishing mortality etc) will be calculated for use in the model projections.

Scalar: This is used to increase or decrease the projected fishing effort or catch by the amount you desire. So if you wish to decrease future fishing effort to 80% of the mean level specified in the "N years" period, type in a scalar of 0.8. If you wish to increase future fishing effort to 150% of current levels, type in 1.5.



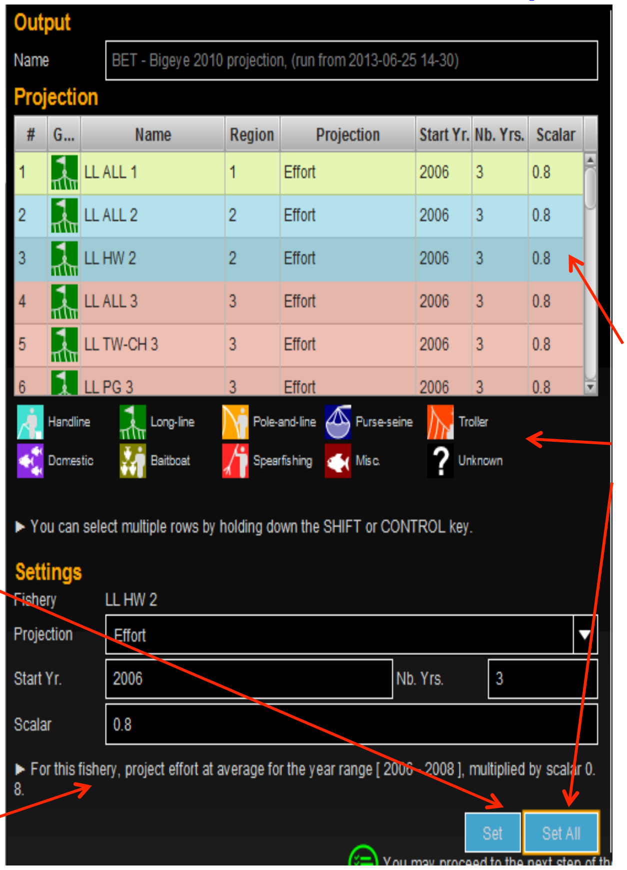
TUMAS in action: an example

9. In this example we change:
   a. **Type** to "Effort"
   b. **Start Yr** to 2006
   c. **N Years** to 3 (representing 2006-2008)
   d. **Scalar** to 0.8 (representing a 20% drop in fishing effort)

If we wanted to only apply this change to the selected fishery, we'd then press "Set"

But because we want to apply these changes to all the fisheries* (#1-25), we click on "Set all".

TUMAS also adds a comment to describe the options chosen

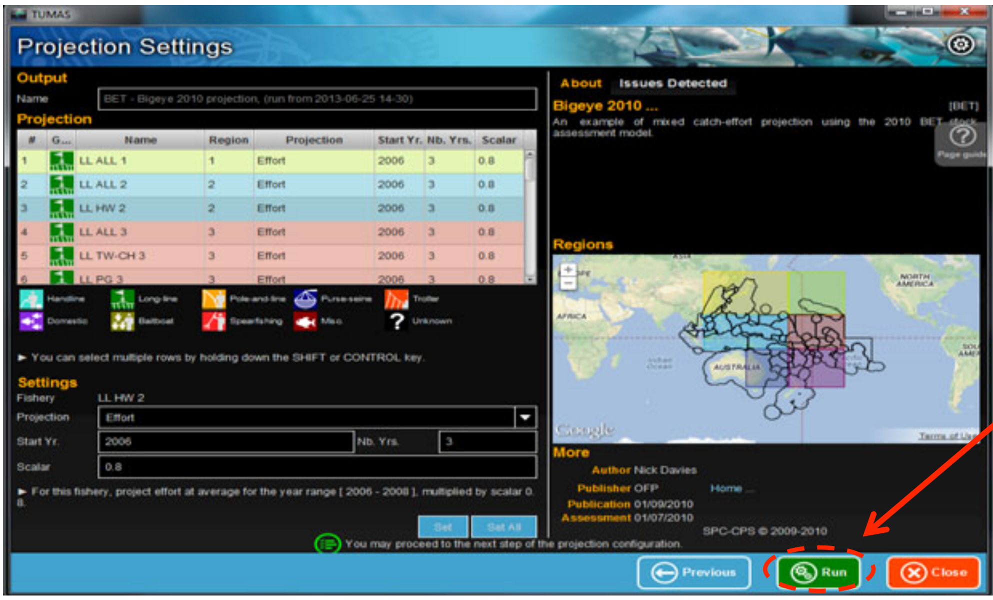


Once changes are made in the data selection fields below for one fishery, they can be applied to all fisheries

Note that not all fisheries are able to be modified at all, while some can only have a different scalar applied but not have differing base years

TUMAS in action: an example

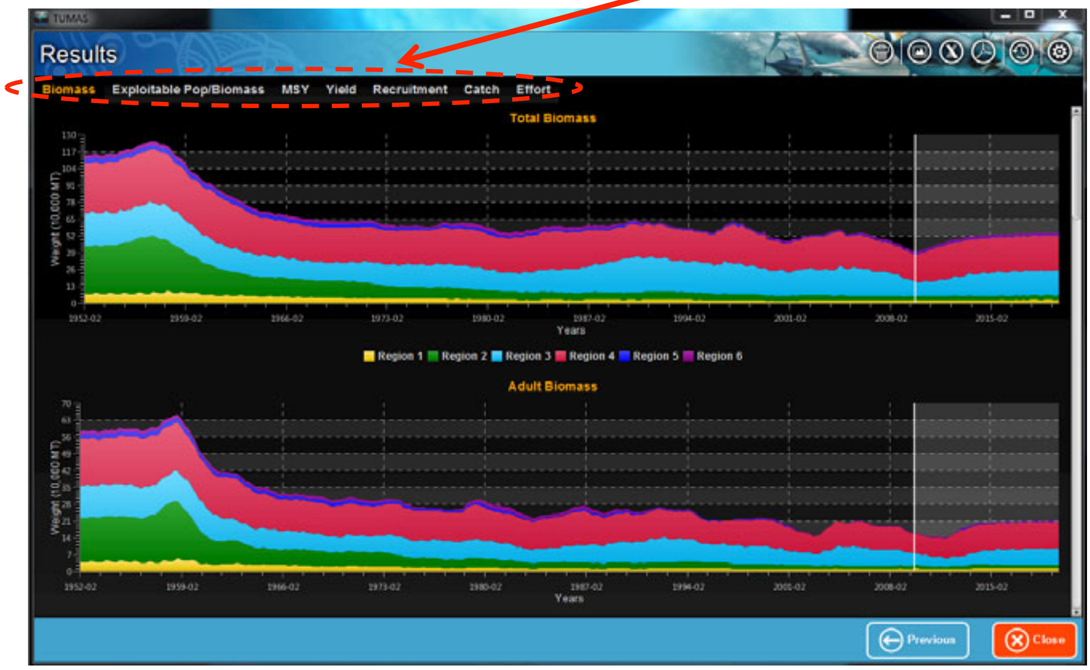
10. Now click on "Run" (bottom right corner) of the Projection Settings screen and please wait while TUMAS uses MULTIFAN-CL to run the projection of your management options.



While TUMAS is calculating the projection, various MULTIFAN-CL numeric and text outputs will appear on screen. You can ignore these and wait until the graphical outputs screen appears.

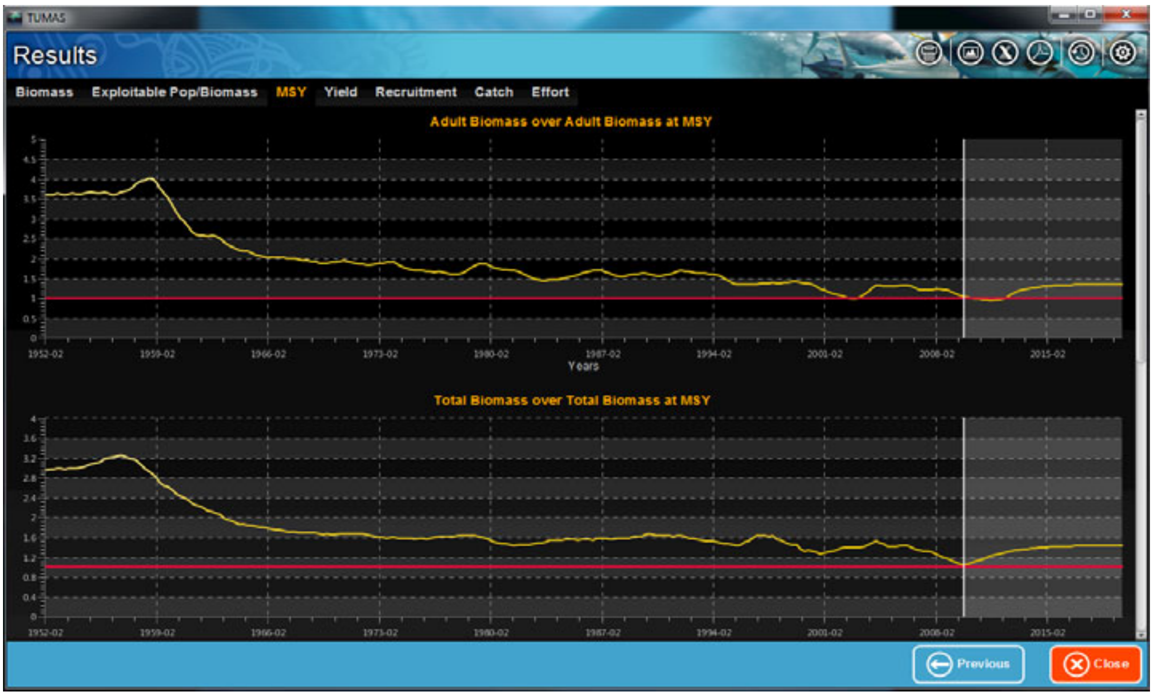
TUMAS in action: an example

This is the first graphical outputs screen to open. It shows total and adult biomass, both in the past, and as predicted to occur in future (grey shaded years on right hand of plot) in response to your specified management option (reduced fishing effort). However, other key outputs can be viewed by selecting them from the drop down menu at the top of screen.



TUMAS in action: an example

Here we have selected plots of the MSY based reference points used by the WCPFC, showing how these have changed in response to past fishing impacts and how they are predicted to change in future in response to your management option.



TUMAS in action: an example

There are a number of other outputs which can be viewed from the drop down menu including:

- Exploitable biomass by fishery
- Equilibrium yield
- Recruitment (which is currently fixed at average levels defined in the base period)*
- Catch by fishery
- Fishing effort by fishery

Other outputs may be added in future.

You can create multiple different management options analyses simply by selecting "New" and typing in a new file name each time you want to run a different analysis.

These analyses are automatically saved by TUMAS when you click on "Close" after you have finished (there is no "Save" button)

When you want to view outputs from a past analysis, click on "**Review**" in the "Welcome to TUMAS" screen. If you want to modify a past analysis, click on "**Open**" in the "Welcome to TUMAS" screen. In both cases you are presented with a list of all past analyses from which you can select the one you wish to view or modify.

Status and plans

- Funded by the PFRP and SPC
- New releases occur periodically
  - Bigeye, yellowfin, skipjack assessments
  - Development started January 2010
  - Developed by Fabrice Bouyé of SPC
  - Project led by Simon Hoyle and Shelton Harley
- Further work planned
  - More plots – Kobe plots, fish size information
  - More species – albacore
  - New management options – spatial closures, time-varying management
  - Web-based updates

Seeking input to improve TUMAS

- How can we make this more useful for you?
- What kinds of information about management outcomes do you need?
  - Figures?
  - Tables?
  - Management options?
- How can we improve the user interface?

How to get it

- www.tumas-project.org
- Download and run
- User manual also available to download
- Requirements
  - Your PC needs at least 1.2GB of RAM to run MULTIFAN-CL
  - You need administrative rights on your computer

Chapter 14

What are (some of) the implications of the assessment for your national fisheries?

Introduction

The WCPO region comprises many different countries and territories, all of whom have direct or indirect fisheries based economic interests in the regions tuna resources.

The species of most economic or social importance varies between countries/territories. For any given species, some countries will have significant economic reliance upon the fishery catching that species, and others very little etc. Some have significant reliance on revenue or food derived from fisheries targeting multiple species.

Hence, the national level implications of any given assessment will differ depending on the species and between countries.

Introduction

Determining the implications of a given assessment for a given country will depend initially on the following:

A) The outcomes of the assessment (resource status and scientific advice in response to that)

B) Your countries contribution to overall fishing impacts

C) Your countries economic, social or food security dependence on the resource being assessed**

D) The management options being considered in response to the assessment outcomes – which of these options might impact on the fishery operating in your EEZ (domestic, foreign) or your flagged vessels operating outside the EEZ? Will they impact on food security or employment?

Introduction

The role of science is to help you understand the impacts on catch, effort, catch rates, sizes of fish caught, now and in the long term......but the flow on social and economic impacts are best assessed by those with knowledge and expertise in those areas (often the fishers, managers, economists) in consultation with the stakeholders, and not by scientists.

The following slides outline a series of steps which might help you to assess the implications of an assessment for your fisheries.

1. Where is your fishery located?
2. How much catch is taken in that region

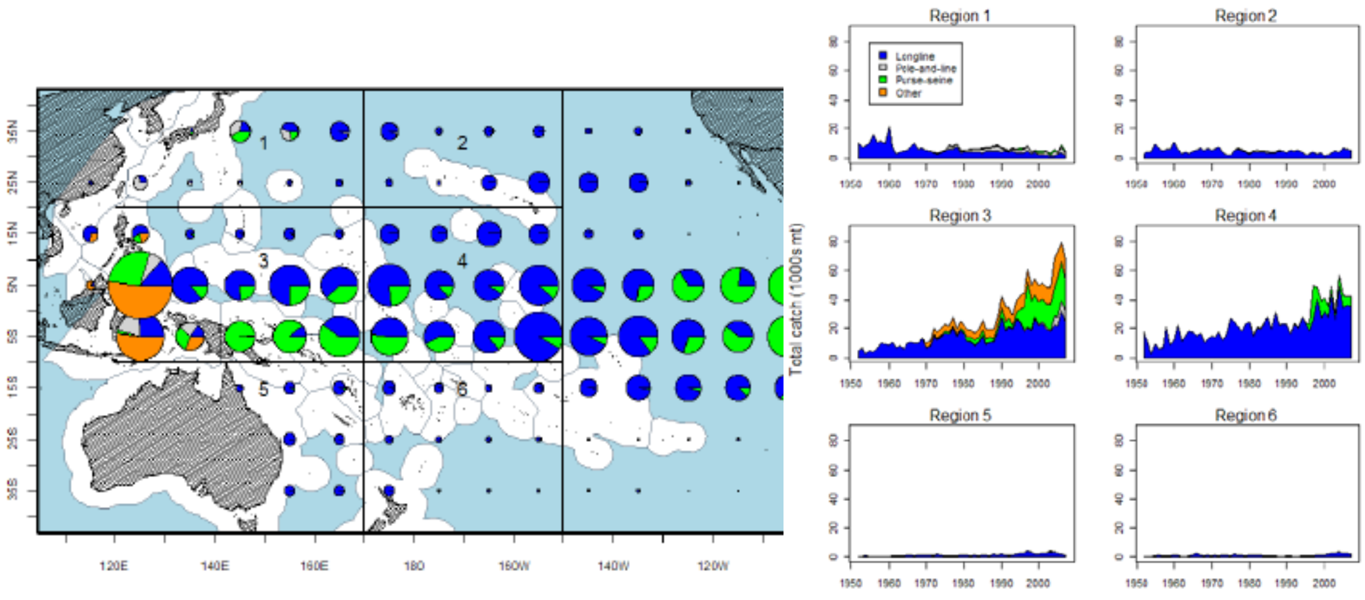


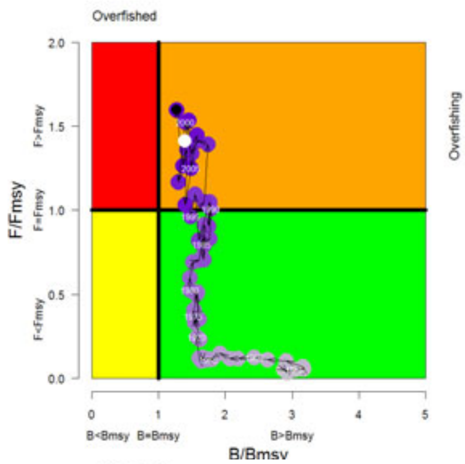
Figure 4. Total annual catch (1000s mt) of bigeye tuna by fishing method and MFCL region from 1952 to 20

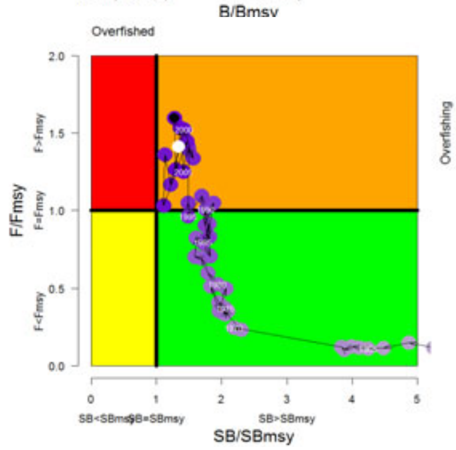
2. What is the status of the resource?

<u>SC-6 Conclusions</u>
The base model indicates that overfishing is occurring for the WCPO bigeye tuna stock but the stock is not in an overfished state.

<u>SC-6 recommendation</u>: A minimum 29% reduction in fishing mortality from average 2005-2008 levels is required to maintain the bigeye stock at levels capable of producing MSY.

SC6 reiterated that the intended 30% reduction in fishing mortality intended under the current Conservation and Management Measure is extremely unlikely to be achieved by that measure.





