FISH 6001: Ecology, Management, and Practice of North Atlantic Fisheries

Module on Population Dynamics

Instructor: Matthew Robertson

Matthew.Robertson@mi.mun.ca

Overview

- Day 1 – The two branches of fisheries science (Feb. 26)
- Day 2 – Population growth and life history (Feb. 28)
- Day 3 – Population dynamics models (Mar. 4)
- Day 4 – Scientific advice for fisheries management (Mar. 6)

Learning Objectives

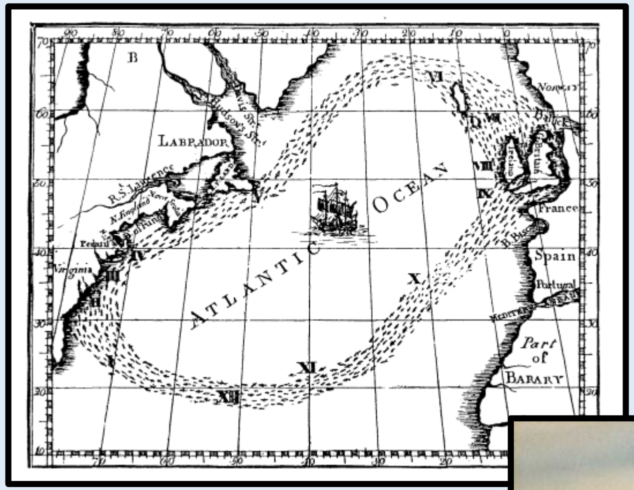
- General history of fisheries science
- What are the key mathematical underpinnings of population growth theory?
- What biological characteristics define population growth?
- How do we use these theories and biology to track population dynamics?
- What are the key population dynamics models?
- How do population dynamics models inform fisheries management?

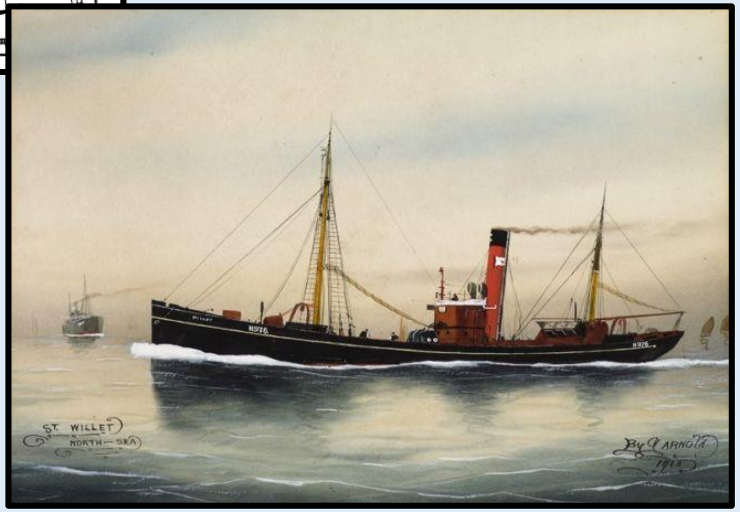
Assignment Overview

- Using an Rmarkdown simulation, examine theoretical population dynamics for your fish stock
  - Find the necessary traits as inputs to run the population dynamics model
  - Identify differences between your stock and a pre-defined stock
  - Determine whether your stock maintains a more sustainable fishery than a pre-defined stock
- Due March 15, send completed markdown to my email

Day 1 – The two branches of fisheries science

- Understanding fisheries population dynamics and dominant theories today is easier when viewed in the light of how this science developed over time



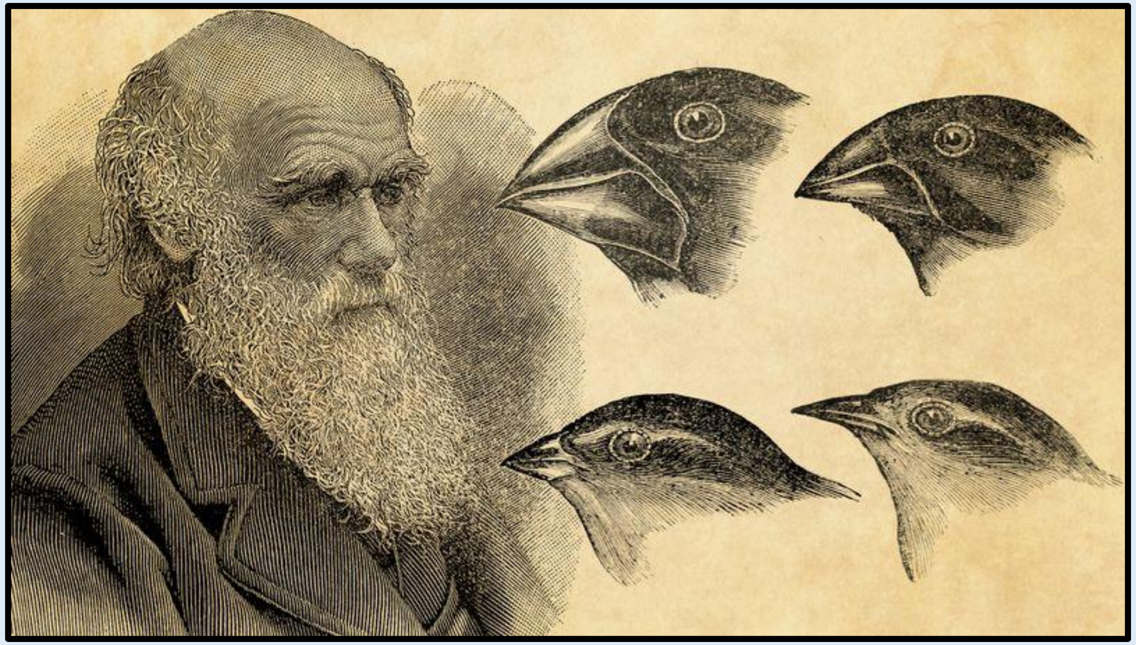


Learning Objectives

- **General history of fisheries science – ICES development**
- What are the key mathematical underpinnings of population growth theory?
- What biological characteristics define population growth?
- How do we use these theories to track population dynamics?
- What are the key population dynamics currently applied?
- How do population dynamics models inform fisheries management?

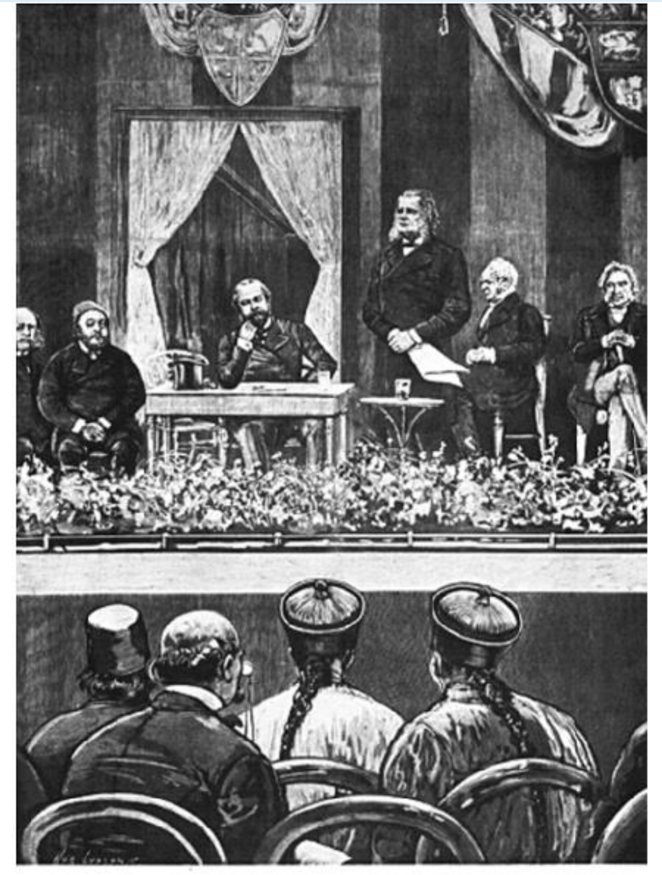
Essentialist species

- Pre-Darwin, the dominant view was that god created species and "an eternal essence for each species"
- Effectively, the number of individuals in a species were constant
- Component populations were not recognized



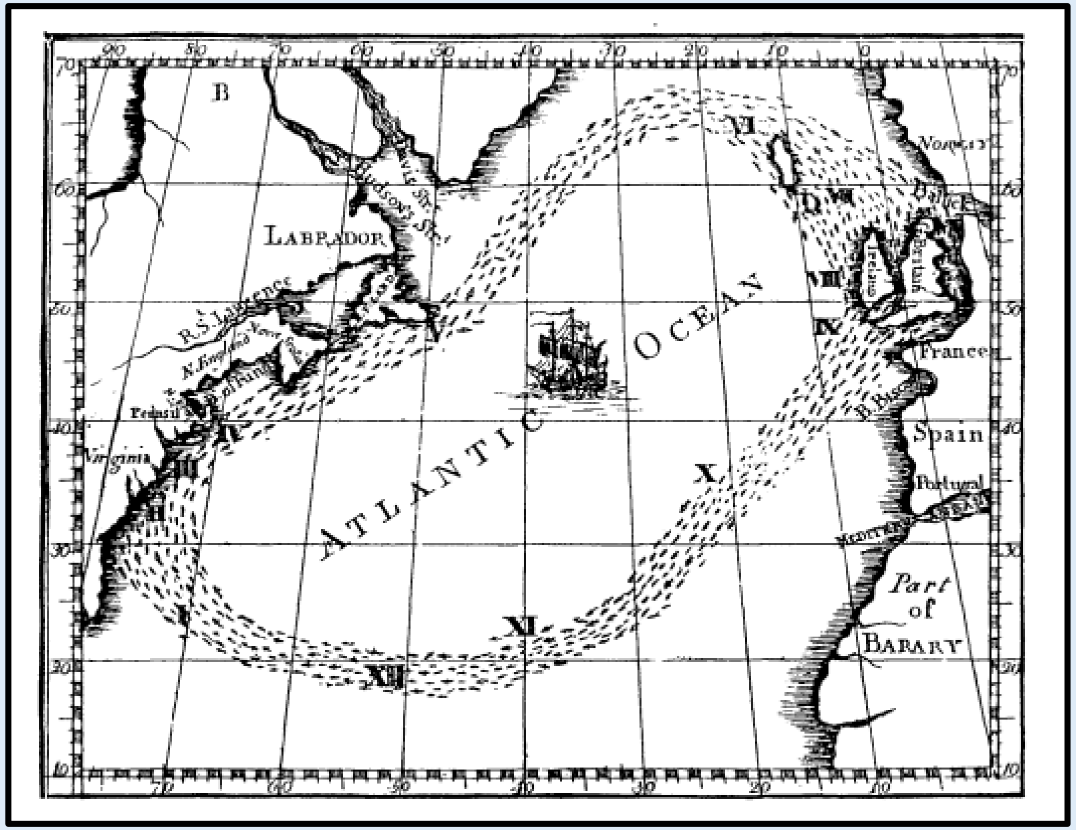
The inexhaustible seas

- “I believe, then, that the cod fishery… and probably all the great sea fisheries, are inexhaustible: that is to say that nothing we do seriously affects the number of fish. And any attempt to regulate these fisheries seems… to be useless.”
  - Thomas Huxley, 1883