Country contributions to impacts

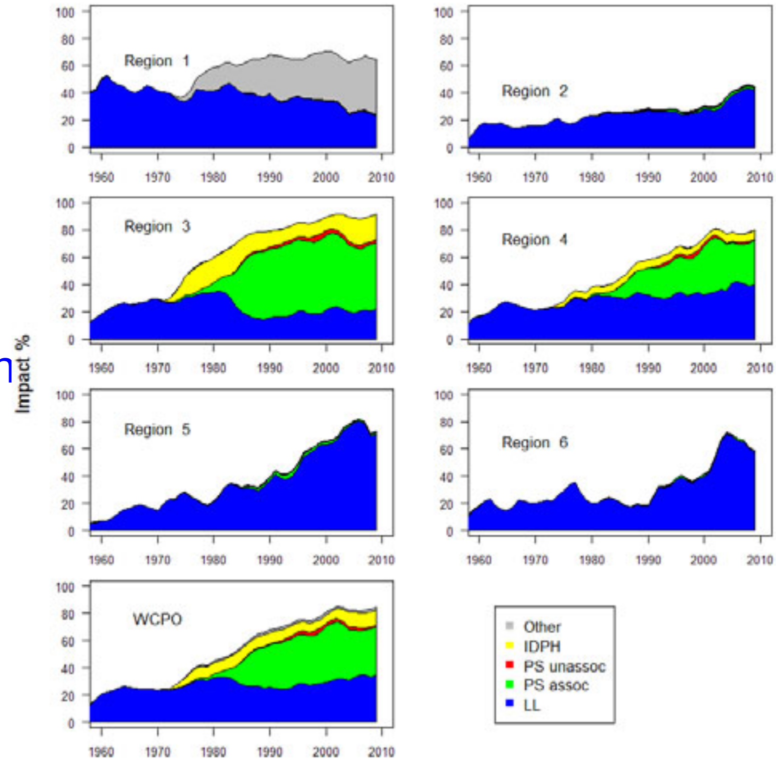
Look at the region in which your country is situated, and consider the following:

A. Is a large portion of the stock located there?

B. Are there high impacts on the regional biomass?

C. What proportion of your regions catch is taken by your fishery?

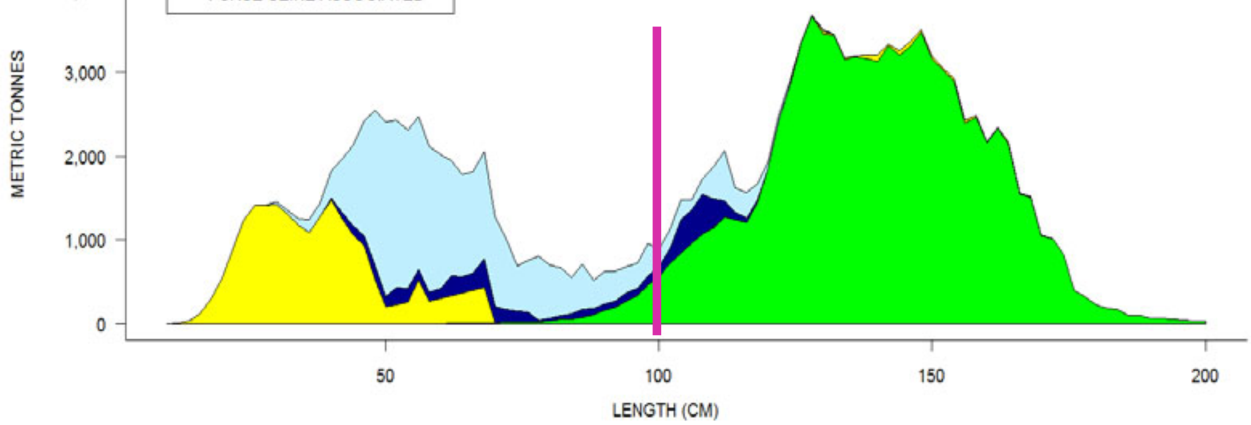
D. What proportion of the WCPO catch is taken by your fishery



Country contributions to impacts

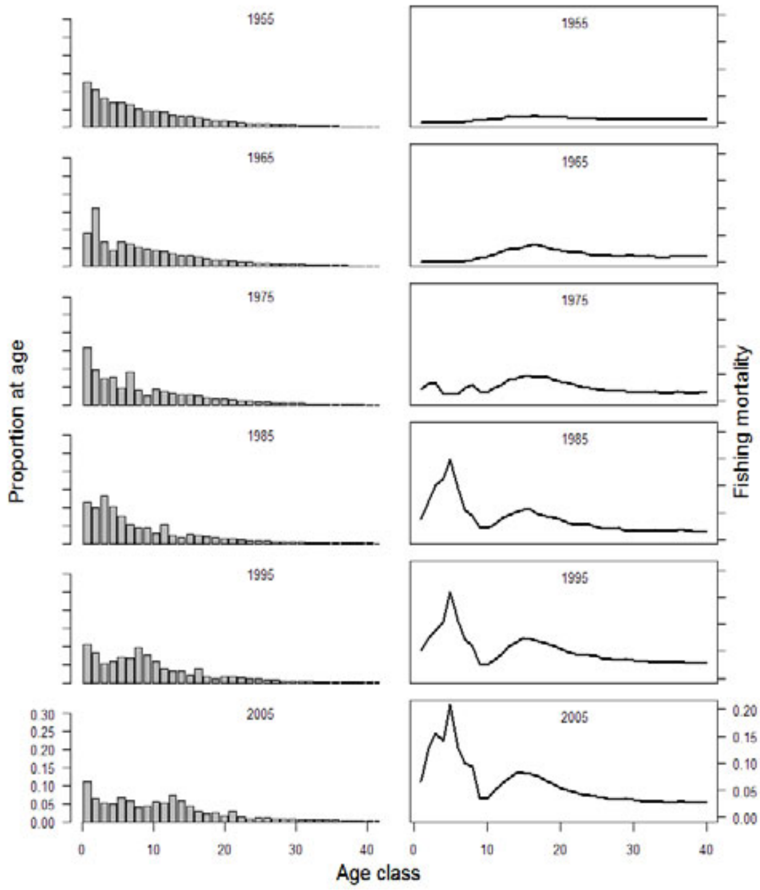
- Which gears is your fishery based on and to which component (age classes) will your fishery contribute the highest impacts?

<u>Age at start of maturity</u>
Females 50% mature at 102cm (2 yrs) (Farley et al 2006) at ~ 3+ years of age



Country contributions to impacts

- Which gears is your fishery based on and to which component (age classes) will your fishery contribute the highest impacts?

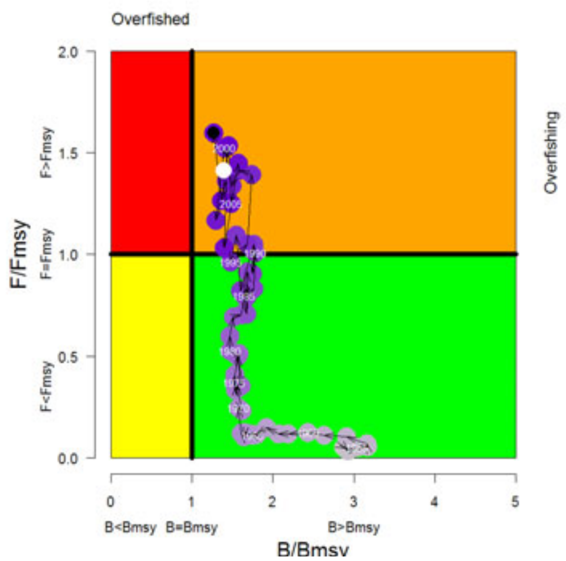


Resource Status

So… do management recommendations relate directly to your region, your fishery, the gears operating within your fishery and the age classes being impacted most by your fishery?

Is the sustainability of the resource being assessed of importance to your fishery/country ?

If the species is not important to your fishery or country, might the management actions effect your fishery anyway (as a byproduct)…e.g BET and SKJ



Management options implications

The key implications of an assessment become more apparent through consideration of the management options being considered in response to assessment outcomes:

Is your countries food security dependant upon the sustainability of the stock?

Is the fishery a major employer?

Does the fishery generate significant national revenue (e.g. licence fees)

Therefore long-term sustainability may mean longterm employment base, food security and national revenue....or it may not.

Management options implications

Are the management measures currently in place likely to achieve their objective?

All of these questions are questions you might want to consider when reviewing the results of a regional tuna stock assessment paper and associated management options analyses.

Chapter 15

Stock Assessment of Yellowfin Tuna in the Western and Central Pacific Ocean

Nick Davies[2], Shelton Harley[1], John Hampton[1], and Sam McKechnie[1]

WCPFC-SC10-2014/SA-WP-04

[1] Oceanic Fisheries Programme, Secretariat of the Pacific Community
[2] Consultant, Secretariat of the Pacific Community

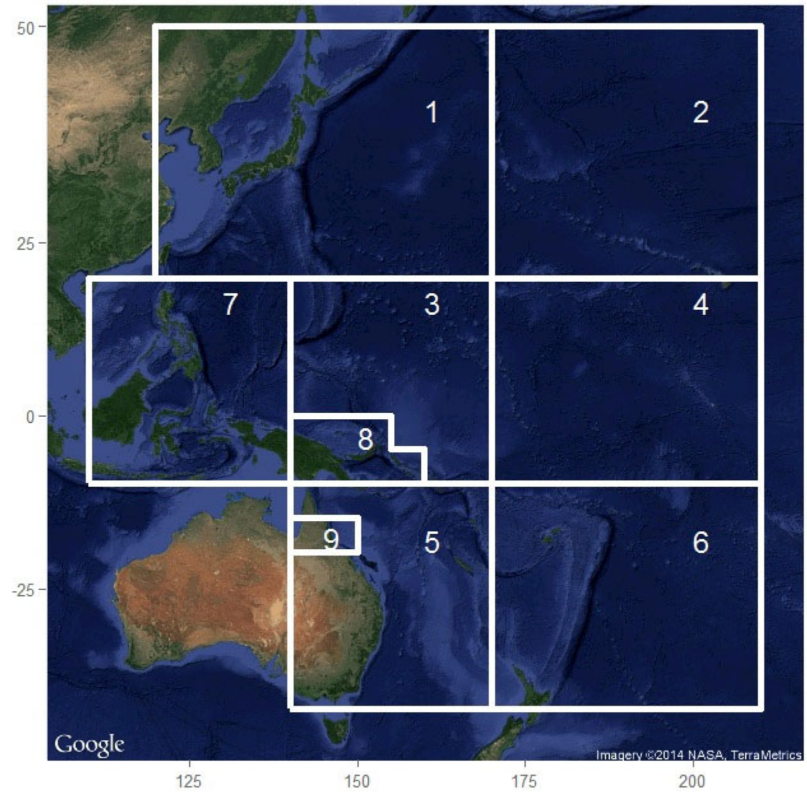
Overview

- Developments from 2011 assessments
- Main data inputs
- Stepwise model runs to achieve 2014 reference case
- 2014 reference case
  - One-off sensitivities to the reference case
- Stock status and conclusions

Major changes

Component	2011 assessment (LLcpueOP_TWcpueR6_PTTP)	2014 assessment (Ref.Case)
Regional structure	Six regions	Nine regions with two new regions added to the western equatorial region and one to the south western region.
Fishery structure	25 fisheries	33 fisheries and the first inclusion of some Japanese and Vietnamese coastal fishery catches
Longline CPUE	Operational indices based on Japanese logsheet data.	Operational CPUE indices based on either Japanese logsheet data, or all operational data (combined flags) available to SPC.
Longline size data	All available data. Japanese data spatially weighted by CPUE	Either weight or length used for fisheries depending on quality and coverage. Japan data weighted spatially by catch and all fleets data for some fisheries.
Purse seine size data	Selectivity bias corrected observer samples	Selectivity bias corrected observer samples plus Pago Pago port sampling data. All weighted by set catch.
Recruitment and spawner recruitment relationship	All deviates estimated and moderate constraint on fitting the SRR curve	Terminal four recruitment deviates not estimated and these and the first 56 recruitment deviates (first 14 years) not included in the estimation of the SRR. Lognormal bias correction applied to the SRR and low penalty on fitting the SRR.