Migration theory

- Fish of a given species were all part of the same group throughout the geographical range of that species
- Variability in catches was expected to be driven by oceanic-scale migrations



Migration theory was divisive

- Debated throughout the 1800s and early 1900s whether migration theory was correct or if there were geographically restricted self-sustaining populations
- Population theory was based on observations of morphological differences for herring across space

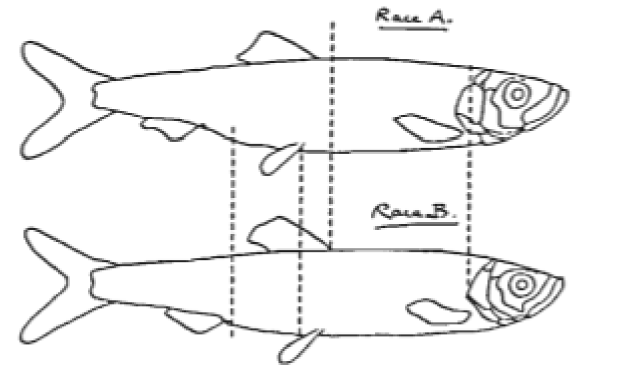


Figure 1. – Illustration of representatives of two populations of herring spawning in the vicinity of Kiel (appended to Weldon's 1894 application to the Royal Society for funding).

Sinclair & Solemdal (1988)

Recognition of fish populations

- In 1898, Friedrich Heincke used recently developed mathematical statistics to characterize morphological differences
- Specifically wanted to identify if characteristics only varied with age, sex, etc. or based on populations
- Observed differences in number of vertebrae, keel scales, and fin rays, which led him to conclude:
  - "The existence of local populations of herring is proven beyond a doubt"
    - This idea took some time to be fully recognized by the community

Sinclair & Solemdal (1988)

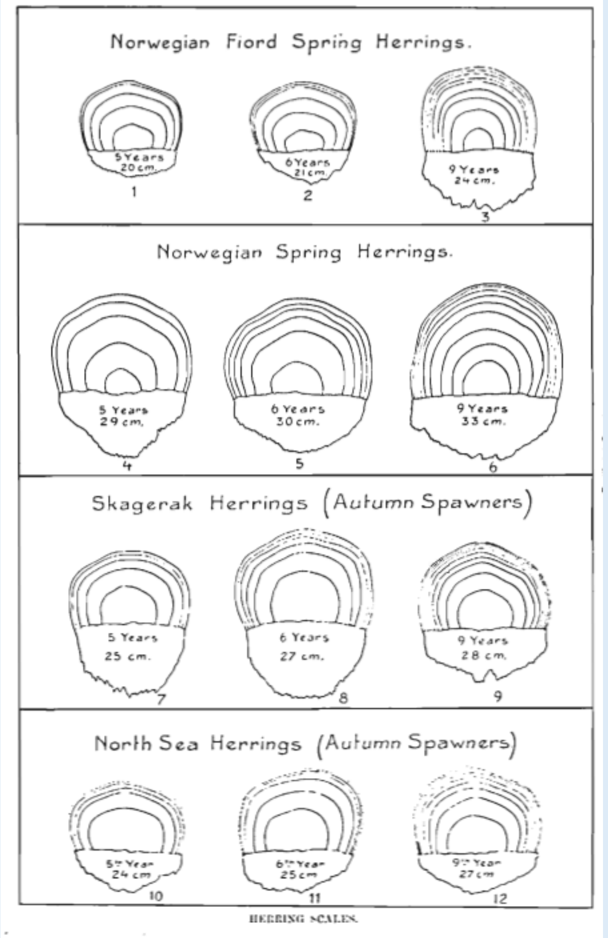
ICES and herring

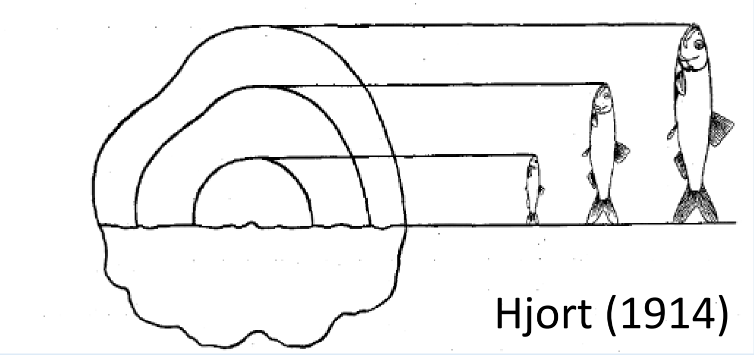
- International Council for the Exploration of the Sea (ICES) established in 1902 over growing concern about decadal variations in fisheries landings
- ICES Committee A, the Migration Committee
  - Chaired by Johan Hjort
- ICES Committee B, the Overfishing Committee
- Both were heavily focused on herring
  - “The coffee bean, the tea leaf, the species of the Torrid Zone [tropics], and the silkworm, have less influence on the wealth of nations than the herring of the northern seas...It has been named the Great Fishery.”

The importance of ageing

- Members of Johan Hjort’s lab noted that scales could determine herring age

Hjort (1914)





Hjort (1914)

The importance of ageing

- Members of Johan Hjort's lab noted that scales could determine herring age
- Used this to track how the ages of herring and other species varied over time

Hjort (1914)

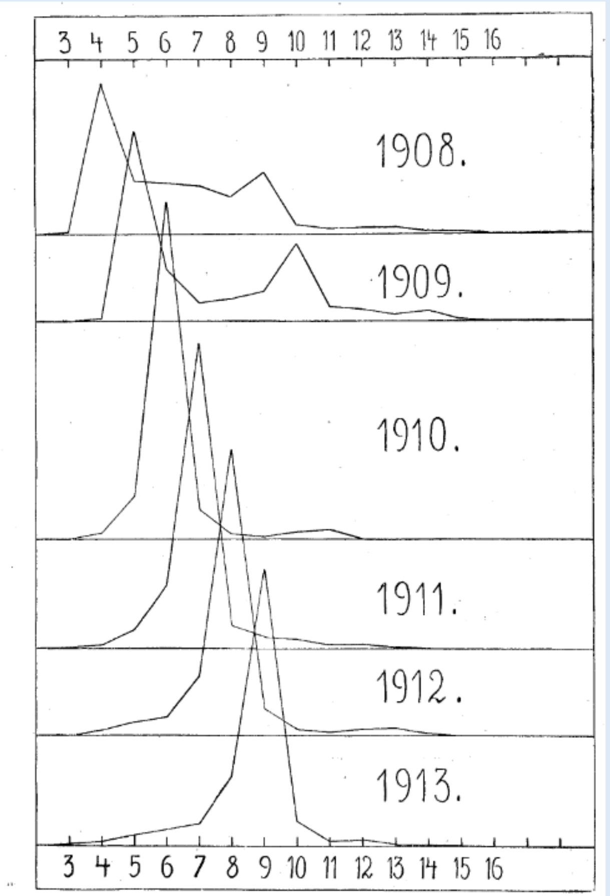
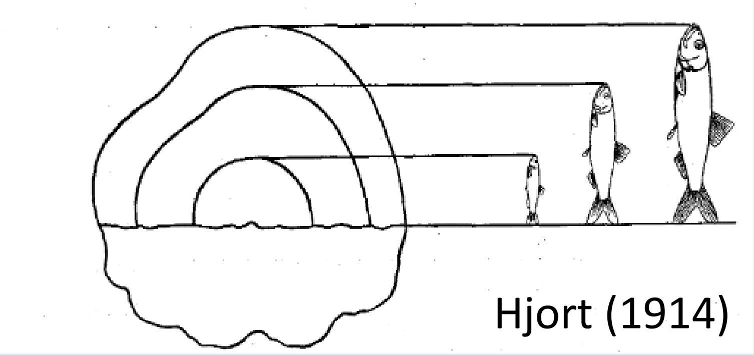