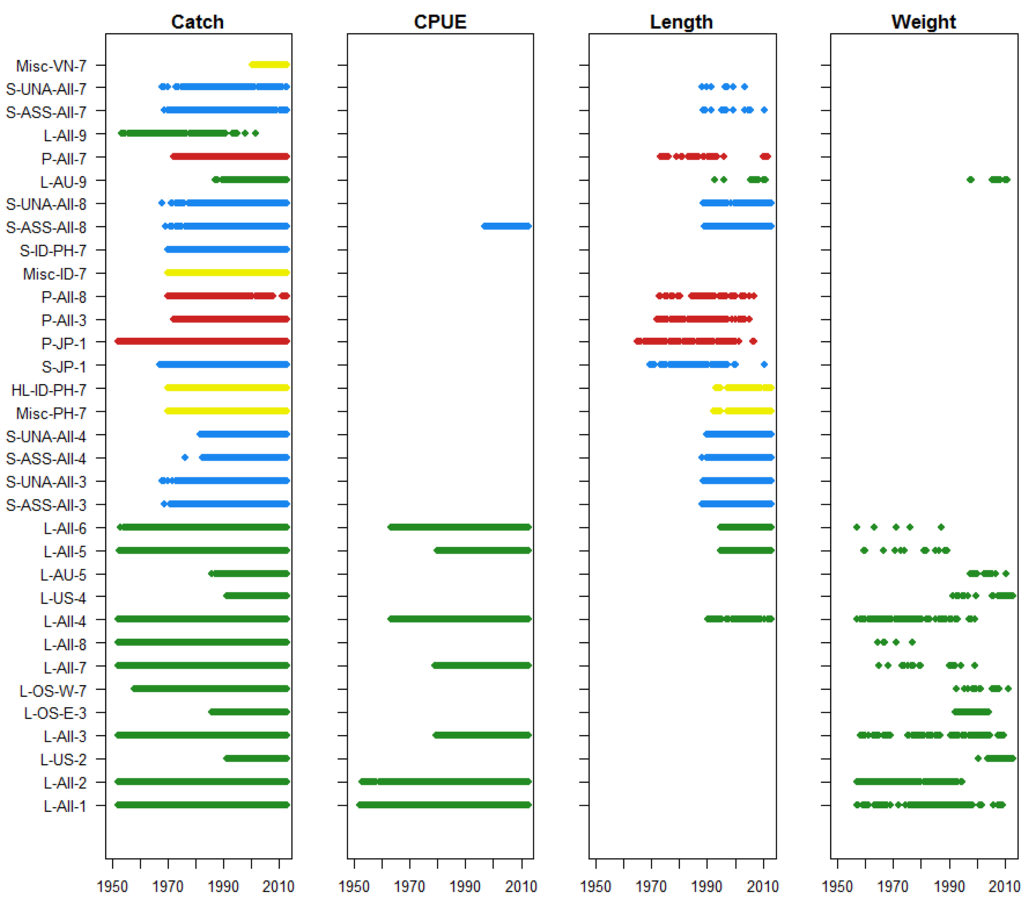
2014 Model Regions



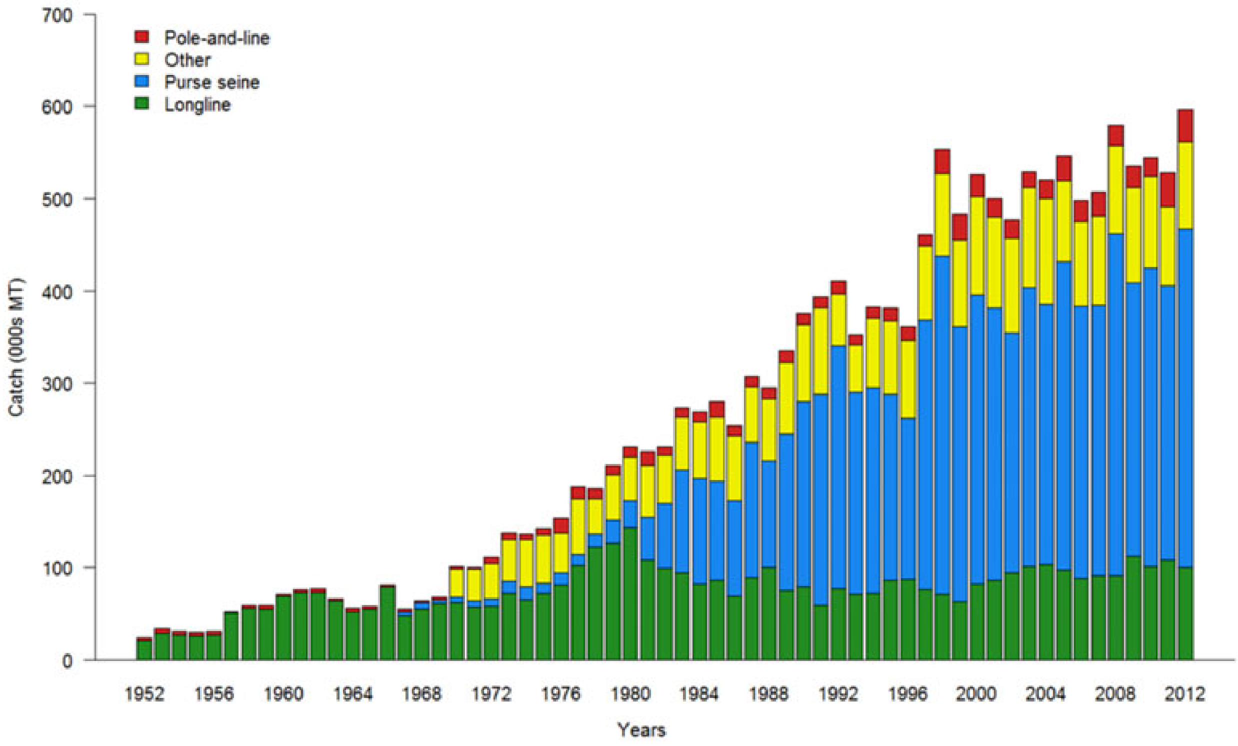
2014 Fisheries Definitions

Fishery	Nationality	Gear	Regi
1. L ALL 1	All	Longline	1
2. L ALL 2	All, except US	Longline	2
3. L US 2	United States	Longline	2
4. L All 3	All, except CT-Offshore, CN, FSM, MH, PH, ID, and PW	Longline	3
5. L OS-E 3	Eastern LL region 3: CT-Offshore, CN, FSM, MH, PH, PW, and ID	Longline	3
6. L OS-W 7	Western LL region 7: CT-Offshore, CN, FSM, MH, PH, PW, VN, and ID	Longline	7
7. L All 7	All, except CT-Offshore, CN, FSM, MH, PH, ID, and PW	Longline	7
8. L All 8	All	Longline	8
9. L All 4	All, except US	Longline	4
10. L US 4	United States	Longline	4
11. L AU 5	Australia	Longline	5
12. L All 5	All excl. Australia	Longline	5
13. L All 6	All	Longline	6
14. S-ASS All 3	All, except ID and PH dom	Purse seine, log/FAD sets	3
15. S-UNS All 3	All, except ID and PH dom	Purse seine, school sets	3
16. S-ASS All 4	All	Purse seine, log/FAD sets	4
17. S-UNS All 4	All	Purse seine, school sets	4
18. Misc PH 7	Philippines	Miscellaneous (small fish), including purse seine within PH archipelagic waters.	7
19. HL ID-PH 7	Philippines, Indonesia	Handline (large fish)	7
20. S JP 1	Japan	Purse seine, all sets	1
21. P JP 1	Japan	Pole-and-line	1
22. P All 3	All, except Indonesia	Pole-and-line	3
23. P All 8	All	Pole-and-line	8
24. Misc ID 7	Indonesia	Miscellaneous (small fish), including purse seine within ID archipelagic waters.	7
25. S PHID 7	Philippines and Indonesia	Offshore purse seine in waters east of about 125°E (and outside of PH and ID archipelagic waters).	7
26. S-ASS All 8	All	Purse seine, log/FAD sets	8
27. S-UNS All 8	All	Purse seine, school sets	8
28. L AU 9	Australia	Longline	9
29. P All 7	All	Pole-and-line	7
30. L All 9	All	Longline	9
31. S-ASS All 7	All, except ID and PH dom	Purse seine, log/FAD sets	7
32. S-UNS All 7	All, except ID and PH dom	Purse seine, school sets	7
33. Misc VN 7	VN	Miscellaneous including purse seine and gillnet within VN waters	7

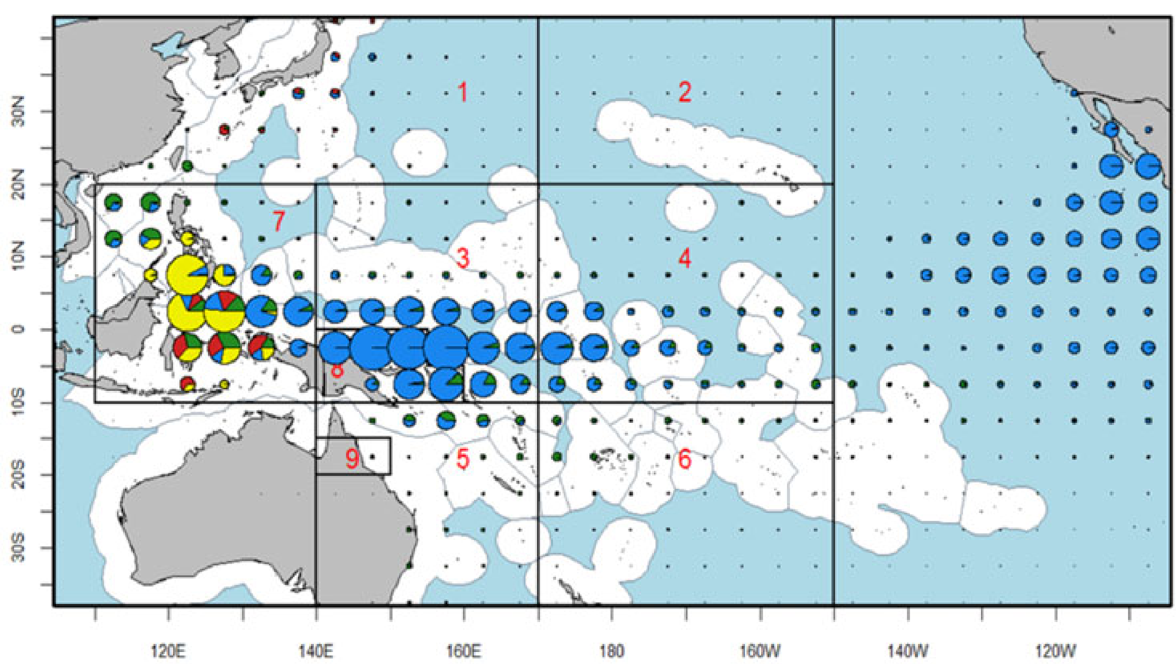
2014 Data availability



Total catches

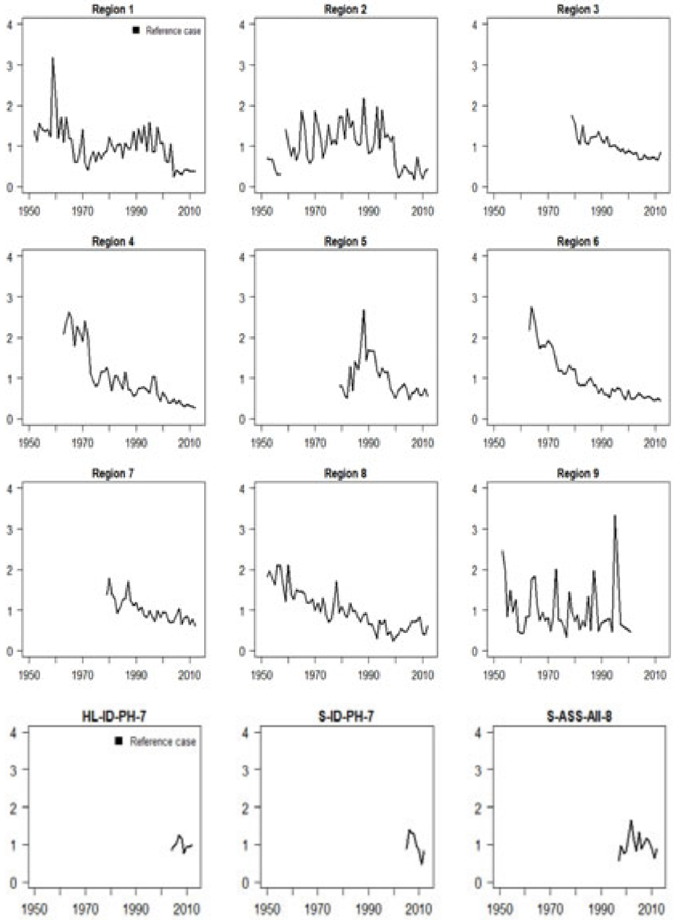


Catch distribution



Standardized CPUE indices

SPC CPS

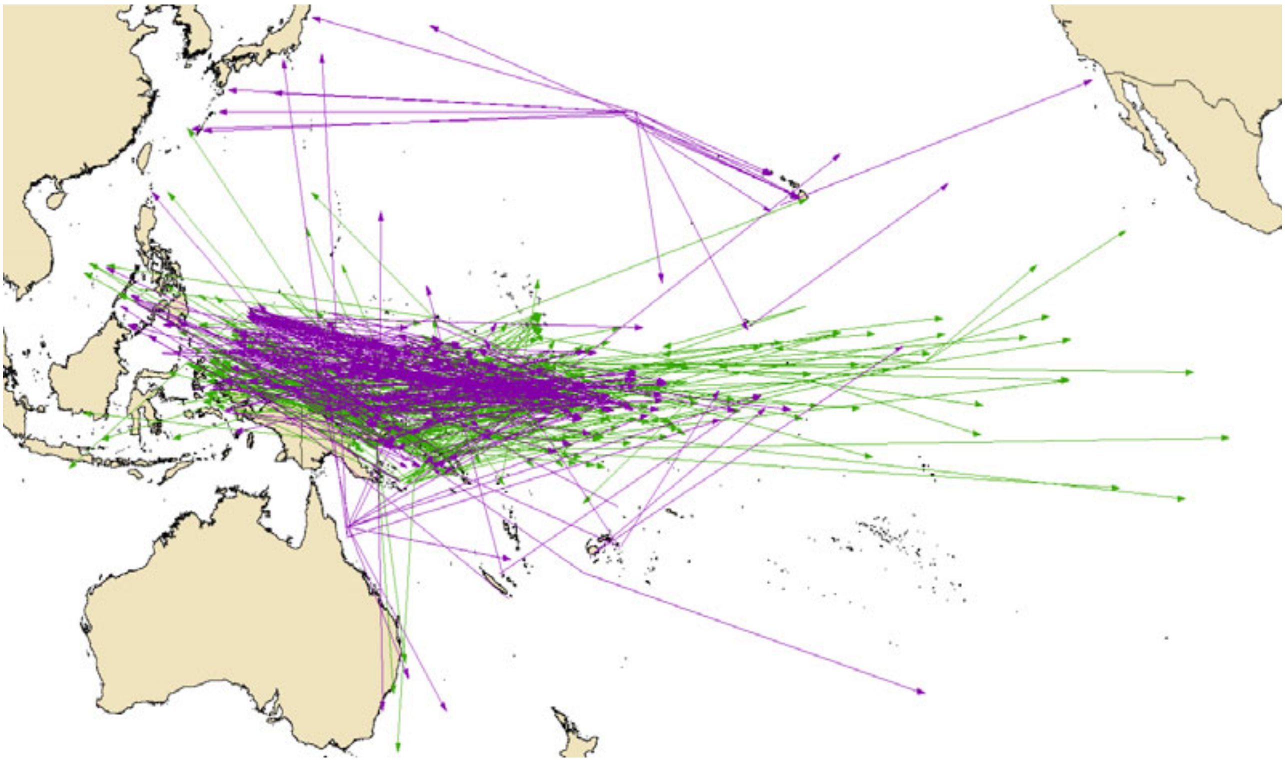


Tagging Data

SPC CPS

Programme		Region							Total
		3	4	5	6	7	8	9	
Coral Sea	n. groups	-	-	2	1	1	1	3	8
1991-1995	n. release	-	-	578.1	30.8	3086.1	173.1	2567.4	6435.6
	n. recaps	-	-	4	-	952	22	66	1044
PTTP	n. groups	11	6	5	-	3	15	-	40
2005-2012	n. release	5202.7	1649.0	3143.8	-	6184.7	36274.8	-	52455.0
	n. recaps	1023	335	460	-	1396	10293	-	13507
RTTP	n. groups	7	5	2	2	6	8	-	30
1989-1992	n. release	2259.1	1840.6	869.7	656.7	7687.1	10377.6	-	23690.8
	n. recaps	232	177	19	7	1414	721	-	2570

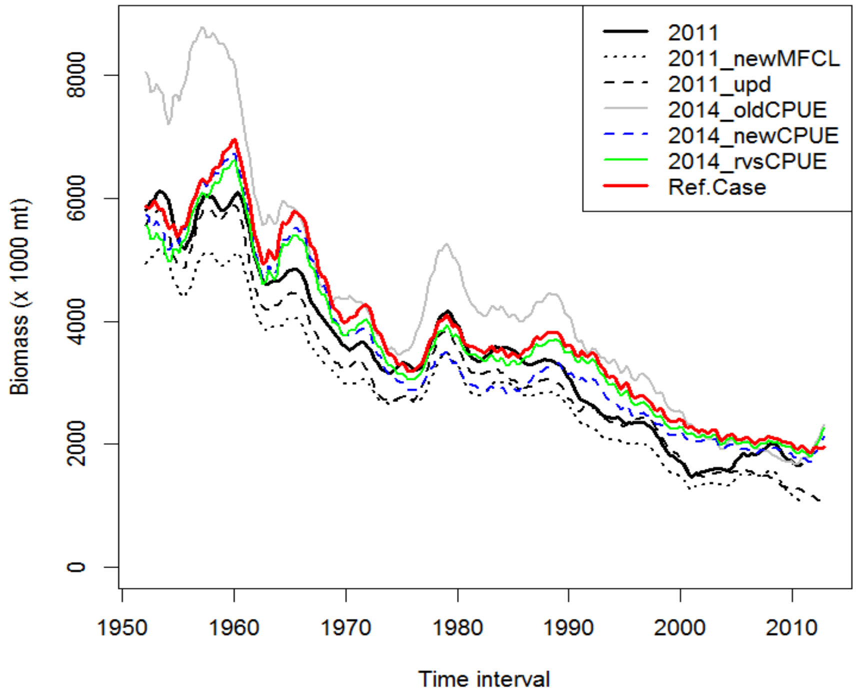
Tagging movement



Stepwise model runs to achieve 2014 reference case

Run	Description
2011	2011 reference case: Japanese longline operational CPUE for regions 1-5, Taiwanese CPUE for region 6, size data weighting n/20, corrected purse seine catch estimates, steepness = 0.8, excludes Japanese tag data.
2011_newMFCL	As above: re-fitted using latest MULTIFAN-CL
2011_upd	As above: input data updated to 2012, Japanese LL CPUE spliced with indices from aggregate data for 2011-12, revised estimates of the tag reporting rate priors, tag releases scaled for initial mortality.
2014_oldCPUE	Revised model structure and fisheries definitions (9 regions, 33 fisheries). Input updated CPUE data from model **2011_upd**, but applied the region 3 Japanese spliced operational CPUE indices to regions 7, and 8. Changes to selectivity and reporting rate groupings as appropriate. Longline size data rescaled relative to catch.
2014_newCPUE	As above, but with longline standardised CPUE from operational level data for all fleets.
2014_rvsCPUE	As above, but exclude CPUE indices from the fit for fisheries LL ALL 8 and PH HL 7, revised settings for effort deviates and catchabilities, and restricted the BH-SRR fit to a subset of the model period.
Ref.Case	As above, but exclude estimation of terminal recruitment deviates in 2012.

Stepwise model runs to achieve 2014 reference case

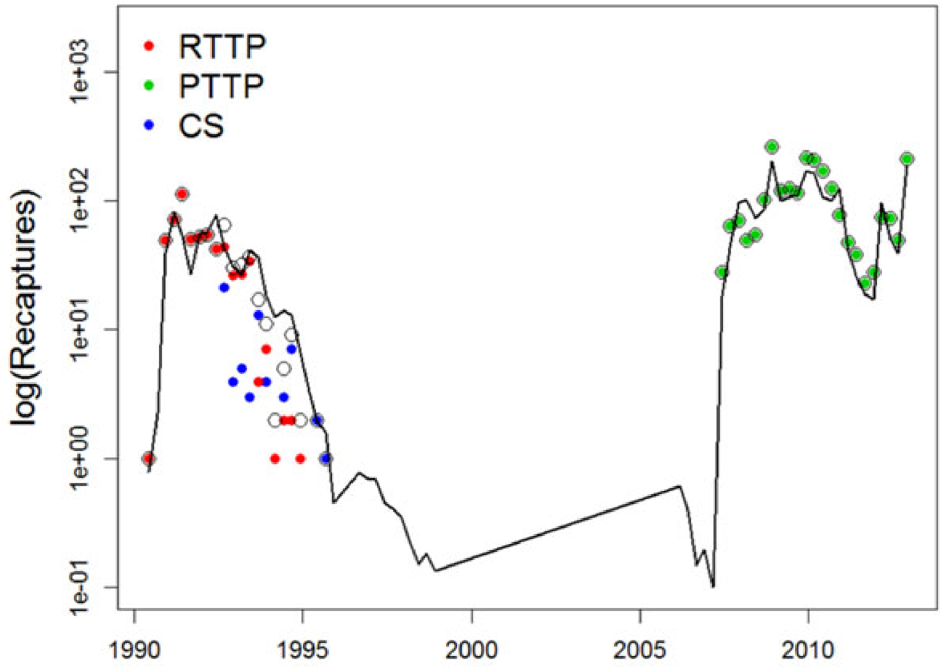


Settings of reference case MFCL runs

- SRR steepness set to 0.8
- Long term R defined by 1965-2011
- M-at-age fixed by external analysis
- Size data weighting 1/20th sample size
- Tag mixing set to 2 quarters
- Last 4 quarterly recruitments assumed to be average

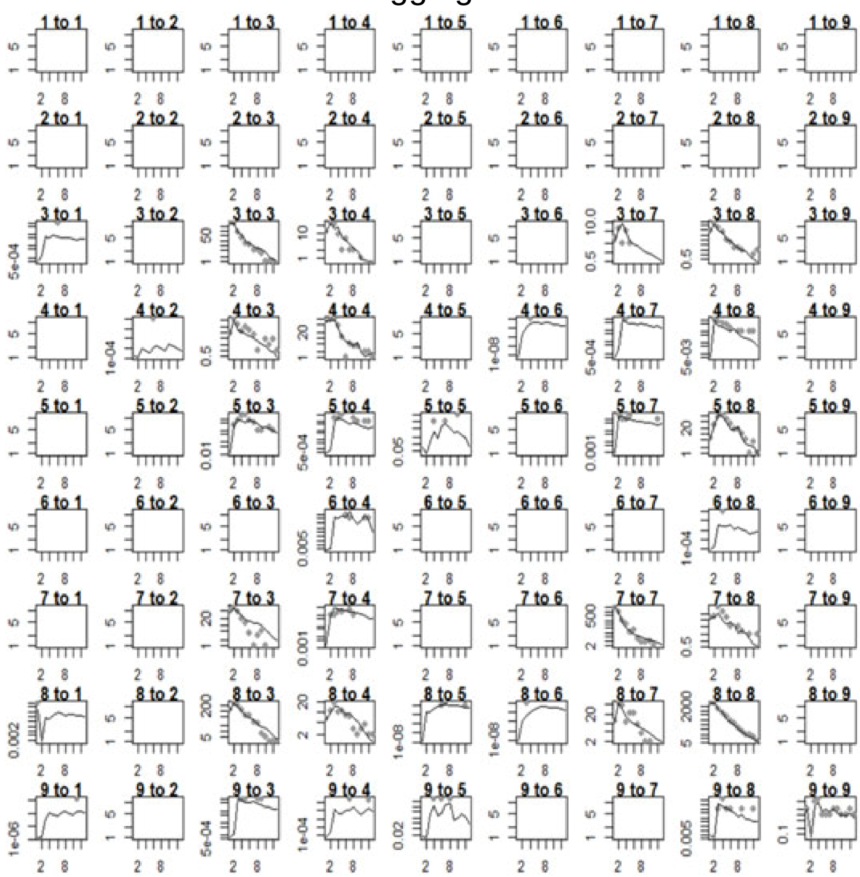
2014 reference case

Fit to tagging data



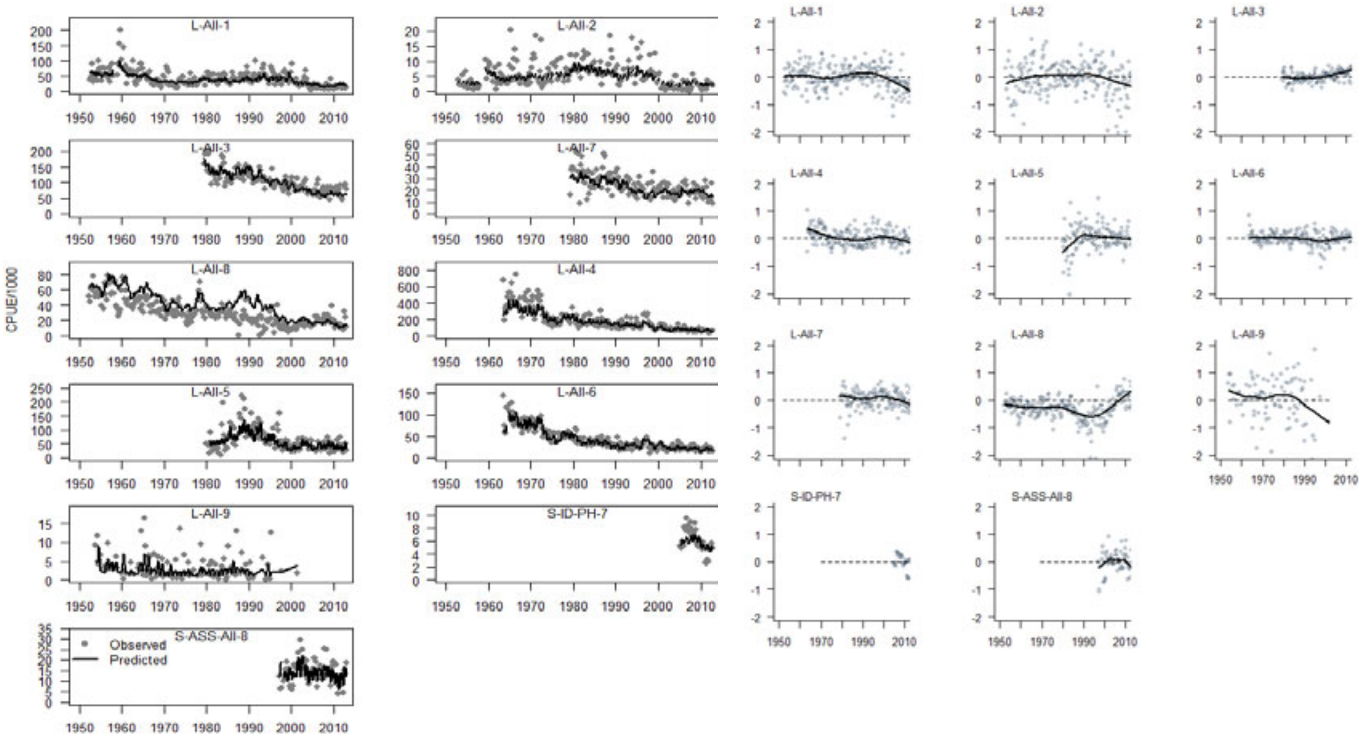
2014 reference case

Fit to tagging data



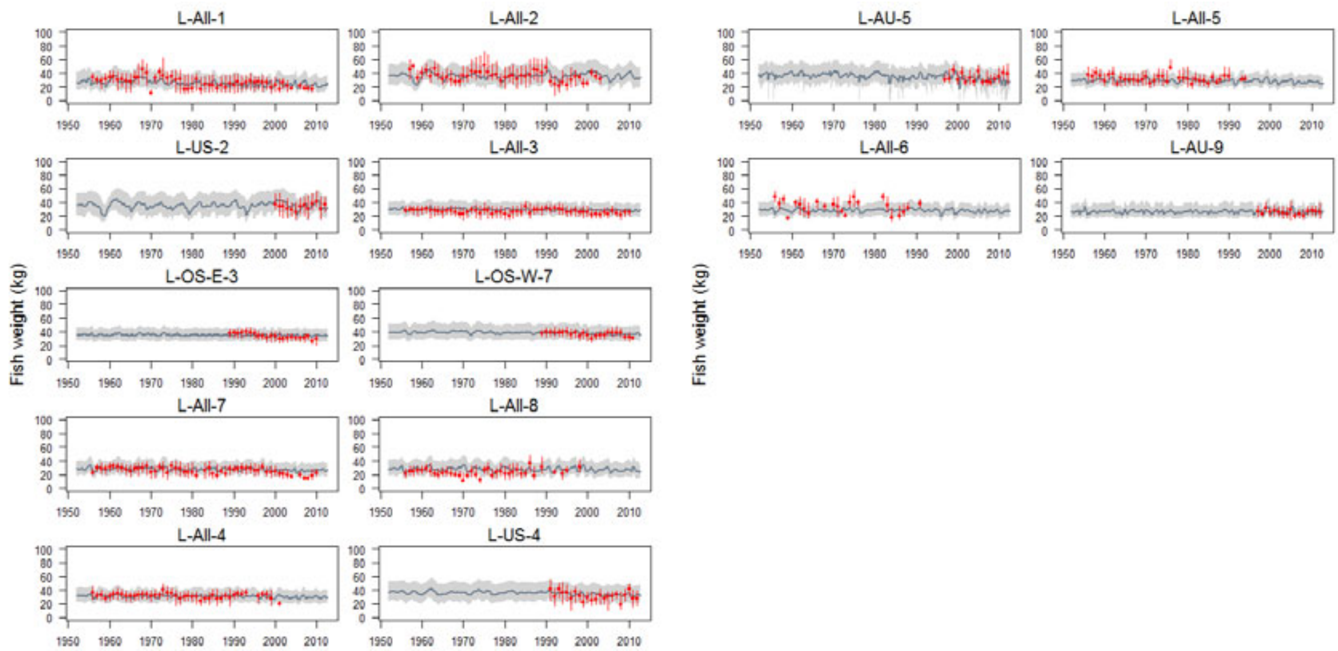
2014 reference case

Fit to CPUE derived from by Region



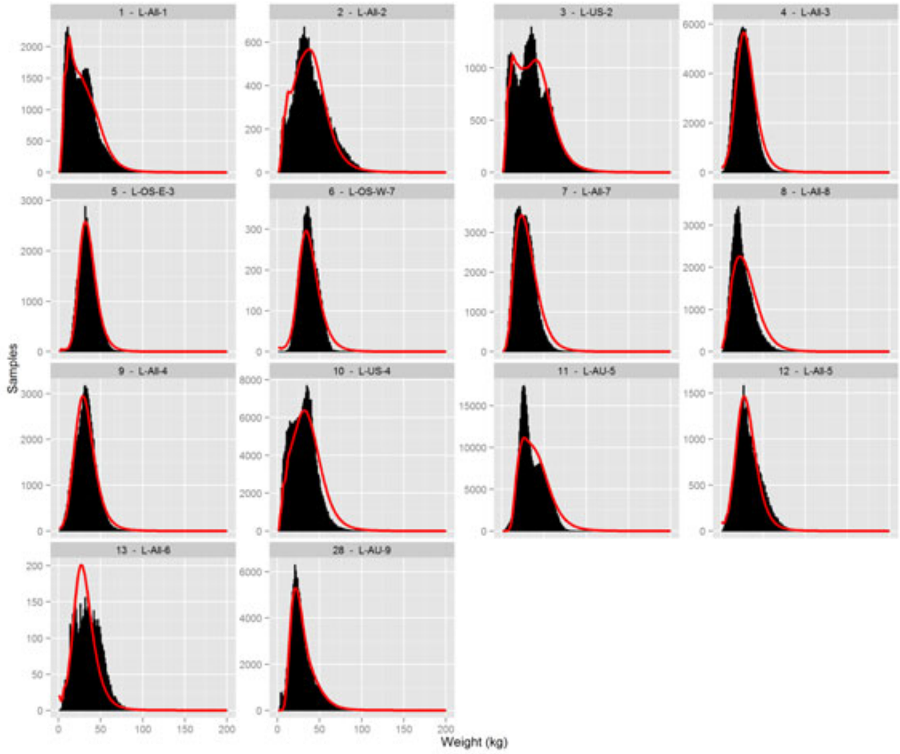
2014 reference case

Fit to weight-frequency data



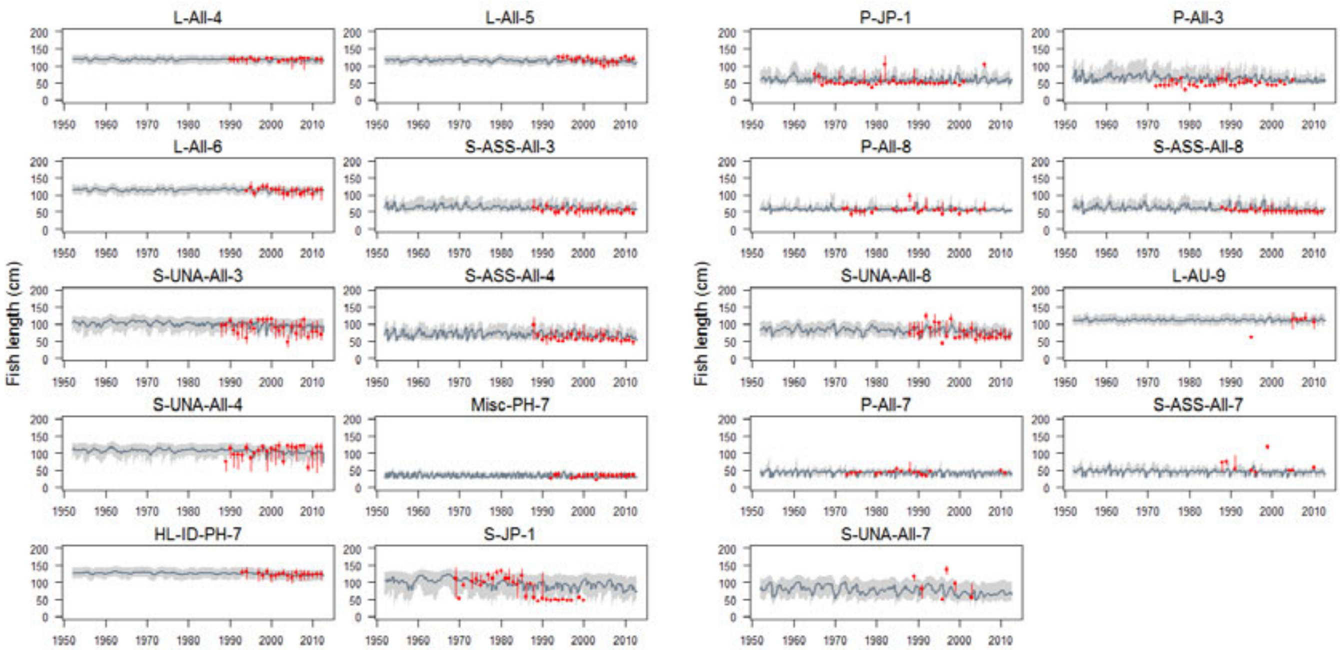
2014 reference case

Fit to weight-frequency data



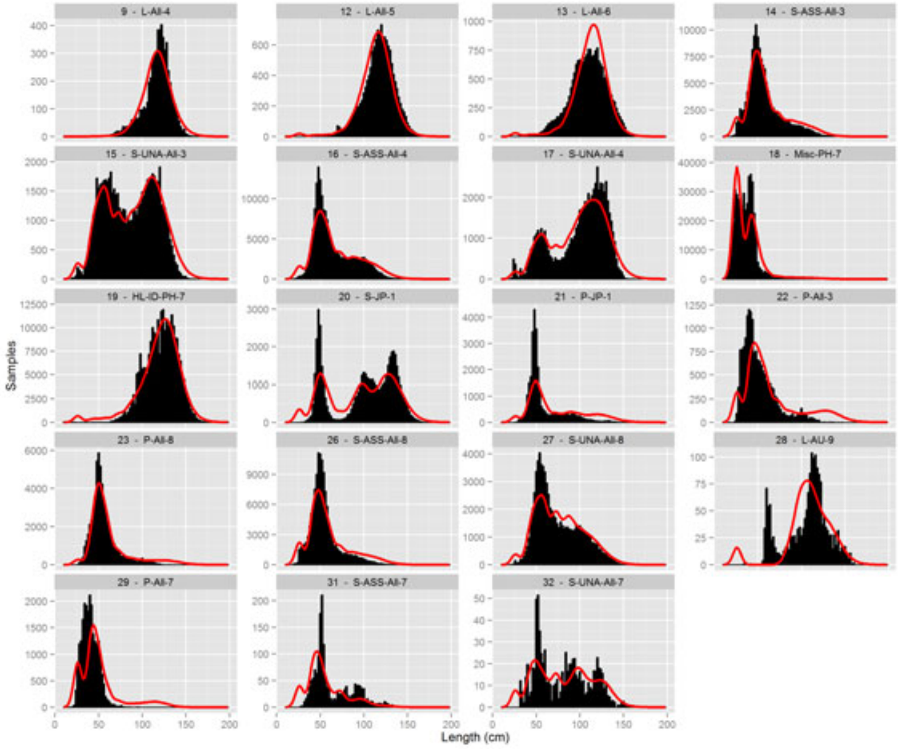
2014 reference case

Fit to length-frequency data



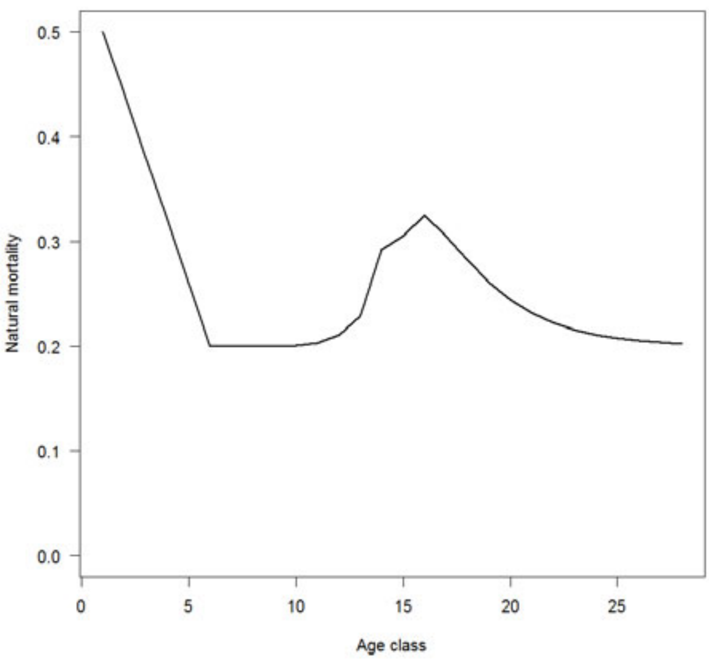
2014 reference case

Fit to length-frequency data