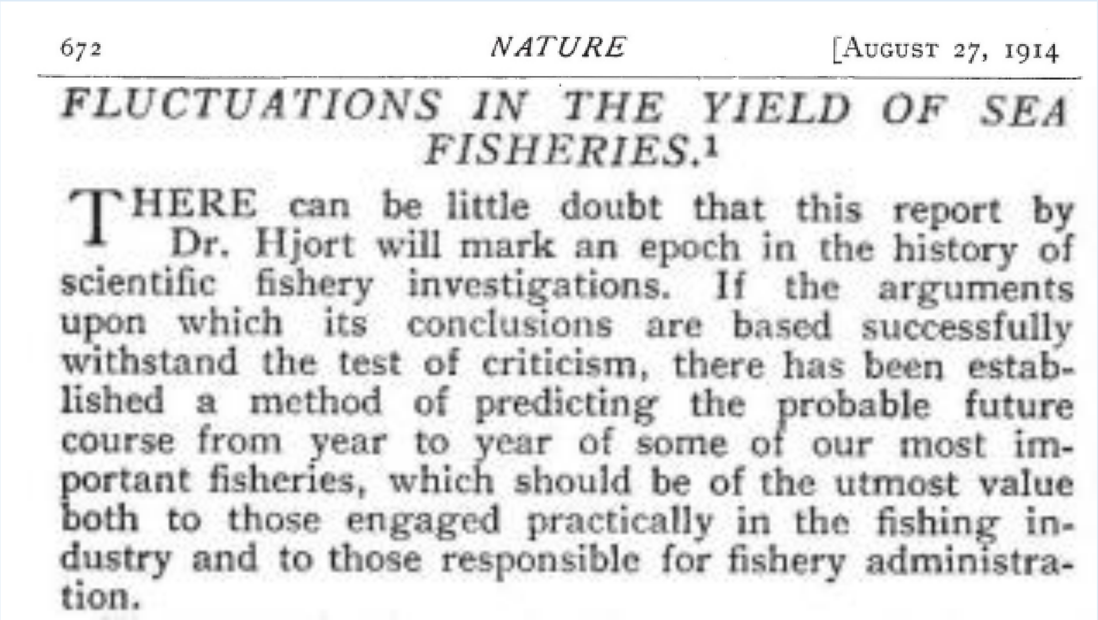
Fig. 16. Composition in point of age of spring herring, 1908—1913. 4 = 4 years old (scales showing 4 winter rings).



Hjort (1914)

From focusing on migrations to populations

- Variability in landings not due to migrations but instead growth of age-structured, geographically defined populations
- Studying the survival of larvae could allow prediction of future catches



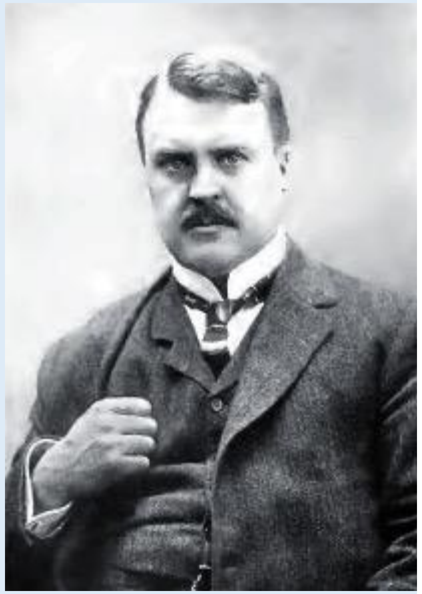
672 NATURE [AUGUST 27, 1914

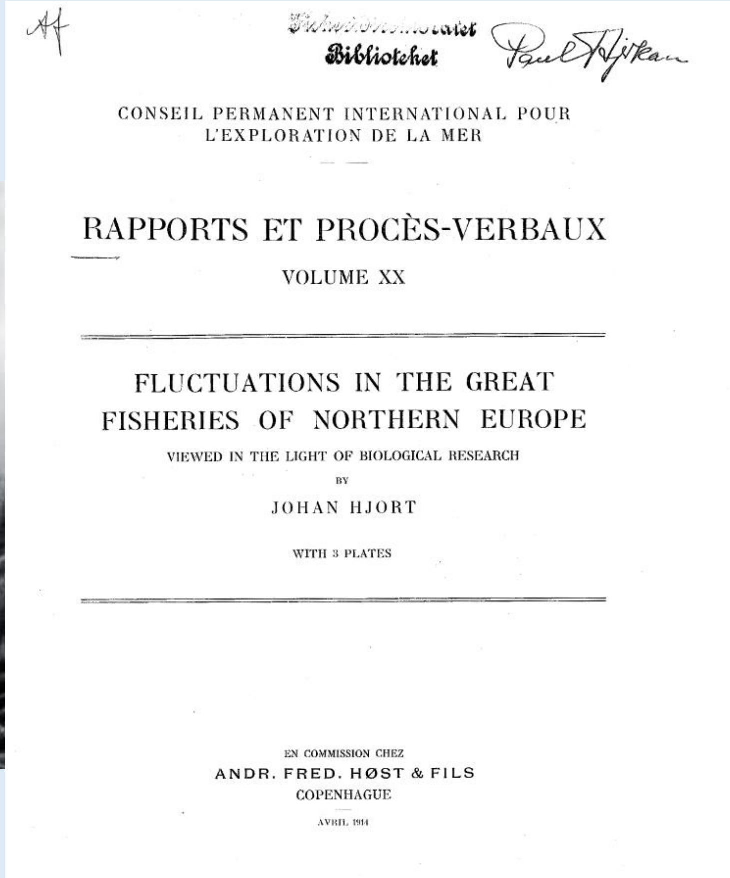
FLUCTUATIONS IN THE YIELD OF SEA FISHERIES.[1]

THERE can be little doubt that this report by Dr. Hjort will mark an epoch in the history of scientific fishery investigations. If the arguments upon which its conclusions are based successfully withstand the test of criticism, there has been established a method of predicting the probable future course from year to year of some of our most important fisheries, which should be of the utmost value both to those engaged practically in the fishing industry and to those responsible for fishery administration.

Johan Hjort's postulates

- Fluctuations in abundance not driven by migration
- Instead, due to variability in reproductive success (i.e., recruitment)
  - Critical period hypothesis
  - Aberrant drift hypothesis





CONSEIL PERMANENT INTERNATIONAL POUR
L'EXPLORATION DE LA MER

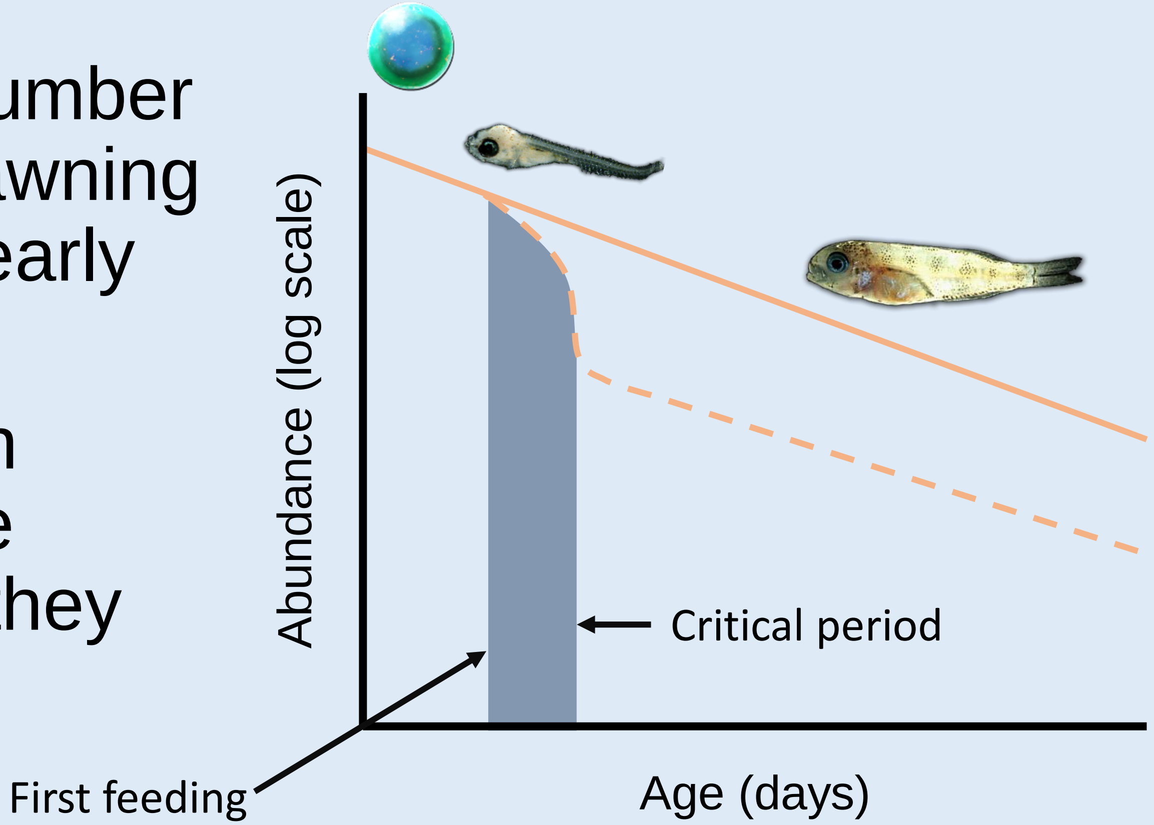
RAPPORTS ET PROCÈS-VERBAUX
VOLUME XX

FLUCTUATIONS IN THE GREAT
FISHERIES OF NORTHERN EUROPE
VIEWED IN THE LIGHT OF BIOLOGICAL RESEARCH
BY
JOHAN HJORT
WITH 3 PLATES

EN COMMISSION CHEZ
ANDR. FRED. HØST & FILS
COPENHAGUE
AVRIL 1914

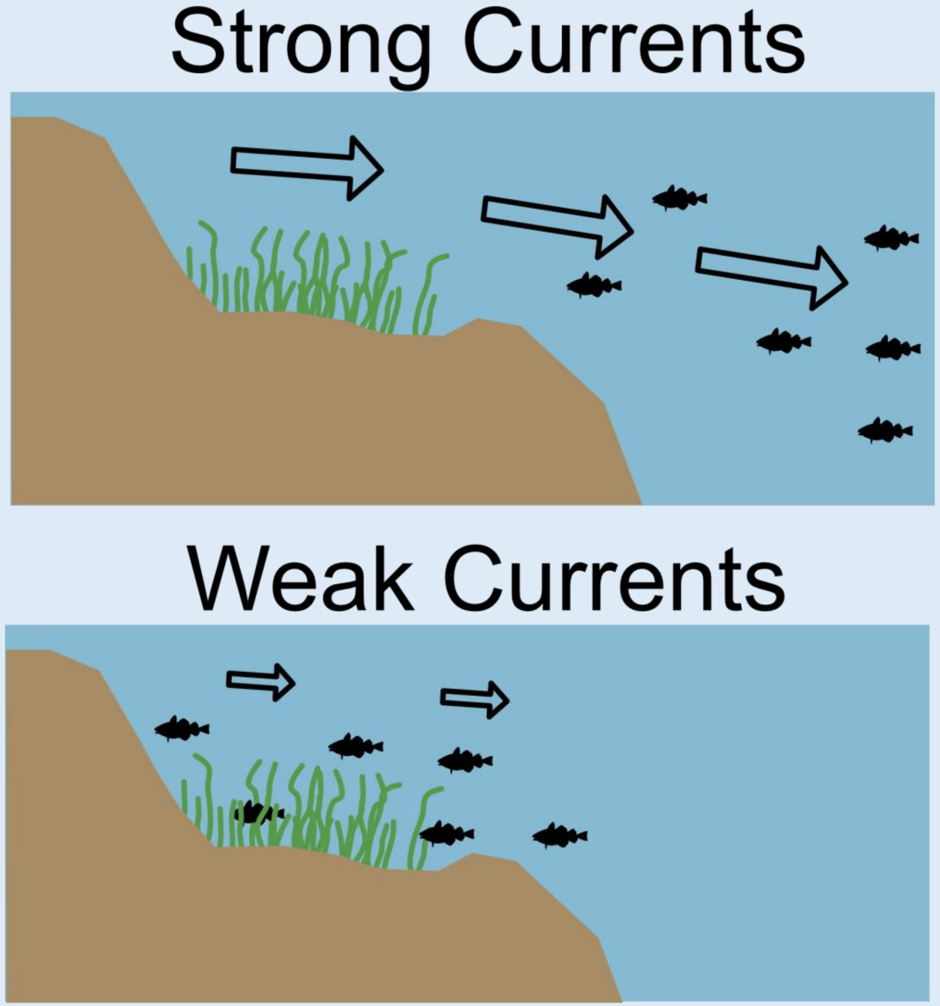
Critical period hypothesis

- Year class strength (i.e., number of fish spawned in one spawning period) determined in the early larval stage
- Once yolk is absorbed, fish larvae need to find suitable planktonic prey quickly or they will die



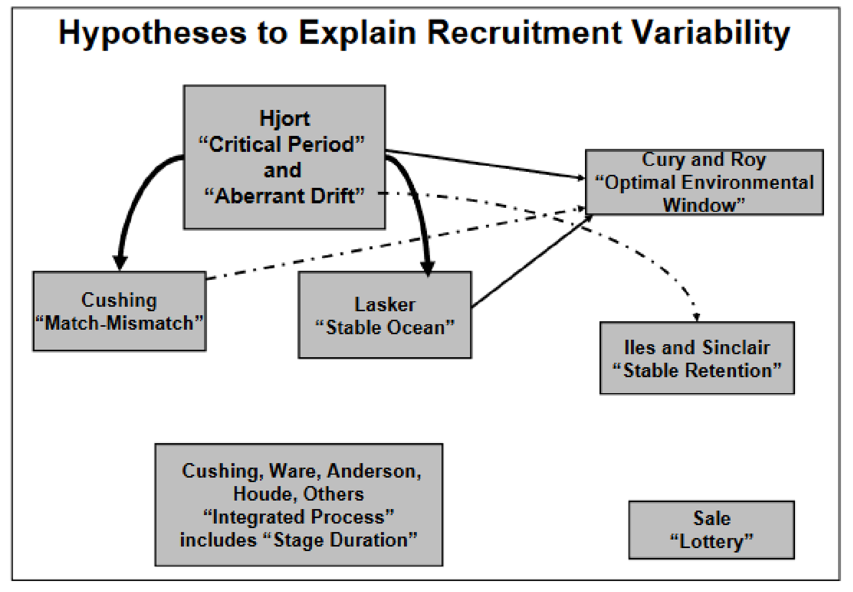
Aberrant drift

- Dispersal of early-life stages by winds and currents outside essential larval and juvenile habitat influences juvenile survival



Larval Fish Ecology

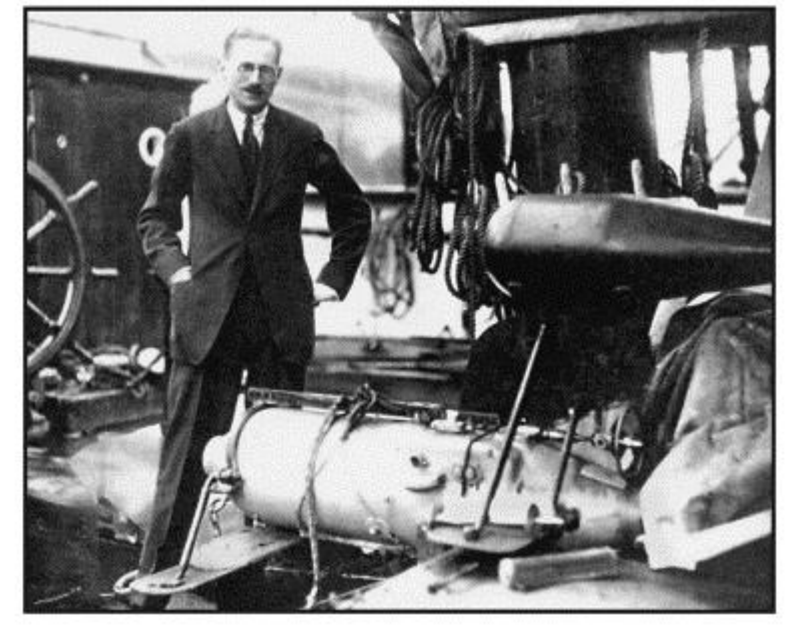
- These “postulates” spurred much of larval fish ecology and recruitment theory for the following century
  - Match-mismatch hypothesis
    - Cushing (1969); Cushing (1990)
  - Stable Ocean Hypothesis
    - Lasker & Zweifel (1978); Lasker (1981)
  - Optimal Environmental Window
    - Cury and Roy (1989)
  - Member/Vagrant Hypothesis
    - Iles and Sinclair (1982)



For a more detailed description of this type of work, see bonus slides and Houde (2008)

Plankton as indicators?

- Hjort’s ideas spurred research into using plankton as predictors of recruitment success
- Alister Hardy tried to relate plankton sampling to young herring abundance
  - Led to his development of the Continuous Plankton Recorder (CPR)



Reid et al. 2003

Forecasting herring catch

- Hardy studied the use of plankton indicators for setting nets within a fishing trip
- Found that herring avoided large phytoplankton blooms and preferentially fed on zooplankton
- Fishing industry did not adopt this practice due to a high frequency of false positives

Sinclair, 2009

Age-census

- Hjort and Heincke determined that an annual “age-census” should be conducted for important stocks
- Expected that the composition of ages could allow the prediction of future catches
- This ended up relying on work done in the overfishing committee and will be discussed later

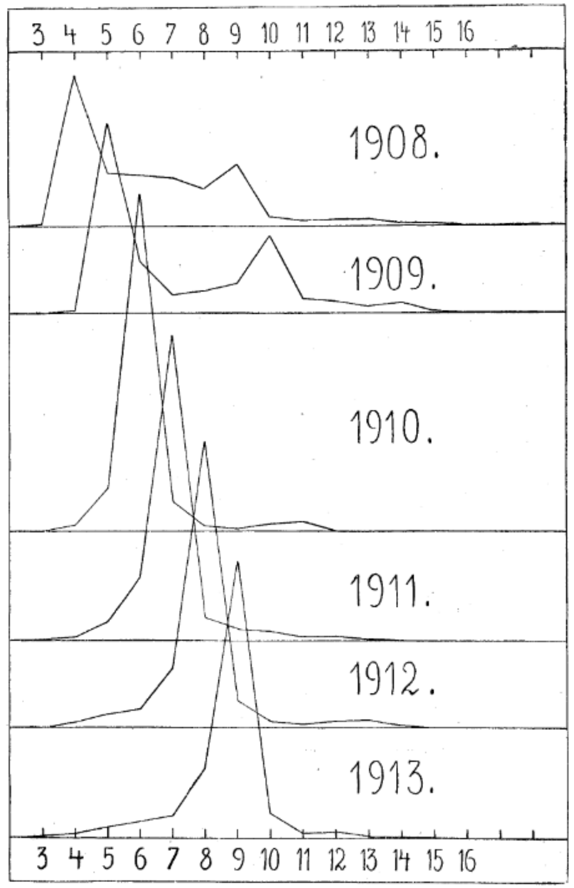


Fig. 16. Composition in point of age of spring herring, 1908—1913.
4 = 4 years old (scales showing 4 winter rings).

Summary of “The Migration Branch”

- Ultimately envisaged variability in fish populations as being driven by the environment
- Fisheries research should try to understand how the environment affects populations via larval survival
- Try to predict future recruitment to enable fisheries to anticipate change
- This led to many innovations and improved understanding about larval fish, but for the most part, has been unsuccessful for managing fisheries

Foreword of Beverton & Holt, 1954 by Pauly

The Overfishing Committee

- Are steam trawlers harvesting too many fish?
  - Conflict emerging between groups of fishers and countries
- “The most essential object of the International Investigation of the Sea is to procure the necessary data for international agreements as to protection of the fisheries from overfishing”

Rozwadowski, 2004

North sea plaice

- Re-named the “plaice committee” in 1907
- Determined that their focus should be to:
  - “…procure the necessary data for international agreements as to the protection of the fisheries from overfishing, and the institution of measures for the improvement of the same.”

Rozwadowski, 2004

First proposed regulations

- In 1913, the committee determined that the plaice fishery had reduced the number of large plaice which led to an increase in capture of small plaice
- Decided they should allow small fish to grow, recommended:
  - Closing nursery grounds
  - Minimum landing size

Rozwadowski, 2004

World War I

- The war stopped the adoption of regulations
  - Most fisheries were closed anyway
- Closure allowed a unique view of effects of closures on populations
- However, no appetite for regulations after the war

Rozwadowski, 2004

Underfishing?