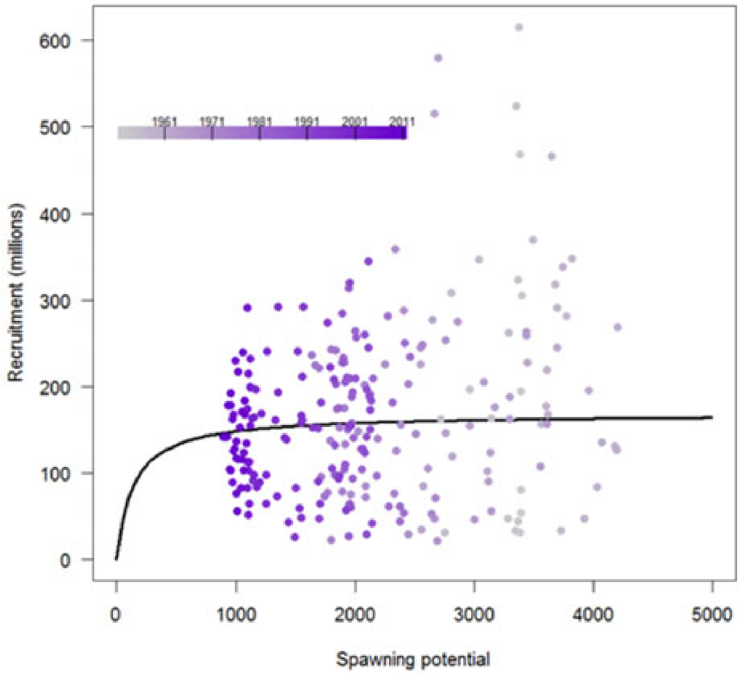
2014 reference case

Assumed Natural Mortality



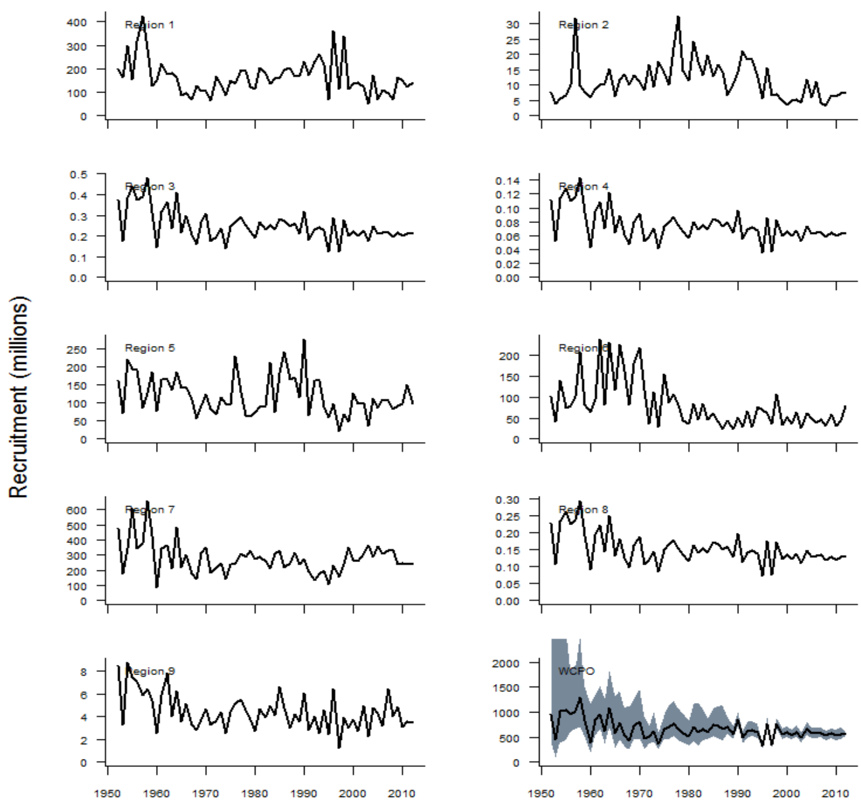
2014 reference case

Estimated SRR



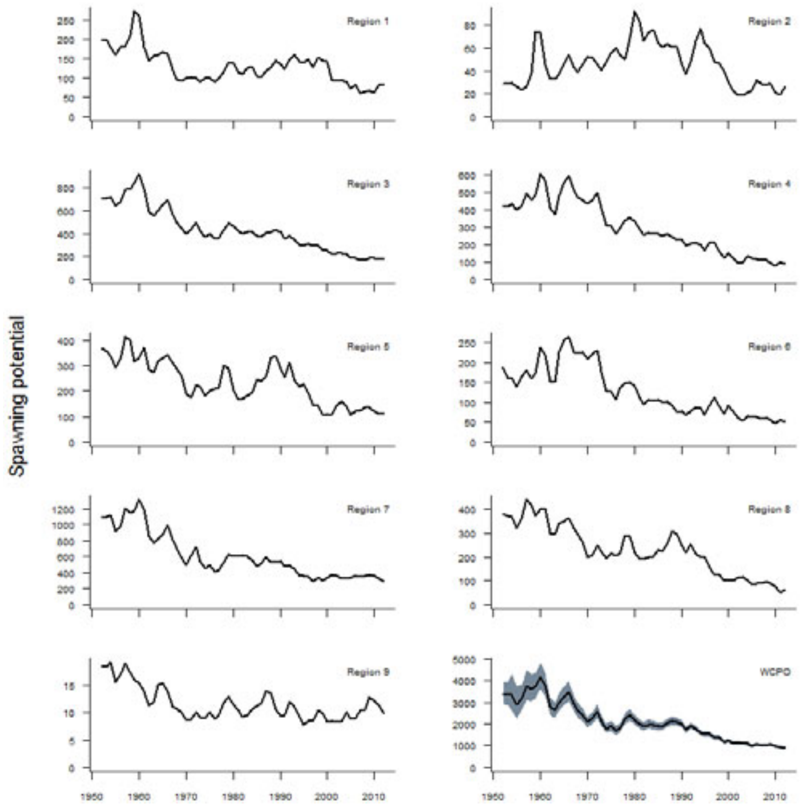
2014 reference case

Recruitment



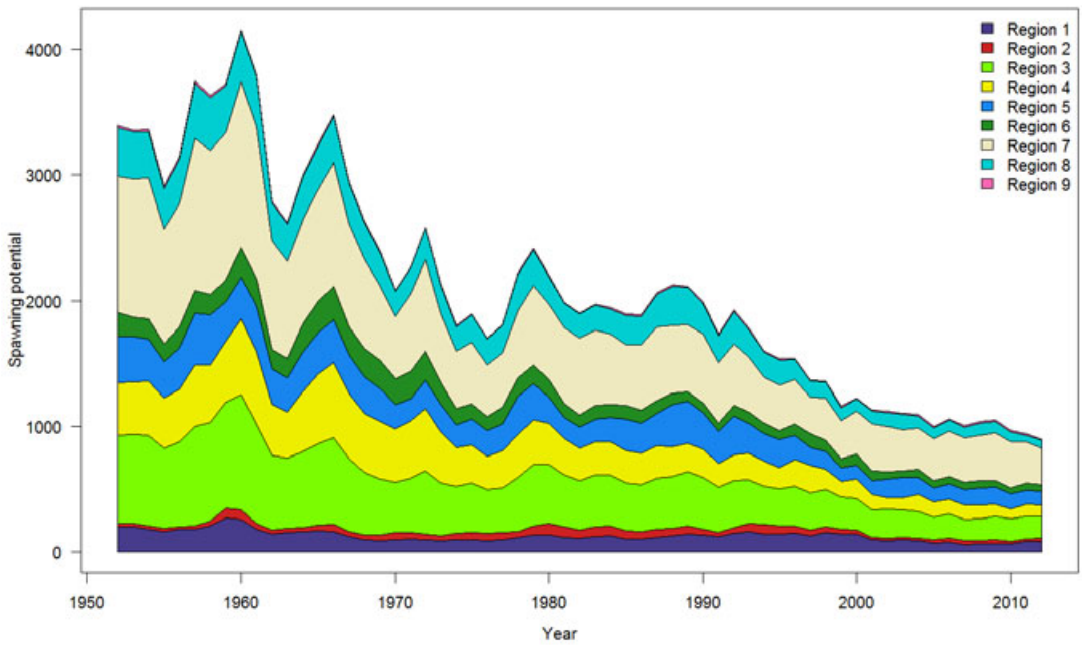
2014 reference case

Spawning potential



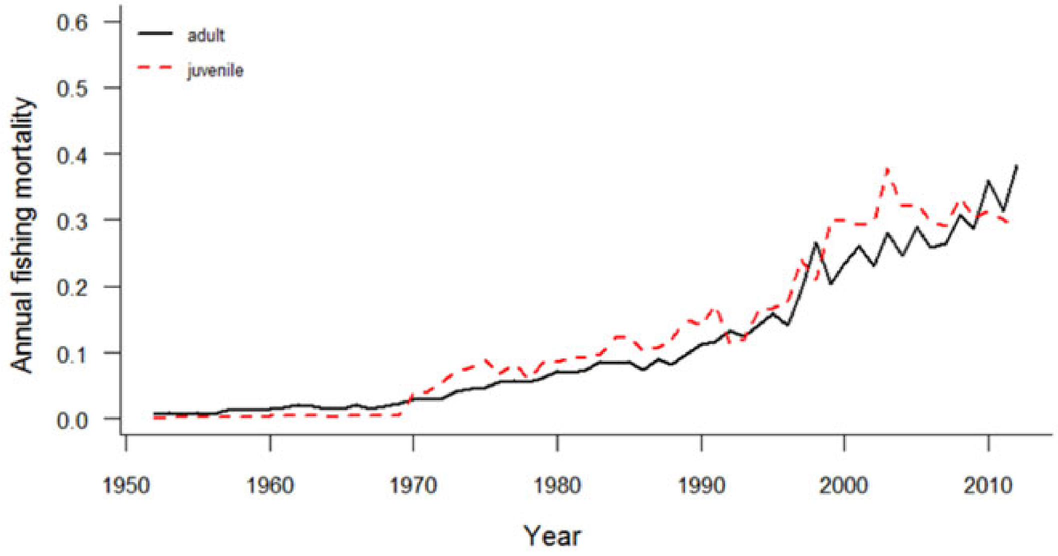
2014 reference case

Spawning potential by region



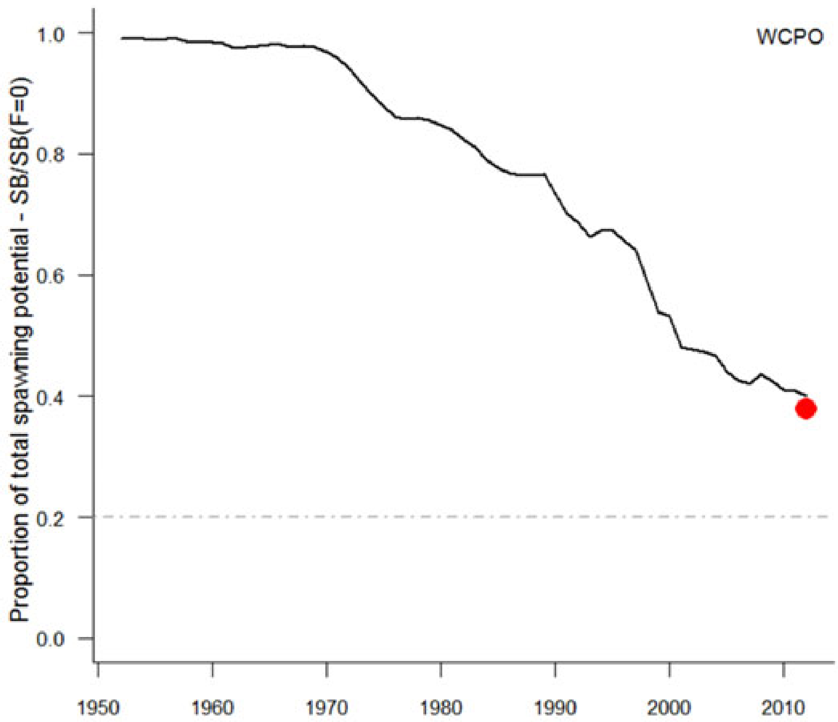
2014 reference case

Estimated Annual Fishing Mortality



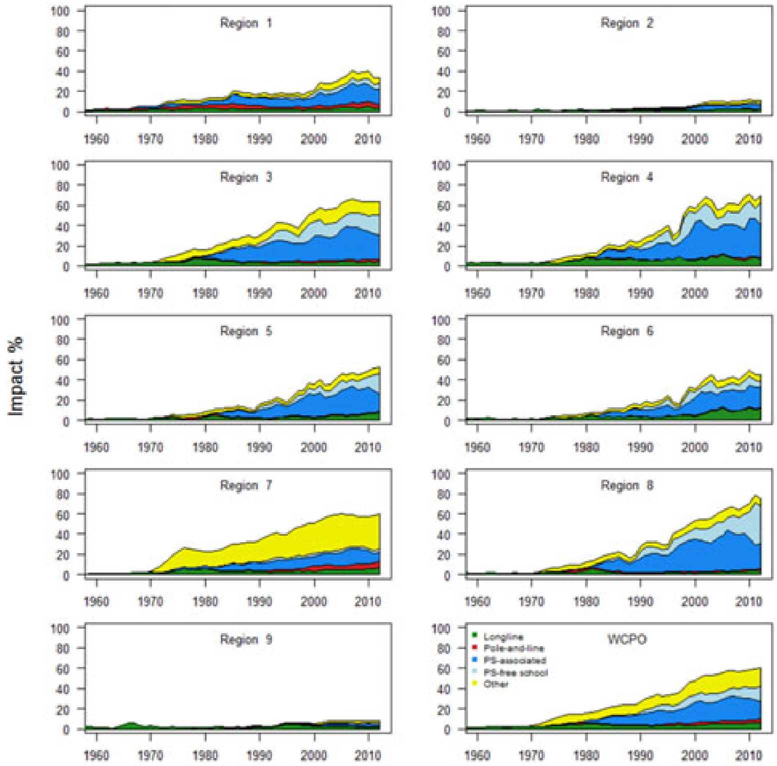
2014 reference case

Depletion – proportion of spawning biomass (decrease)