- Plaice regulations were not implemented after the war
- In fact, scientists began to argue about whether underfishing led to crowded fishing grounds and decreased individual growth

Rozwadowski, 2004

Scientific advice for management

- In 1927, the League of Nations Economic Committee deferred to ICES for advice about exploitation of marine resources
- Scientists started to focus more on predicting catch, notably,
  - E.S. Russell
  - Michael Graham

Predicting catch with ages

- In 1930, Hjort stated:
  - “A biological service must be organized for the regular observation of the age distribution of the stock, and of the relative numerical strength of year-classes. It will be something like the meteorological service ...”
- Soon after, predictions were made for several fisheries by using age composition data and estimates of mortality

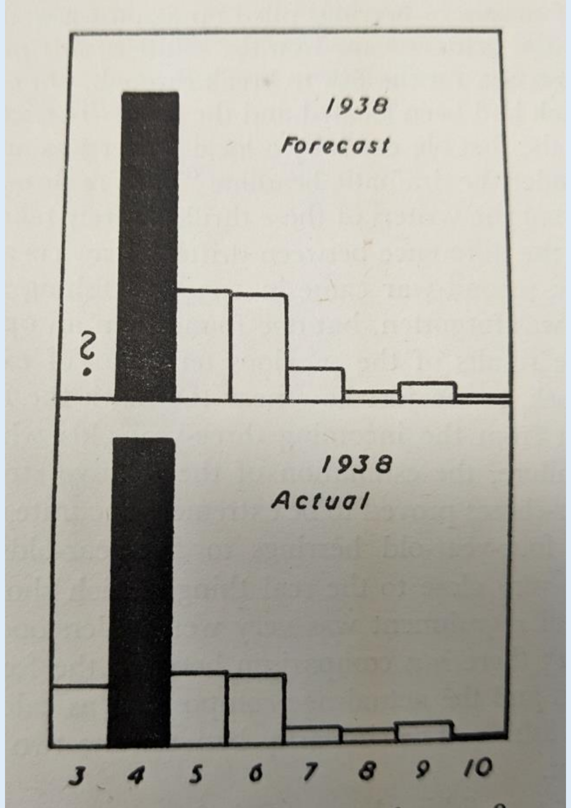


Fig. 17.—The forecast for 1938 compared with the actual age of the herrings.

Mortality estimation

- Predictions were only possible because of new models that allowed mortality estimation
- Simple model developed by E.S. Russell

Biomass next year = Biomass this year + (births and growth) – (fishing mortality and natural mortality)

- Interesting point he makes,
  - "...the assumptions on which these conclusions depend, namely the constancy of rate of growth, rate of natural mortality, and rate of introduction of new stock."

Russell (1931)

The Overfishing problem

- First application of the recently developed “logistics curve” to help predict effects of fishing
- Further highlighted the need for regulations
  - “Fishing has gone beyond the optimum and resulted in depressing stocks below their most profitable level”

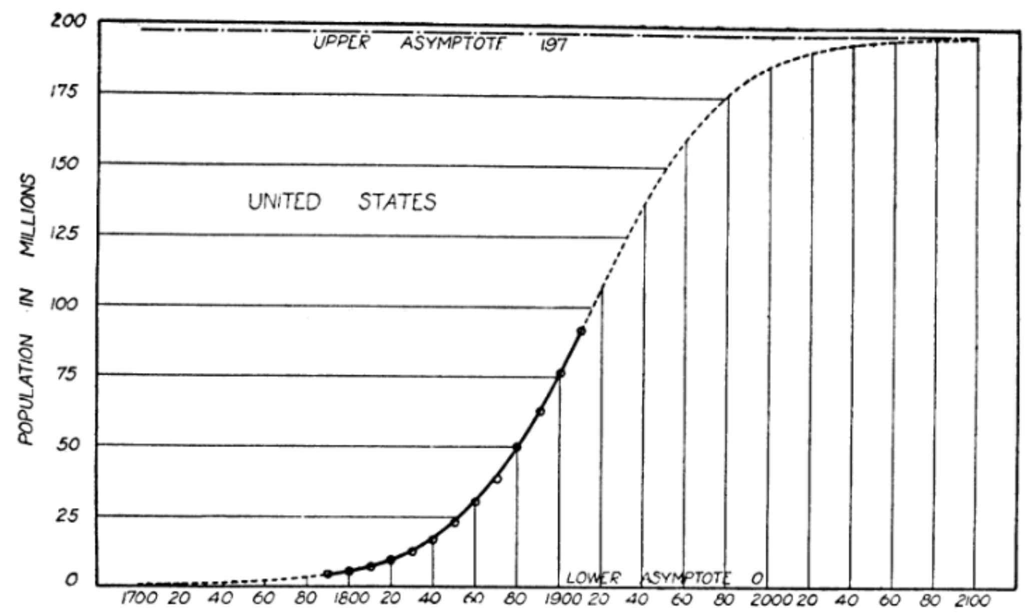


Fig. 1. Symmetrical Logistic Curve Fitted to U.S. Census Data
From Pearl, 1924c.

Russell (1931)

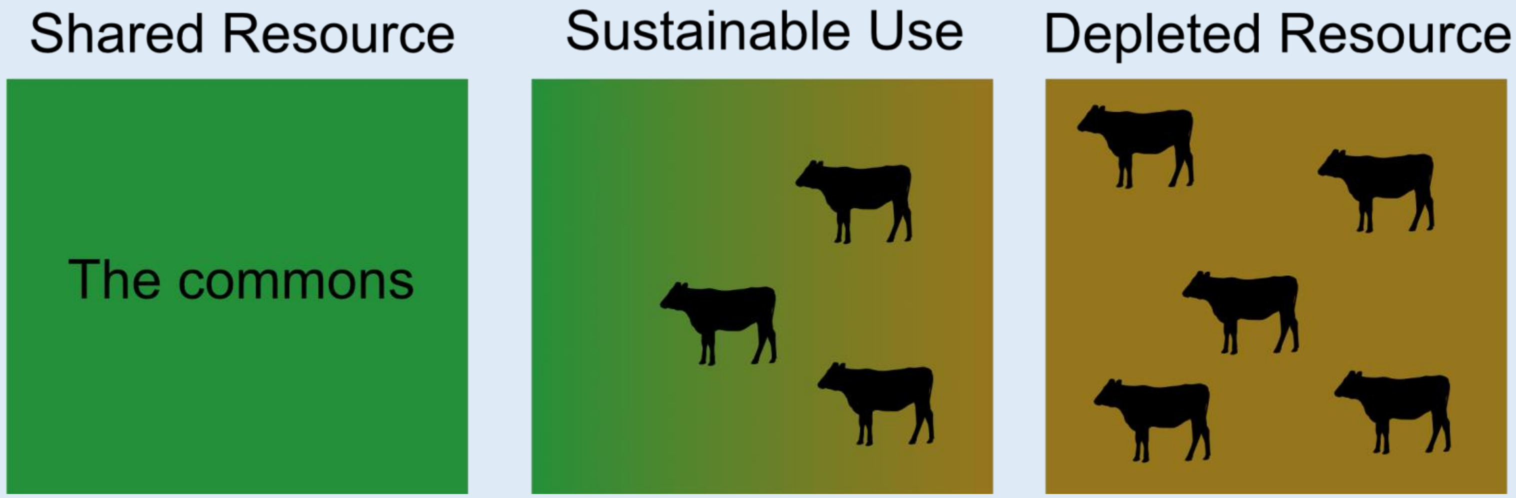
Michael Graham

- Heavily interested in adoption of fishing regulations
  - “Fisheries that are unlimited become unprofitable”
- Fishers leaving the industry due to lack of profit
- Although the theory was not fully developed yet, his thinking fell in line with the problem of the **tragedy of the commons**

Graham was eccentric. He roasted and ground the beans for his coffee at the laboratory, wrote with quill pens fashioned from the feathers of his own geese, and wore a flowing cape with a pocket big enough to carry Ministry files. He also rode his Arab mare around Lowestoft at night with rear lights fitted to his riding hat and stirrups.[6] When he was appointed

Tragedy of the commons

- "A situation in a **shared-resource system** where individual users acting independently according to their own self-interest behave contrary to the common good of all users by depleting or spoiling that resource through their collective action" – [Forster (1833)](); [Hardin (1968)]()

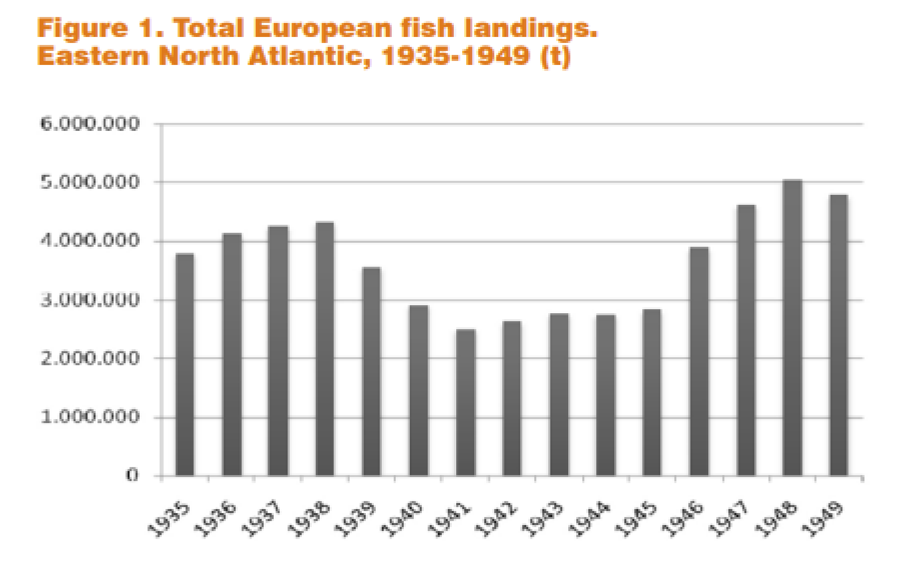


Required conditions for the commons

- Limited resources
- Non-excludable
- Rivalrous harvest

World War II

- Again, progress was made and ten countries signed an agreement to regulate mesh size to allow release of immature fish in 1937
- But, then WWII began
- Marine fisheries were substantially reduced during WWII



A wild aside

- Forecasts for the East Anglian (East of England) herring fishery were made challenging after the war
- Forecasts were based on herring age composition estimates
- But...
  - “many of the early post-war herrings had scales that were quite unreadable...the conclusion was that many of the adventitious rings must have been due to the war, possibly by underwater explosions, the shock waves from which had marked the scales in some strange way.” – Hodgson (1957)

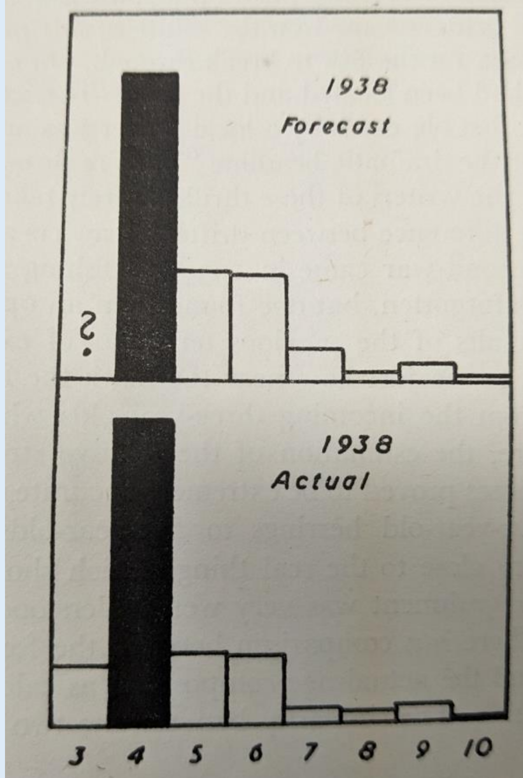


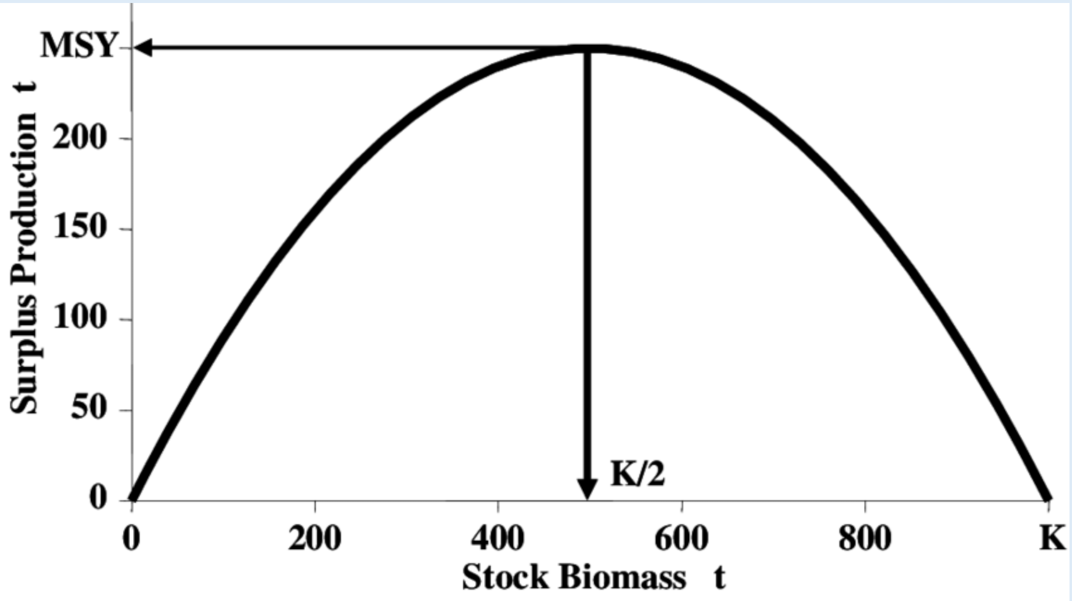
Fig. 17.—The forecast for 1938 compared with the actual age of the herrings.

Post-war regulations this time?

- ICES scientists wanted to avoid repeating what happened after WWI
- **New tools** were allowing calculation of “optimal catches” which intrigued governments
- Scientists wanted to couple biology and economics
- In 1946, the Overfishing Committee became a permanent commission to view and revise regulations

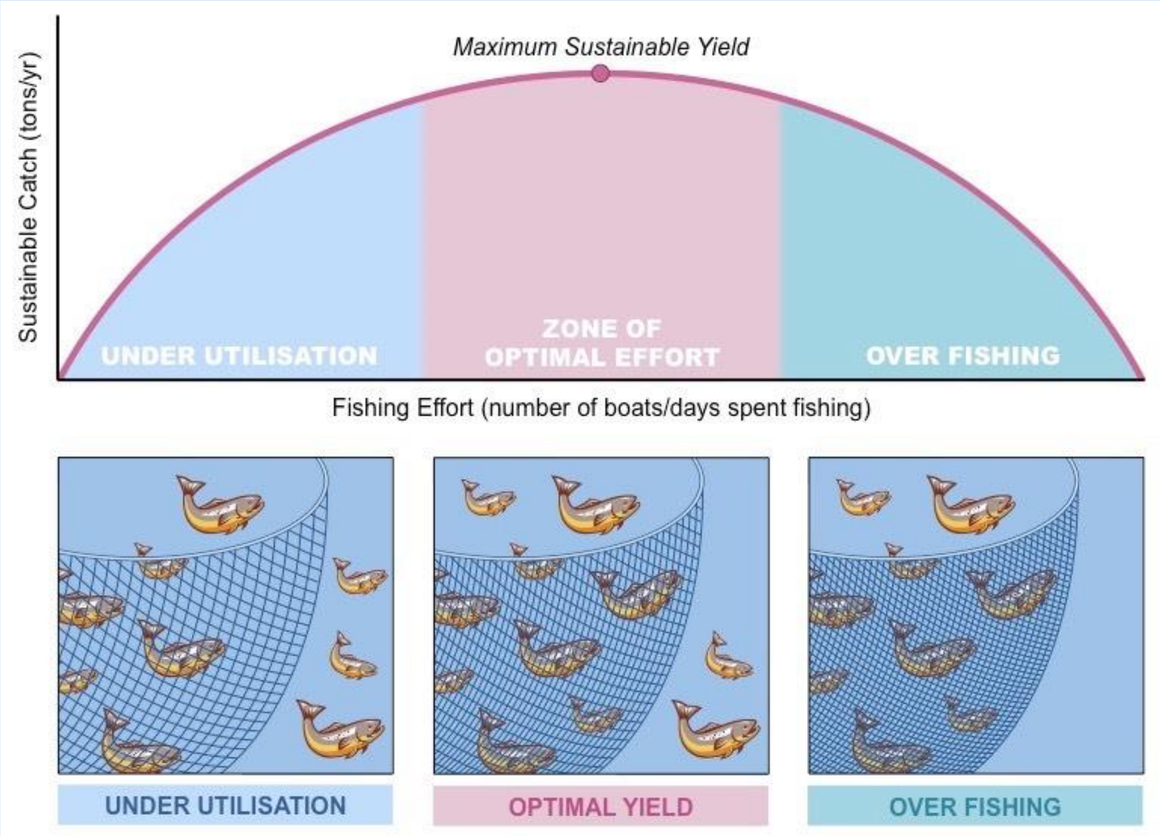
A key tool: Surplus production model

- Schaefer (1954) developed a method to estimate **surplus production** using catch data and changes in relative abundance
- Surplus production – net biomass gain each year that can either produce biomass growth or fisheries yield



Maximum Sustainable Yield (MSY)

- The largest catch that can be taken over an indefinite period
- To do this, population size needs to be maintained at the point of maximum growth rate
    - Only remove the number of individuals that would contribute to population size growing



ICES aim within reach

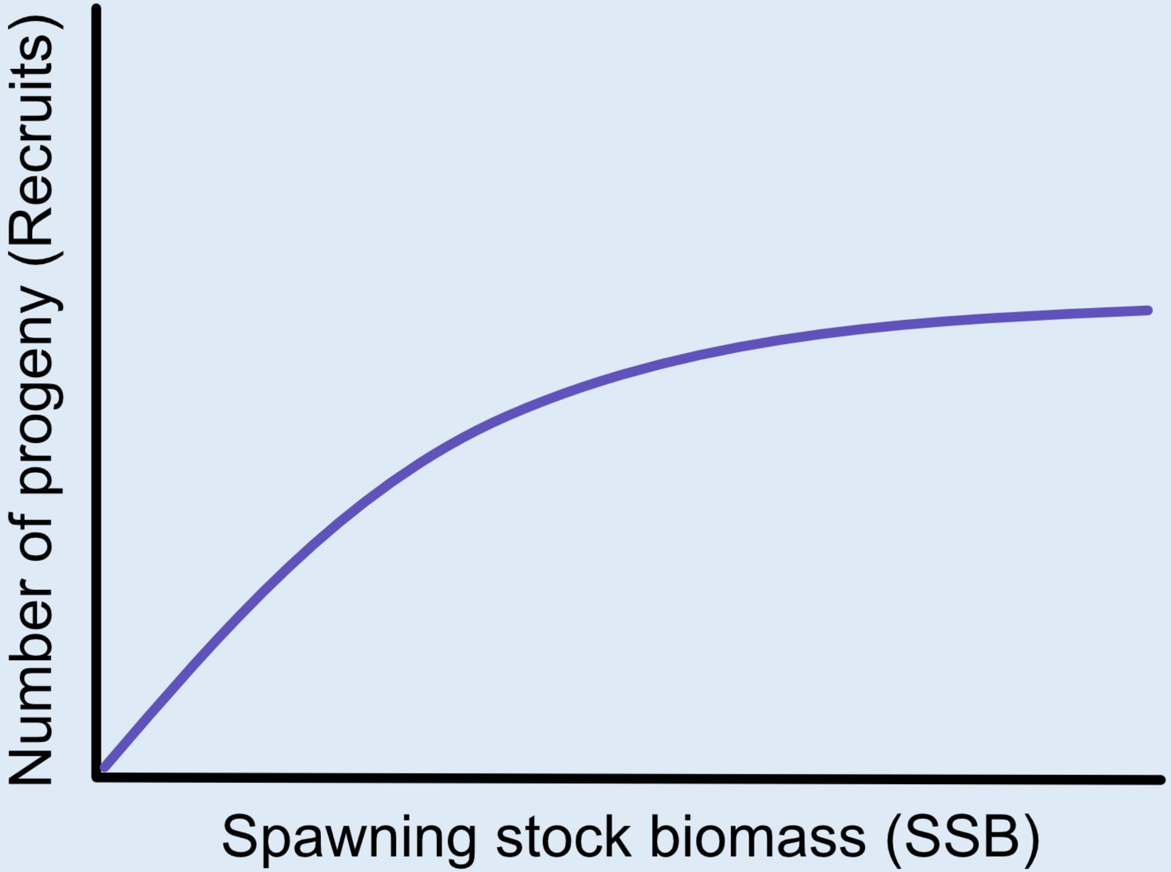
- Science and management were becoming more interlinked through the creation of international commissions
- Regulatory commissions started to reach out directly to ask for advice
- As this was happening, the methods for estimating the effects of regulations became more advanced thanks to **Ray Beverton** and **Sidney Holt**