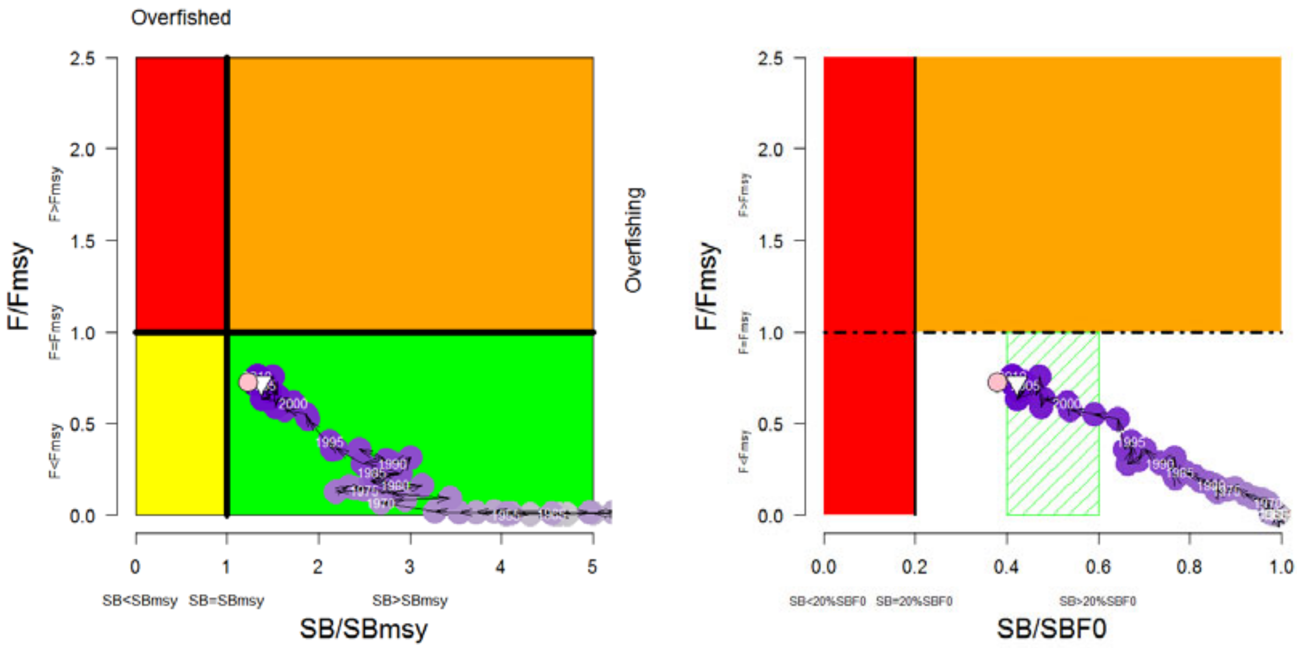
2014 reference case

Fishing impact on SSB – proportion attributable to fishery groups



2014 reference case

Stock status – temporal trends for SB/SB_{MSY} and $SB/SB_{F=0}$

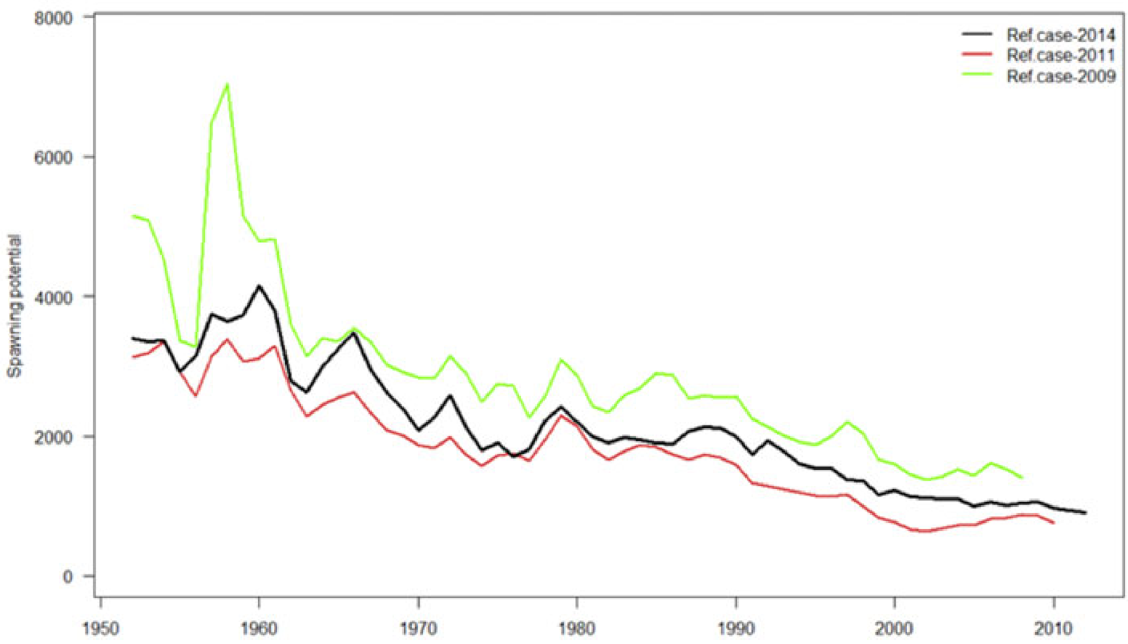


Spawning biomass

Spawning biomass

Reference Case Comparison

Last 3 Assessments



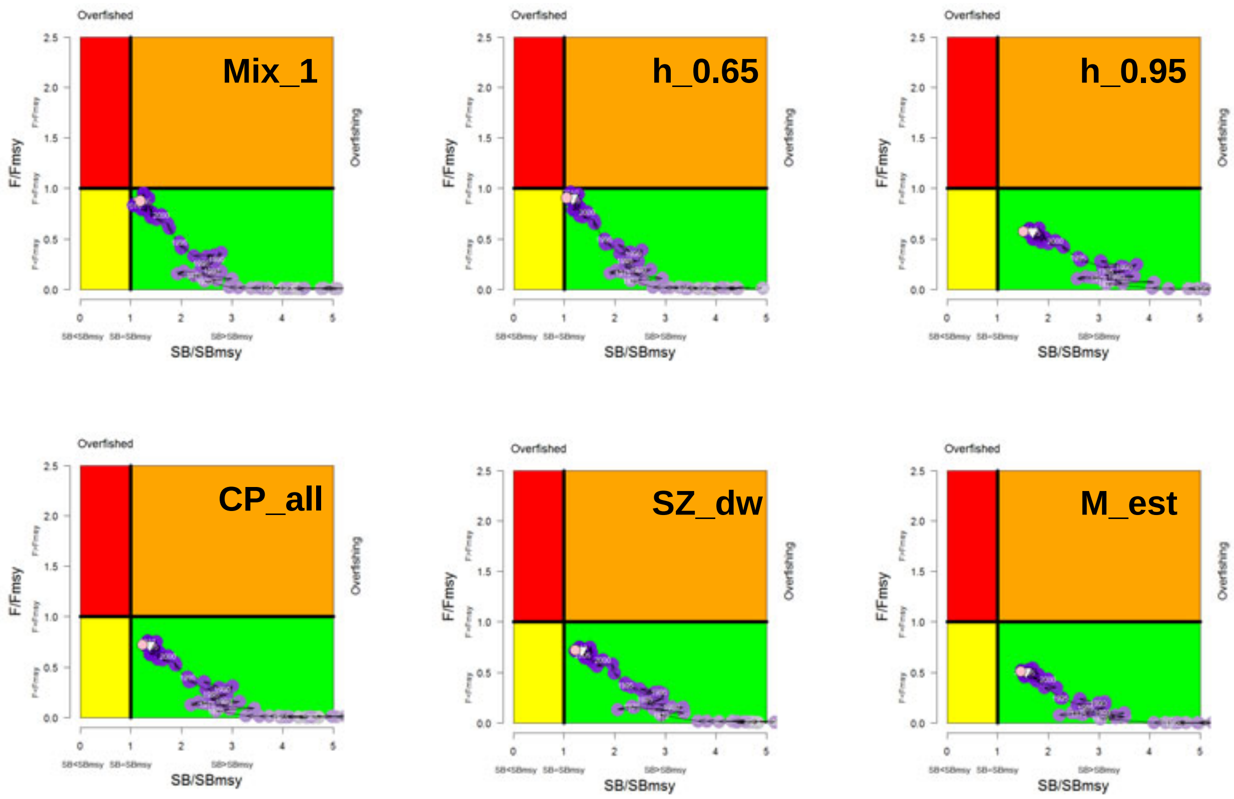
One-off sensitivities to the reference case

Run	Name	Description
run37	Ref.Case	Exclude CPUE indices from the fit for fisheries L-All-8 and HL- PH-7, BH-SRR fit to a subset of the model period (1965-2011), steepness=0.8, size data weighting nsample/20, tag mixing period=2 quarters, natural mortality assumed at fixed values.
tagmix_1qtr	Mix_1	Tag mixing period=1 quarter
steep_0.65	h_0.65	Steepness=0.65.
steep_0.95	h_0.95	Steepness=0.95.
CPUE_ALL	CP_all	Include HL- PH-7 standardised CPUE indices.
sz_wt_40	SZ_dw	Down weight the relative influence of the size data by 100%, nsample/40.
M_est	M_est	Estimate age-specific natural mortality schedule.

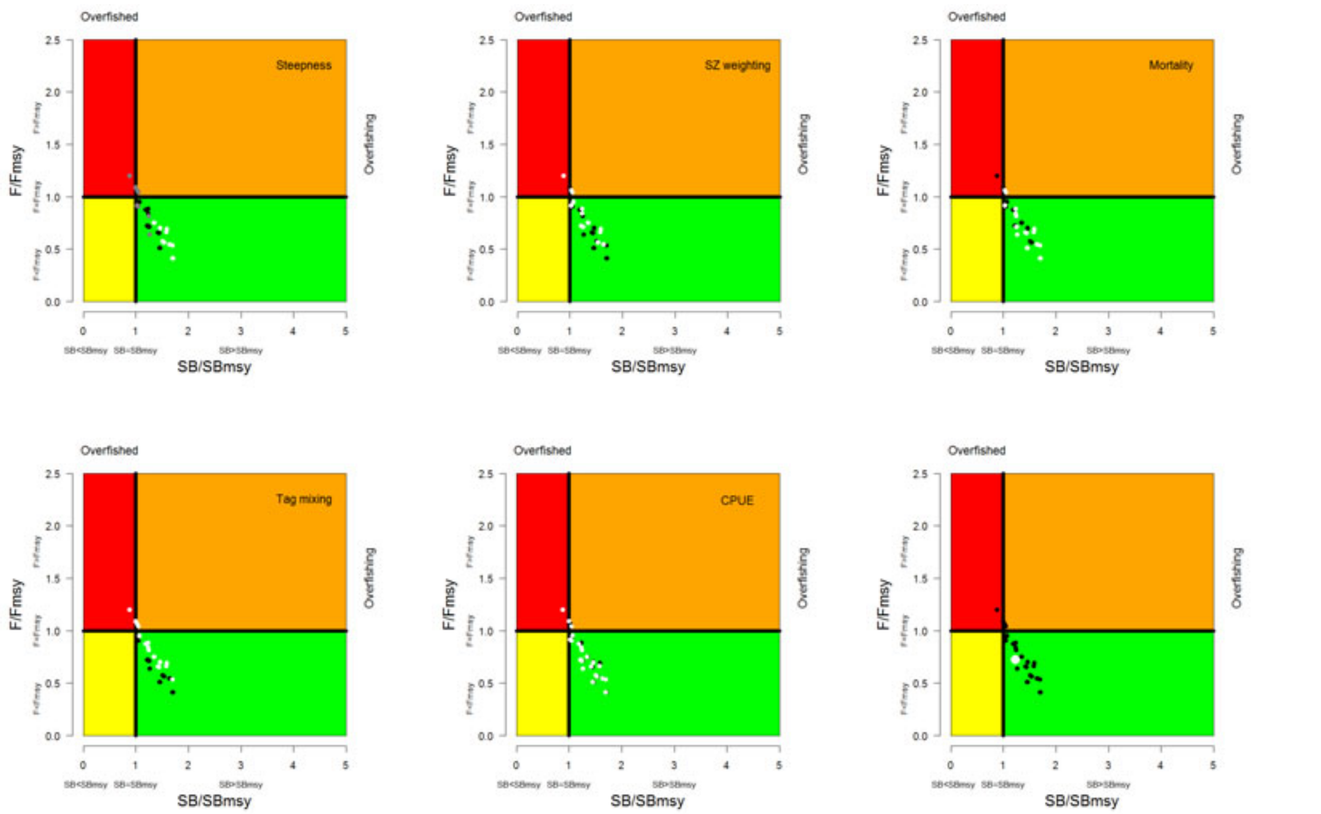
Reference points

	Ref.Case	Grid median	5%ile	95%ile
	586400	583862	477140	745320
	1.02	1.04	0.8	1.24
	0.72	0.76	0.51	1.09
	4319000	4398948	3553000	5693300
	1994655	1945664	1411004	2839906
	2467000	2087812	1192400	2709150
	728300	607024	309150	859990
	2368557	1990529	1086460	2478299
	998622	811014	454639	1307270
	899496	773429	385949	1223085
	0.42	0.41	0.29	0.55
	0.38	0.38	0.29	0.52
	1.37	1.37	0.97	1.82
	1.24	1.29	1.00	1.69

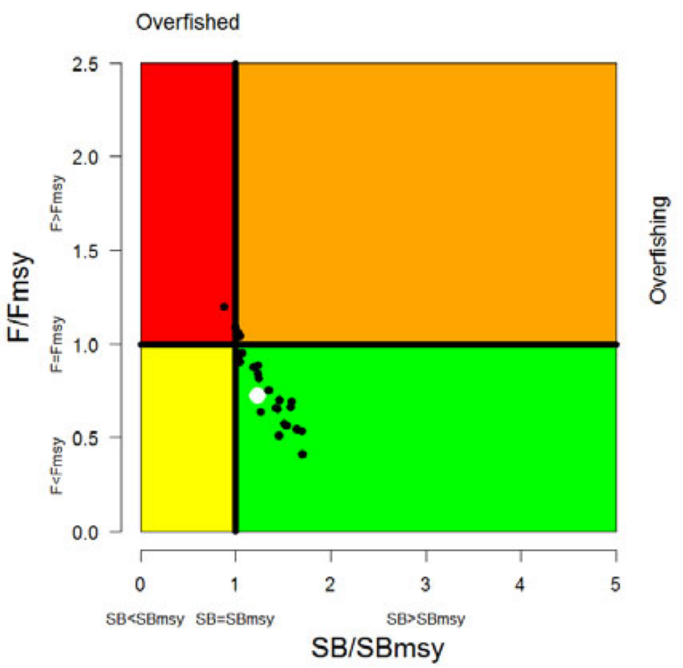
One-off sensitivities to the reference case



Structural uncertainty grid

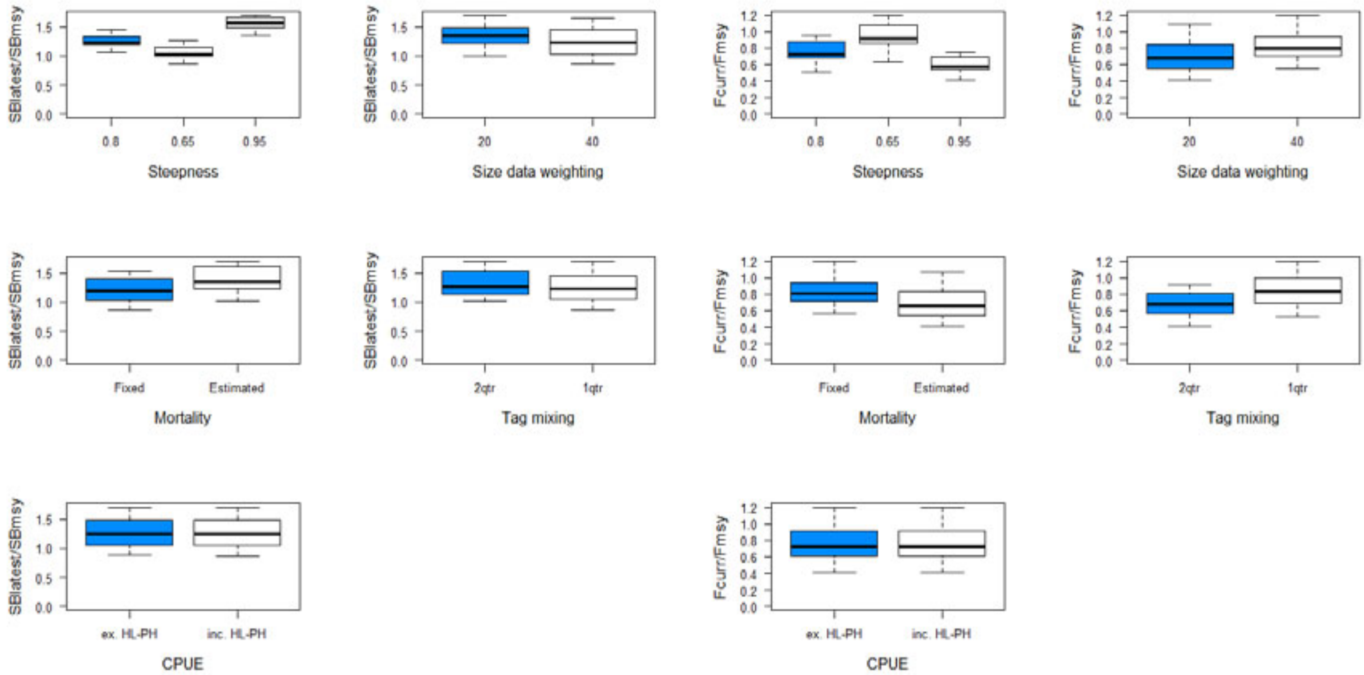


Grid runs – latest status



- Steepness
- Natural mortality
- Tag mixing rates
- Inclusion of PH CPUE series
- Relative weight of size compositions
- All > $0.2SB_{F=0}$

Grid Results



Conclusions

- Latest catches marginally exceed the *MSY*;
- Recent levels of spawning potential are most likely above (based on 2008-11 average and based on 2012) the level which will support the *MSY*;
- Recent levels of fishing mortality are most likely below the level that will support the *MSY*;
- Recent levels of spawning potential are most likely above (based on 2008-11 average and based on 2012) the limit reference point of 20%$SB_{F=0}$ agreed by WCPFC; and
- Recent levels of spawning potential are most likely higher (by 1%, based on 2008-11 average) and lower (by 2% based on 2012) than the candidate biomass-related target reference points currently under consideration for skipjack tuna, i.e., 40-60% $SB_{F=0}$.
- These conclusions are similar to those obtained in 2009 and 2011 assessments.

Conclusions, cont.

- The new regional structure and modelling and data improvements appear to have improved the current assessment with the data conflicts previously found being reduced, thus providing a more informative assessment.
- There appears to be confounding between the estimates of regional recruitment distribution and movement such that certain regions have very low recruitments. While adding complexity to the recruitment process of age 1 fish, this did not add to the uncertainty over the range of runs considered in this assessment.
- Stock status conclusions are sensitive to alternative assumptions regarding the modelling of tagging data, assumed steepness and natural mortality. However the main conclusions of the assessment are robust to the range of uncertainty that was explored. The importance of further research on the tagging data is highlighted.

Chapter 16

Bio-economics

Contents

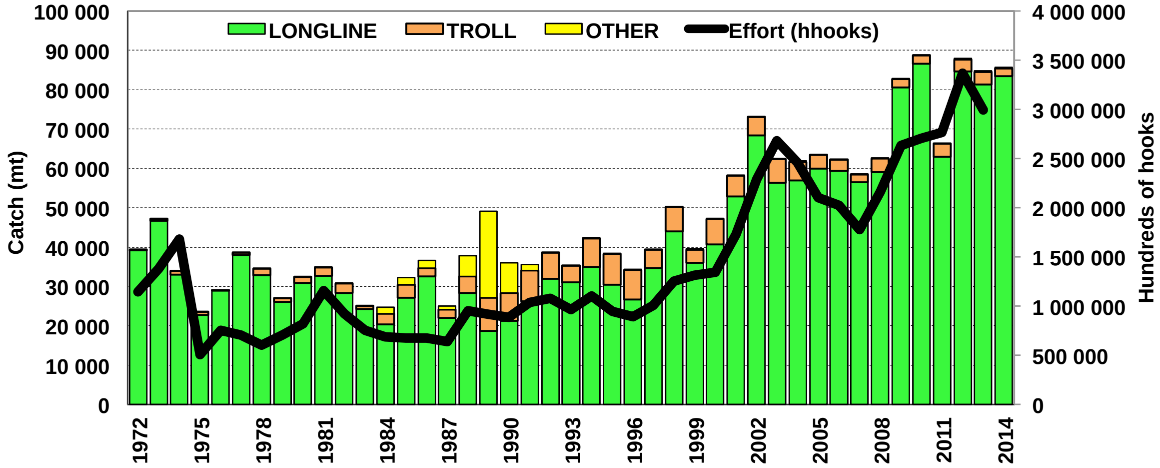
- Why are we interested in bio-economics?
- What's the theory?
- Sub-regional bio-economic models
  - – The 'south Pacific albacore' model [Exercises]
- Next steps – regional bio-economic model

Why are we interested?