Ray Beverton & Sidney Holt

- Regarded as the founders of quantitative fisheries science
- Most well-known for:
  - Model of density-dependent growth
    - Beverton-Holt Model
  - First representation of age-structured population dynamics with size selective fishing
  - Distinguishing between types of overfishing

Beverton-Holt recruitment model

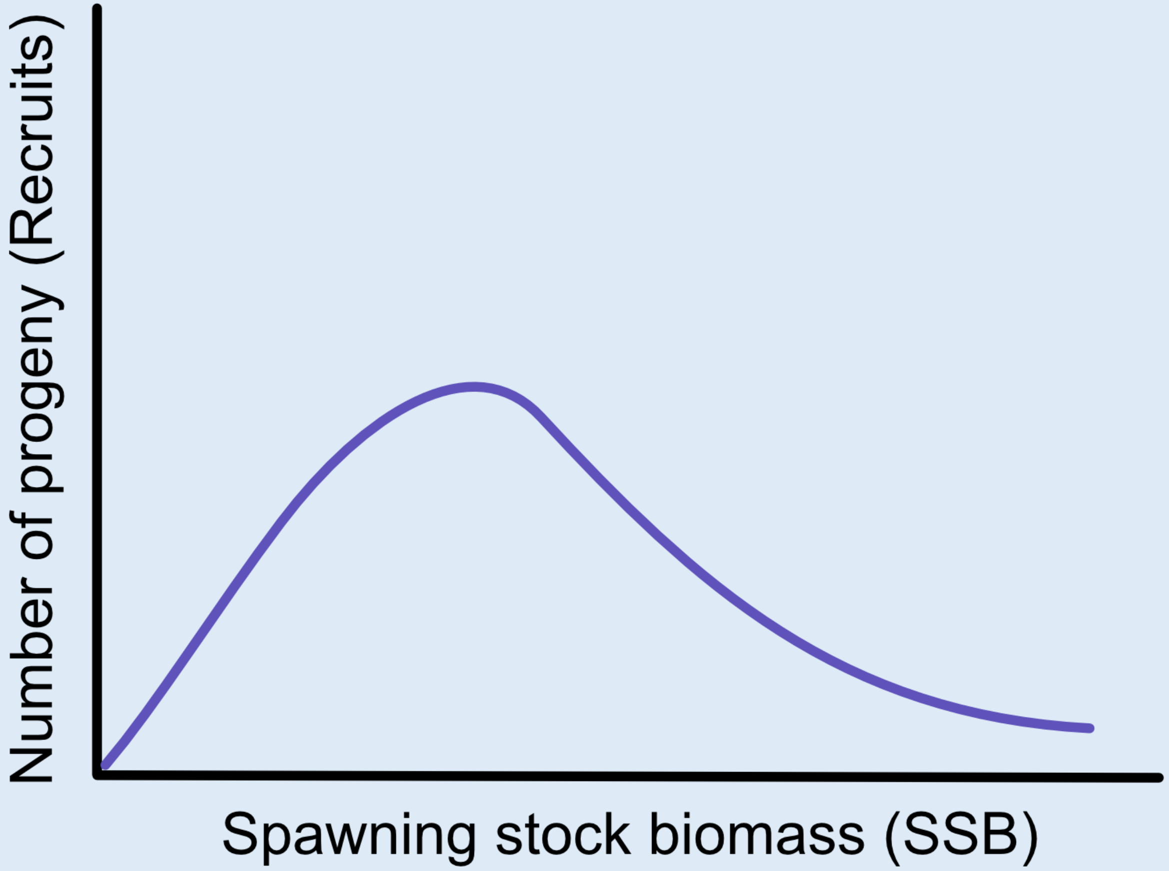
- Developed a model that allows juvenile mortality to be density-dependent
  - Recruitment – addition of new individuals to a population
  - Spawning stock biomass – usually defined by weight of mature females



Ricker recruitment model

- Alternative model for changes in recruitment with stock size
- Identified that biology/ecology of some species may produce “overcompensation”
  - Non-linear effect of density-dependence where recruitment actually declines at high SSB

Ricker (1954)

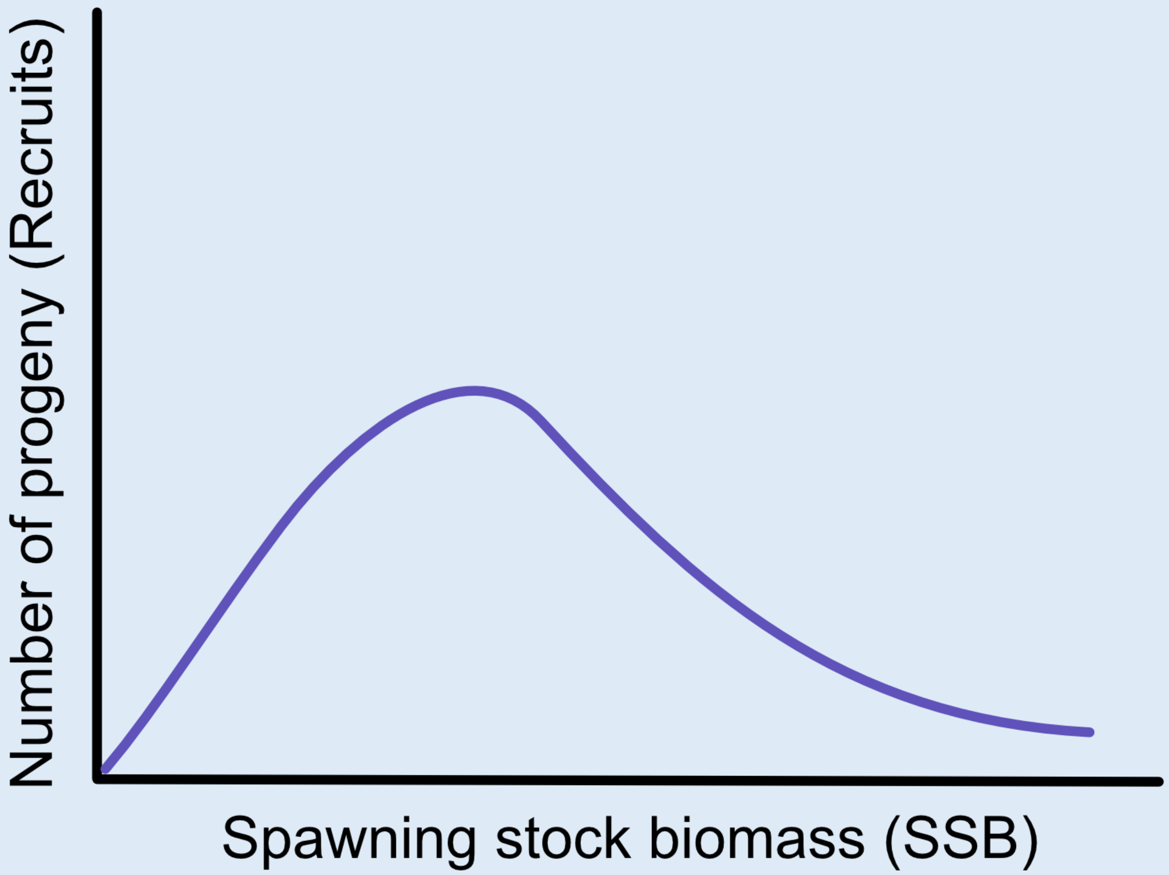


Pacific salmon

- Pacific salmon migrate to natal spawning tributaries where they die after spawning
- As number of spawners increases, competition between spawners and juveniles can actually end up reducing recruitment to the marine environment