- Profitability drives fisheries
- Fisheries drive government revenue
  – licensing/sale of days
  – Port fees
  – Transshipment, etc
- Profitable fisheries drive employment
  – Directly as crew
  – Directly as observers
  – Indirectly through onshore (processing, markets, etc)

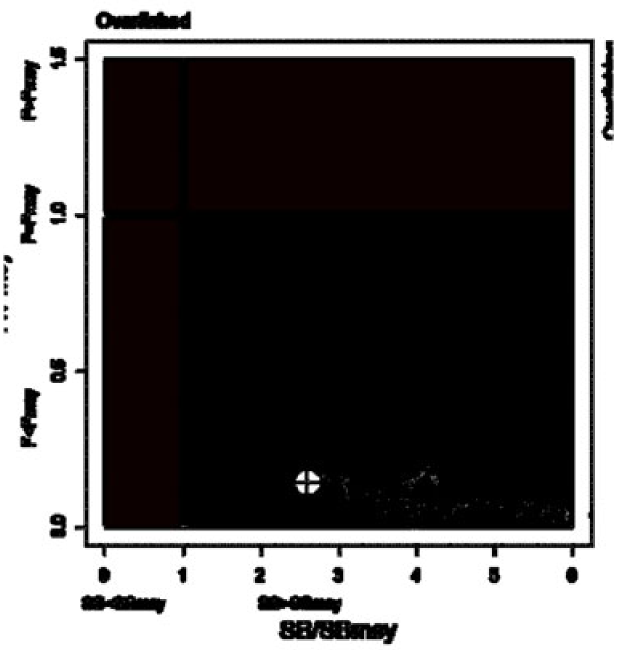
Why are we interested? Using South Pacific albacore as an example

South Pacific albacore catches



- 2014 3rd highest on record
- 2% higher than 2009-13 avg
- Longliners = 96% of catch

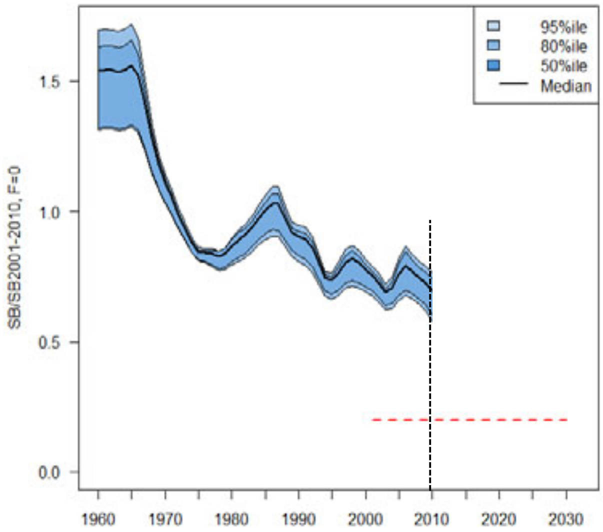
2012 stock assessment



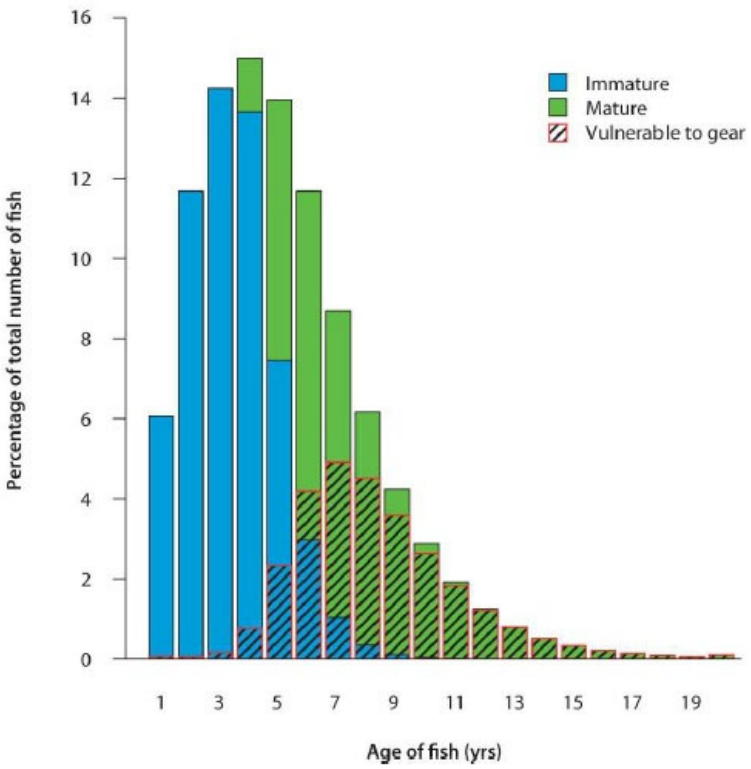
- Represents 2010 average status
- Increased 2009/2010 catches just beginning to feature within the model

Projections under recent effort

2012 effort



Can we break the SPA stock?



Can we break the fishery?

ISLANDS BUSINESS

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View from the Industry - Pacific Islands Tuna Industry Association (PITIA)

From *MATANGI TONGA/PACNEWS*

News
Wed 05 Feb 2014

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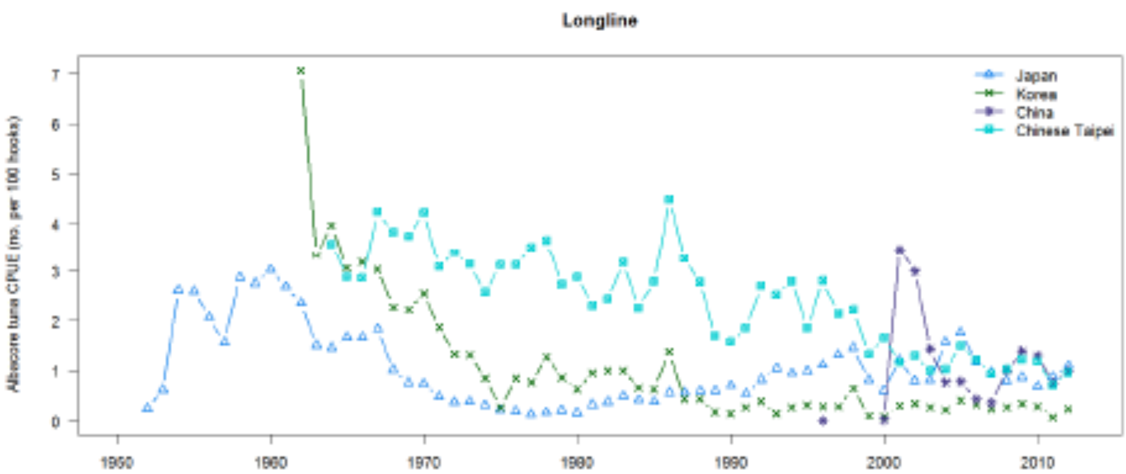
NUKU'ALOFA, Tonga --- The ability of the domestic industry to compete in the southern long-line albacore fishery has hit the point of no return. Tying-up vessels and sending employees home is now the reality that is faced by the Pacific Islands Tuna Industry Association members that have an interest in this fishery.

Scientists have warned for years that increased catches will come at the expense of economic viability. The domestic Industry has called for stronger management to mitigate the impact of the influx of subsidized vessels. The political force that subjects our Pacific Islands governments to other considerations have prevailed and the economic downfall of an industry of some 30 years is the result.

Stock assessments continue to produce relatively healthy results, however, actual experience at sea tells otherwise. Recent trends have shown not just decrease in Catch Per Unit Effort (CPUE) but fish size. Practice shows that there has been fast local depletion regardless of the perceived overall state of t he stock.

Over-fishing

Southerly longline CPUE



- TW fleet (light blue) = general decline

Projected drops in CPUE

Future effort level	LL Vuln Biomass	Troll Vuln Biomass
2012	-16%	-4%

- Average change in VB across runs: VB_{2030}/ VB_{2010}

- 2012 stock assessment (up to 2010) suggests stock 'in the green'
- But recent fishing levels will decrease CPUE levels on average
- Fishery economics worsen
- So need to:
  - Understand the drivers for the fishery;
  - Understand where the stock needs to be to keep fisheries going;
  - i.e need to define targets (Target Reference Points) that guide management to keep the fishery 'where we want to be' = economics, not so much biology.

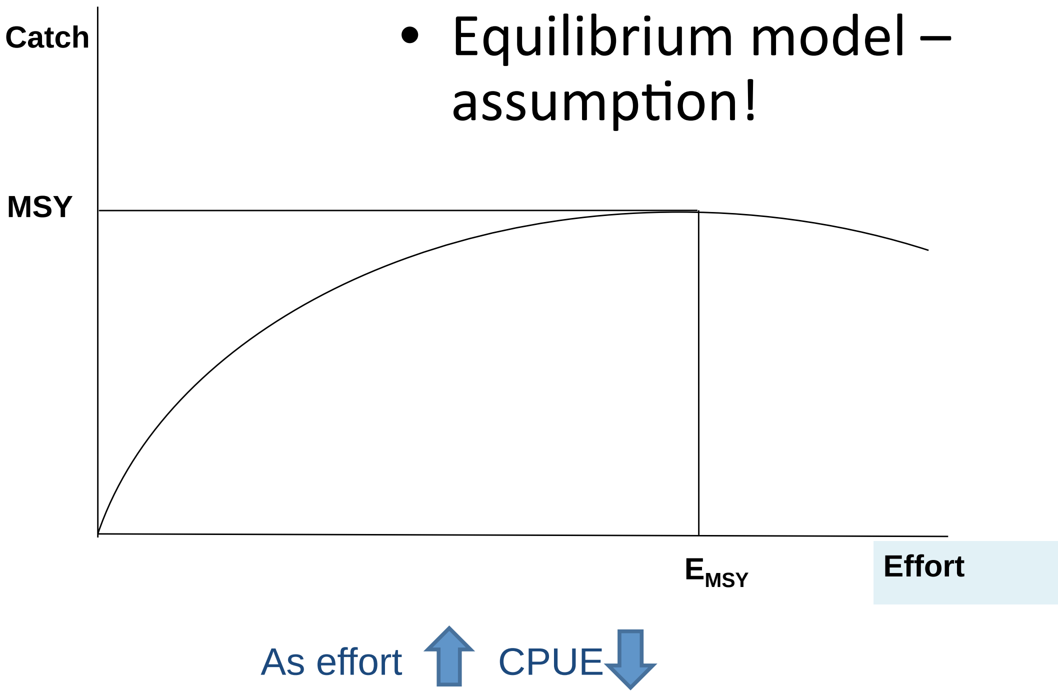
Bio-economics theory

Purpose

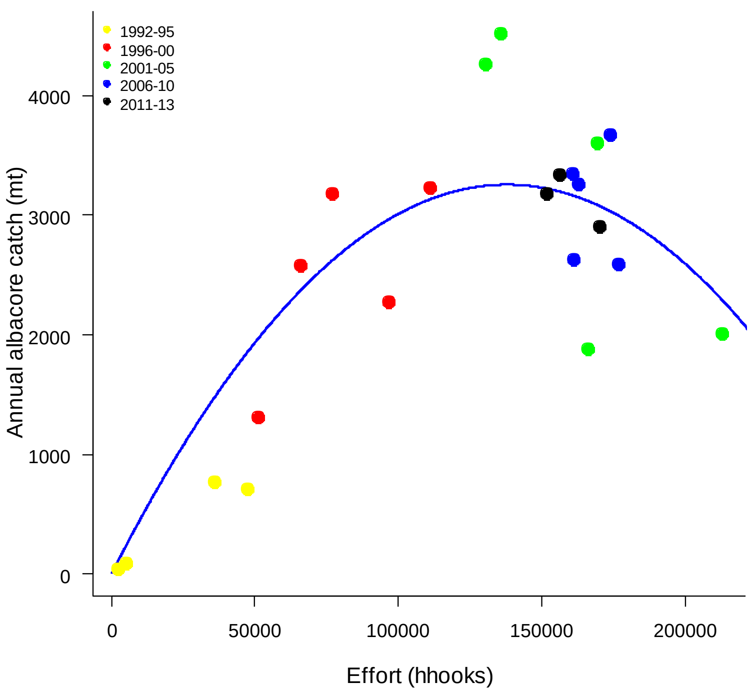
- Management question:
  - What is the 'optimum' number of vessels that provides the Maximum Economic Yield for the fishery?
  - (national, sub-regional or regional WCPO level??)

Framework and concepts – Biological considerations

- Equilibrium model – assumption!

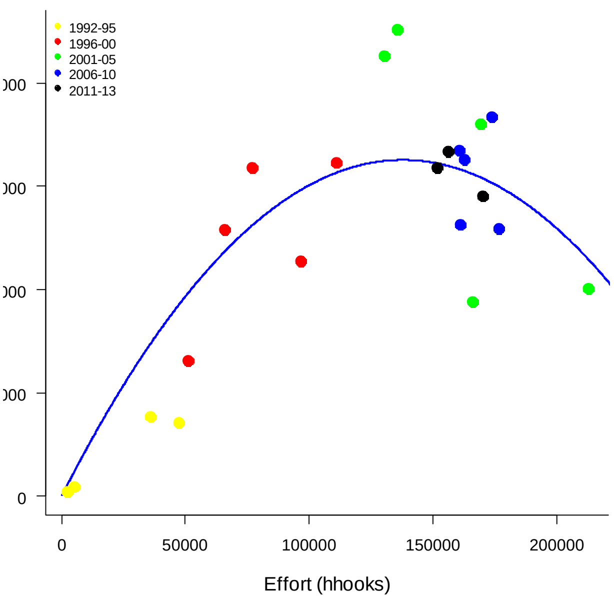


Biology - theory



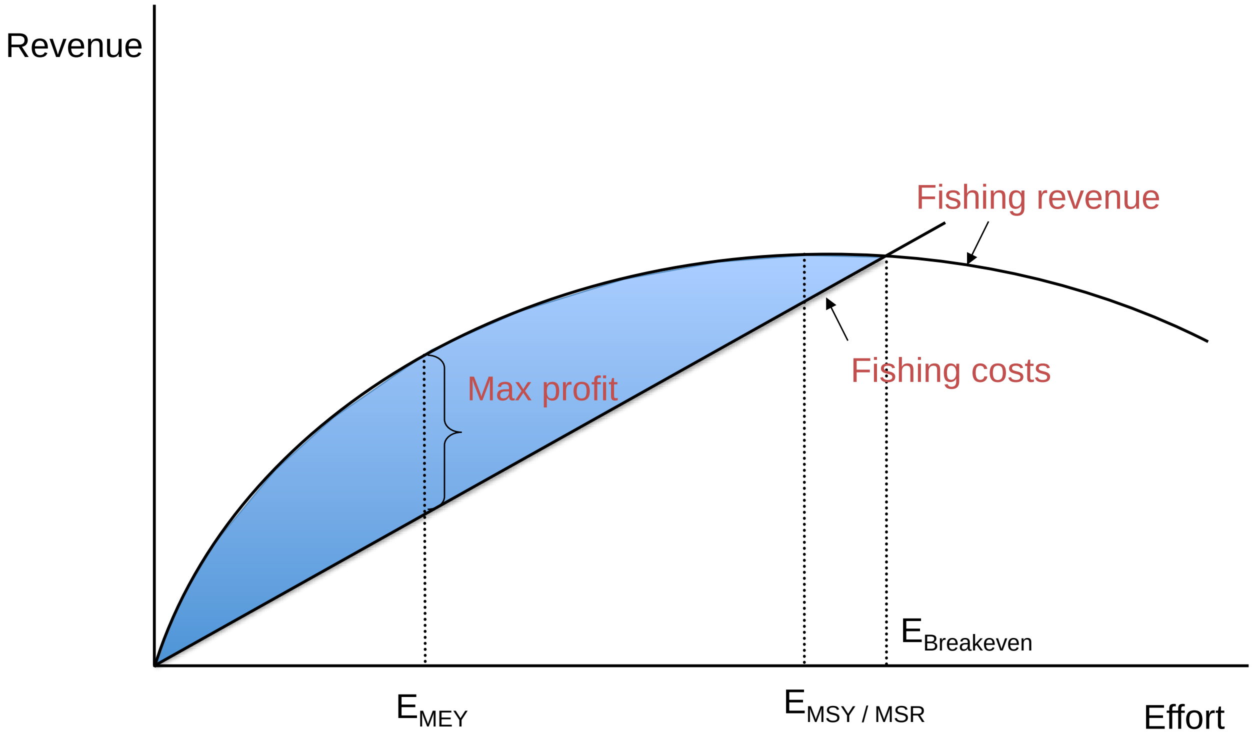
- Changes in catch per unit effort over time are likely to arise through three factors that may impact on the size of the exploitable biomass:
  - the level of exploitation of the stocks at the regional level;
  - the level of exploitation of the stocks at the national level (that is, localised depletion)
  - and changes in oceanographic conditions.
- Of these:
  - only the level of exploitation of the stocks can be directly controlled

Biology - theory

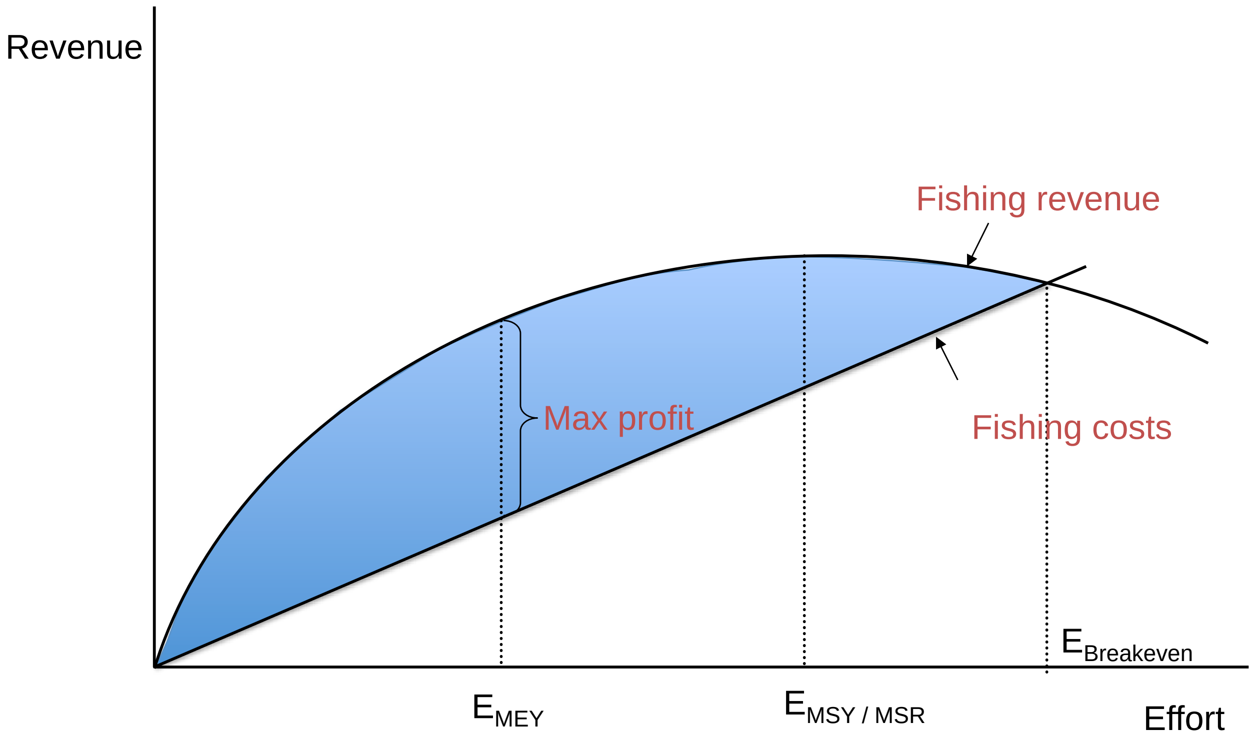


- Analysis assumes:
  - reduced effort levels give increases in catch rates similar to that seen in the past
  - DOES NOT take into account effects of increased exploitation rates at different spatial levels

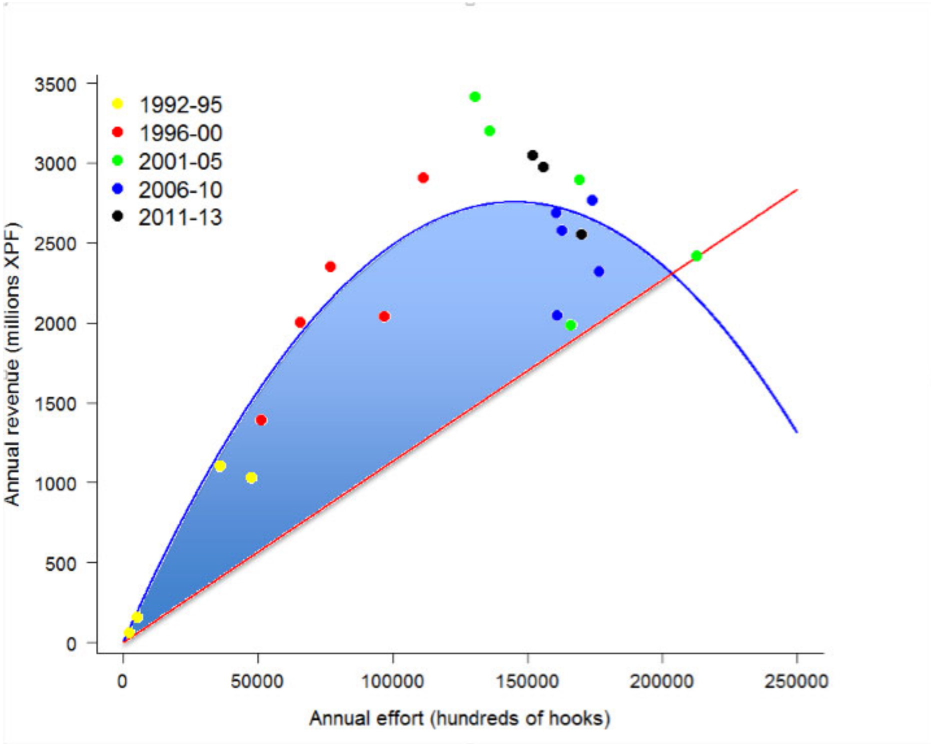
Bio-economics - theory



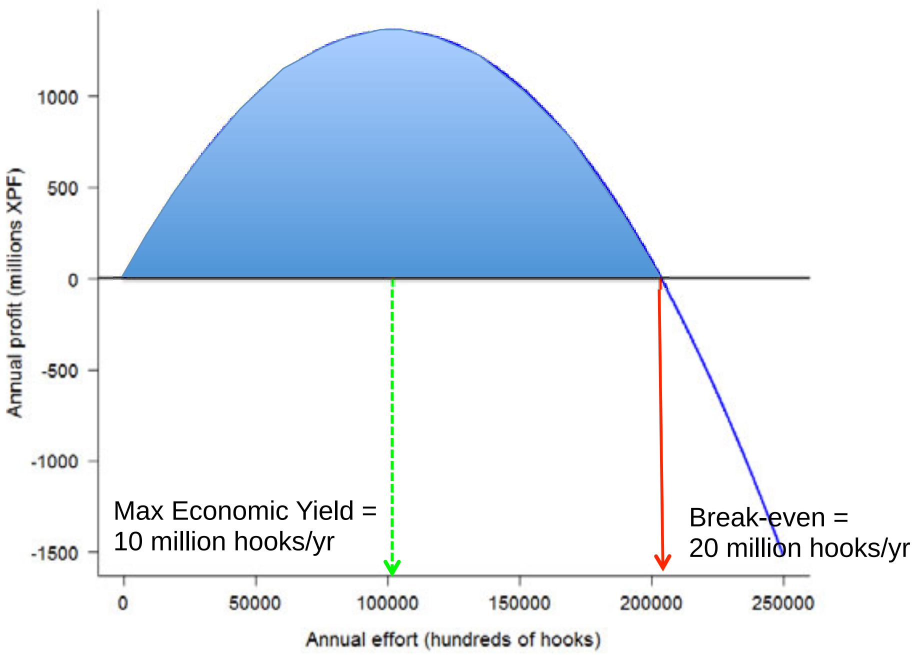
Bio-economics - theory



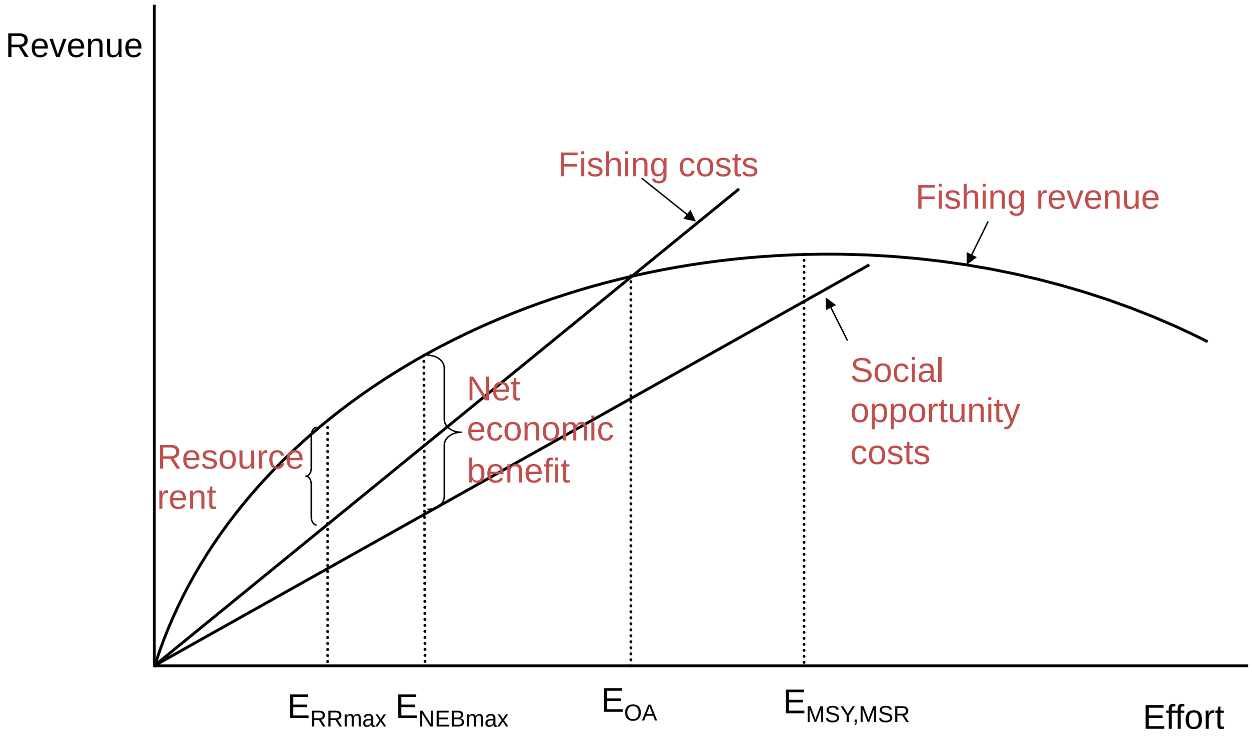
Bio-economics theory



Bio-economics: theory



Framework and concepts – Economic considerations



Potential target reference points that consider profitability of fleets: south Pacific albacore longlining as an example

(WCPFC-SC10-2014/MI WP-04)

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Secretariat of the Pacific Community (SPC), Oceanic Fisheries Programme (OFP), Noumea, New Caledonia

Pacific Islands Forum Fisheries Agency, Honiara, Solomon Islands

Tenth Regular Session of the Scientific Committee (SC 10)
6- 14 August 2014
Majuro, Republic of the Marshall Islands

SPC CPS

Bioeconomic model - approach

- MEY – we define 'economic yield' as the net present **value** of the fishery over a 20 year period of fishing
- Given different effort levels, predict annual changes in catch

Fishing costs (cost/hook)
(inc. 'normal' return on investment)

Fishing revenues (price/mt)
(inc. price received from all catch)

Resource rent *(profit)* = Revenues - Costs

Find the level of effort that maximizes long-term resource rents

SPC CPS

Projections (key features)

- Modelling simplified to provide a worked example rather than attempting to reflect full reality
- Change in longline effort (rel. 2010 levels) applied to 2012 SP ALB assessment model
- Scale longline effort in southern WCPFC-CA only (other fisheries/areas held at 2010 levels)
- Catches of YFT, BET, Billfish, and 'other' valued species included in catch values
- Economics assumed constant across fleets and regions
- Prices achieved do vary (slightly) between fleets

Economic conditions

Scenarios

Parameter	Species	High	Medium	Low
Price/mt (US$)	ALB	2957	2464	1971
	YFT	6376	5313	4250
	BET	9365	7804	6243
	Billfish	5400	4500	3600
	Sharks	1860	1550	1240
	Other[1]	2957	2464	1971
Cost/hook (US$)		1.30	1.10	0.90
Discount rate		7% (0.07)	5% (0.05)	3% (0.03)

3

3

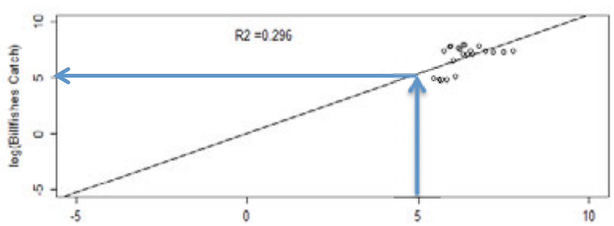
3

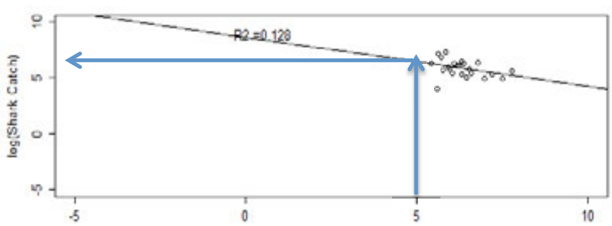
3^3 = 27 combos

'typical' longline vessel

vessel with lower costs (e.g. technically efficient)

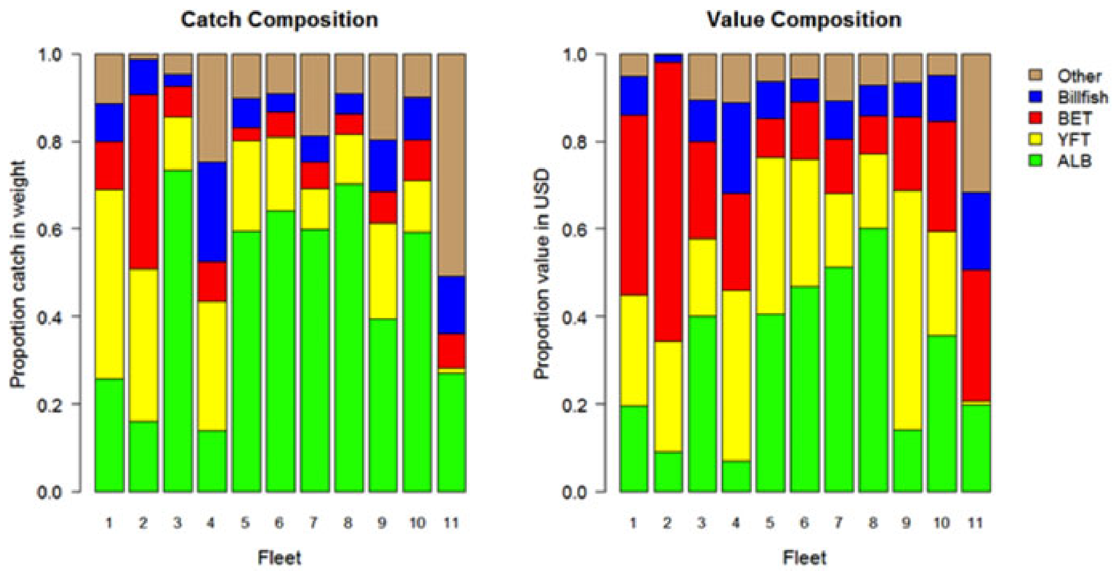
'Multispecies' aspects





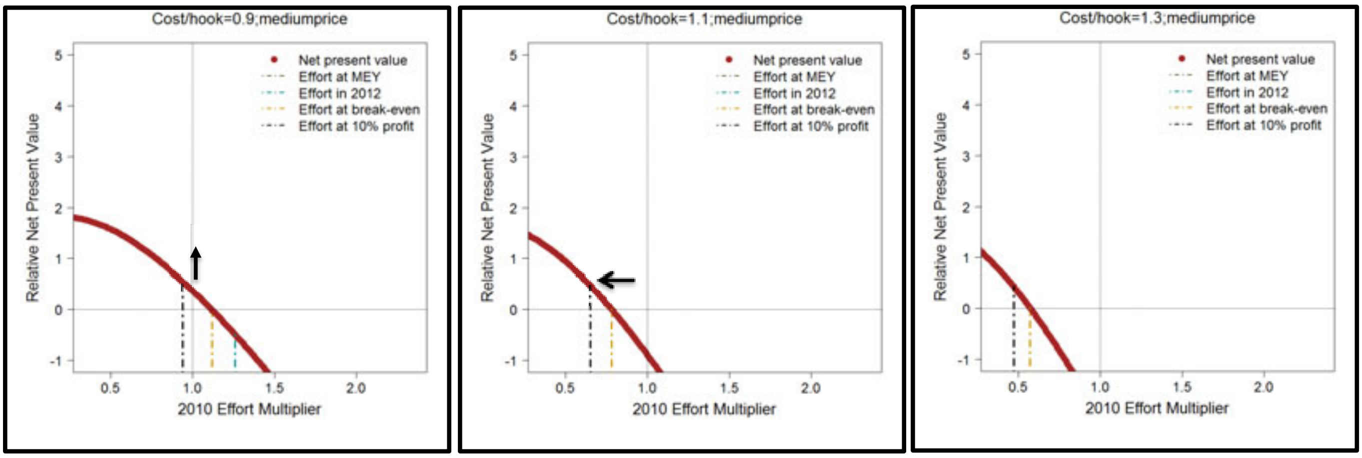
- Here basing the 'bycatch' level on the amount of albacore catch expected from projections under specific future conditions
- i.e. if catch 'X' tonnes of SPA, will catch 'Y' tonnes of YFT, BET, etc.
  - Beware, partic. outside range of data seen

Catch/value composition (2030)



'medium' price structure

MEY/Break-even points



- Cost/hook USD 0.90 compared to USD 1.10
  - max NPV slightly higher , potential profit at 2010 levels
  - recent provisional effort ~ break-even level
- Cost/hook USD 1.1 and 1.30
  - fishery effort levels well above break-even point in 2012

Performance indicators (effort at MEY)

Relative price structure	Cost/hook	Scalar at Max NPV (rel. 2010 effort)	Forgone value (million USD)	Catch ALB-SP (MEY) (mt)	Catch MEY/MSY %	Biomass SB_{MEY}/SB_{MSY} (ratio)	Change ALB CPUE (MEY) (ratio)
MEDIUM	1.3	0.25	3,347	31,064	25	3.36	1.36
	1.1	0.25	2,395	31,064	25	3.36	1.36
	0.9	0.25	1.443	31.064	25	3.36	1.36

Note: effort scalars of 1.07 and 1.26 correspond to observed 2011 and 2012 effort levels relative to 2010. Median $SB_{2010}/SB_{F=0}$ = 0.70.

Performance indicators (effort at break-even)

Relative price structure	Cost/hook (US$)	Scalar at break even (rel. 2010 effort)	Catch ALB SP (mt)	Change ALB CPUE (2030/2010)	Catch YFT-SP (mt)	Catch BET-SP (mt)
MEDIUM	1.3	0.57	56,470	1.14	16,677	11,563
	1.1	0.78	68,175	1.03	17,995	12,560
	0.9	1.12	82.178	0.90	19.630	13.768

Note: effort scalars of 1.07 and 1.26 correspond to observed 2011 and 2012 effort levels relative to 2010. Median $SB_{2010}/SB_{F=0}$ = 0.70.

Main conclusions

- Analysis based on current catch, effort and price levels for SPA suggest there is considerable loss of potential economic value
  - To achieve MEY estimated that reductions >=75% of 2010 effort levels required, depending on economic conditions
  - A more 'realistic' target of 10% profit requires reductions of between 6 and 53%, depending on economic conditions
- Gains in value (and improved catch rates) generally require reductions in fishing effort (note breakeven = 43% reduction to 12% increase, depending on economics)

Main conclusions

- Vessels with lower costs will have sufficient returns to stay in fishery long after other 'average' vessels with higher costs will exit the fishery due to inadequate returns
- Resource rent at MEY or %MEY is one potential economic indicator that can help define TRPs (others incl. employment or other onshore economic benefits); all require access to industry/market data