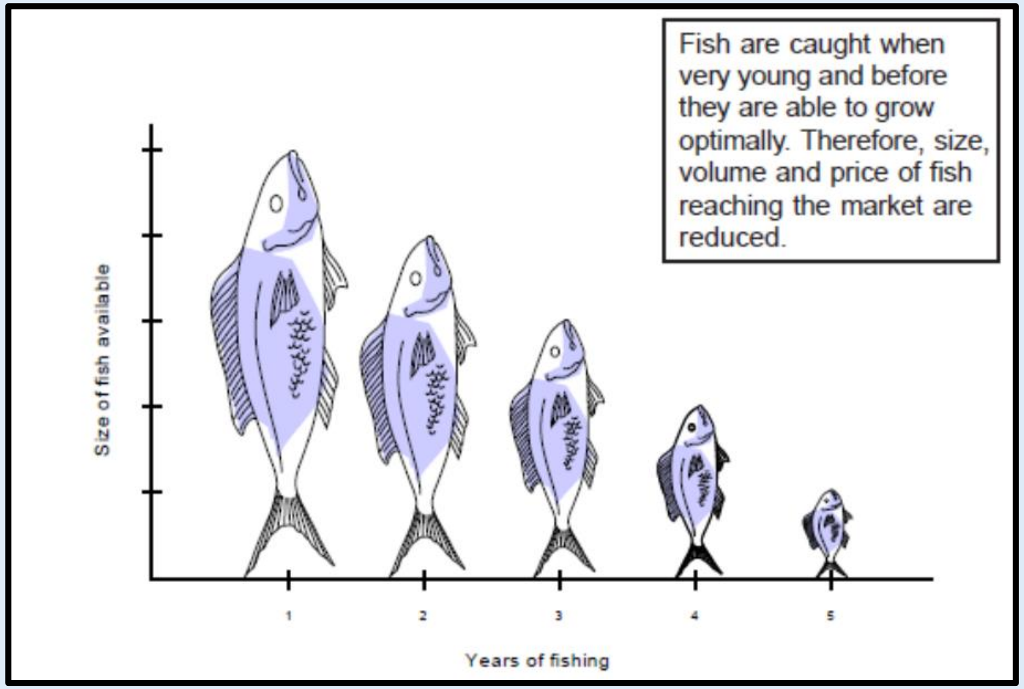
Pacific salmon

- Pacific salmon migrate to natal spawning tributaries where they die after spawning
- As number of spawners increases, competition between spawners and juveniles can actually end up reducing recruitment to the marine environment



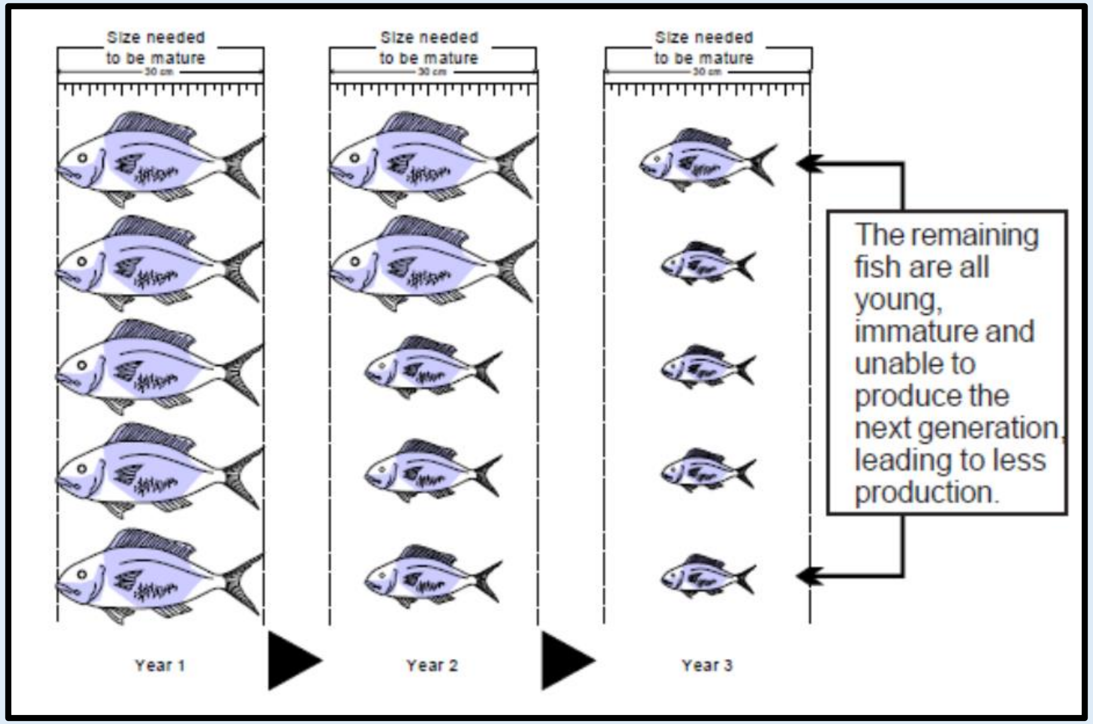
Types of overfishing

- Growth overfishing – fish harvested at smaller sizes than would maximize production
  - Solution: increase average size harvested



Types of overfishing

- Growth overfishing – fish harvested at smaller sizes than would maximize production
  - Solution: increase average size harvested
- Recruitment overfishing – spawning stock size is reduced enough to negatively impact recruitment
  - Solution: reduce fishing mortality



An oft overlooked contribution

- Much of the work of Hjort, Graham, Russell, Beverton, Holt, and others was likely influenced by Fyodor Baranov
- In 1918, he wrote a fundamental paper, “On the question of the biological bases of fisheries”
  - Developed mathematical basis for fishing on age-structured populations and ideas about “optimal exploitation”
- Did not initially receive attention due to publication in Russian (and politics?)

ICES Journal of Marine Science

ICES CIEM

ICES Journal of Marine Science (2021), 78(6), 2166–2172. doi:10.1093/icesjms/fsaa239

Contribution to the Themed Section: ‘*A Tribute to the Life and Accomplishments of Sidney J. Holt*’

Baranov’s contributions to the Beverton–Holt model

Trevor J. Kenchington *

ICES Journal of Marine Science

ICES CIEM

ICES Journal of Marine Science (2021), 78(2), 743–754. doi:10.1093/icesjms/fsaa075

The unknown Baranov. Forty years of polemics over the formal theory of the life of fishes

Alexei Sharov *

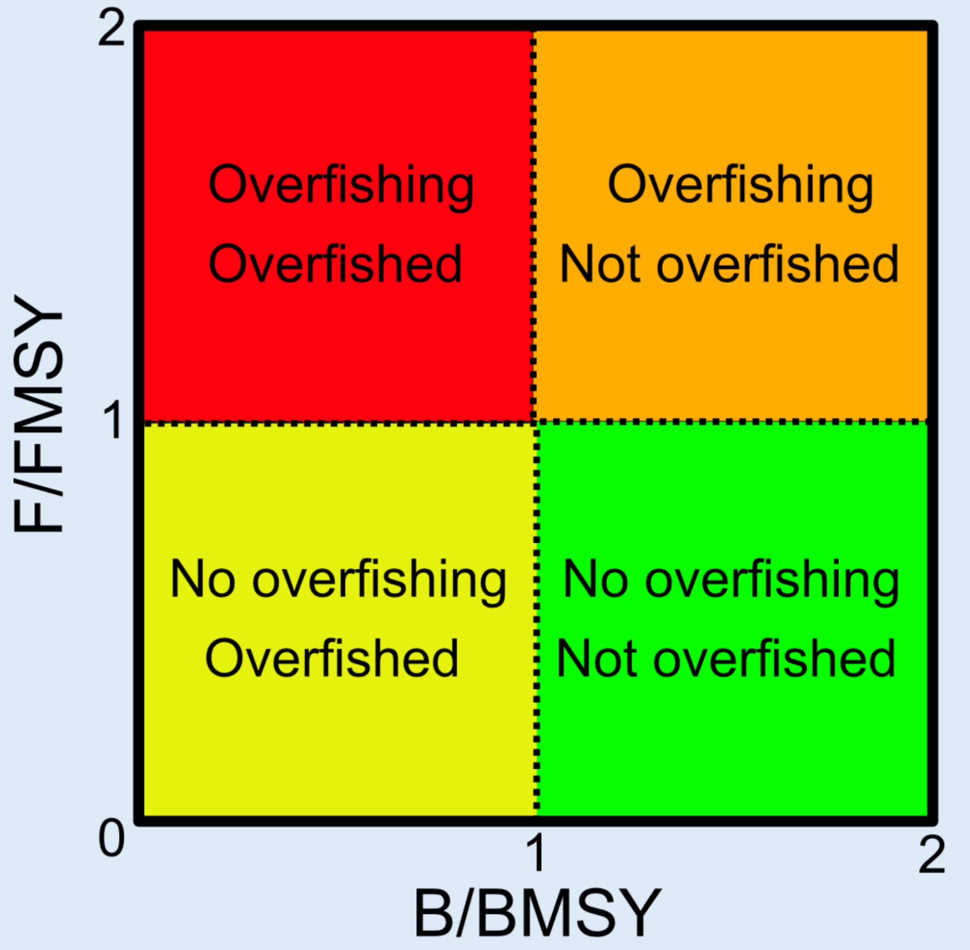
Baranov’s Catch Equation

- Predicted that in a seasonal fishery, increasing effort will lead to an upper limit on catch
  - Set by the number of fish at the start of the season
- Fishing later will catch fewer fish because:
  - Fewer fish present
  - Re-fishing areas that have been fished
- Did not account for change over multiple seasons

Returning to MSY

- Beverton-Holt and Ricker recruitment models were foundational for estimating MSY
- This concept became entrenched as the standard reference for the sustainability of fisheries by many national and international management agencies in the 1950s

“Kobe plot”



Too good to be true?

- Confidence in these new tools and the communication between scientists and regulators was at an all time high in the 1950s
- However, it was not too last
- Many fisheries collapsed in the 1950s and 1960s, due to:
  - Catch efficiency improvements
  - Political interventions limiting uptake of suggested regulations
  - Inability to understand complex socioecological systems

An epitaph for MSY

- Too much reliance on MSY
  - Errors can lead to overfishing
  - Focus on “sustainable yield” can deteriorate biology of population and biodiversity of ecosystem making this rate unsustainable
  - There are situations where maximizing yield should not be a goal in the first place (e.g., recreational fisheries)

[Larkin (1977)]

TRANSACTIONS of the AMERICAN FISHERIES SOCIETY

January 1977
VOLUME 106
NUMBER 1

An Epitaph for the Concept of Maximum Sustained Yield[1]

P. A. LARKIN
Institute of Animal Resource Ecology, University of British Columbia Vancouver, British Columbia V6T 1W5

About 30 years ago, when I was a graduate student, the idea of managing fisheries for maximum sustained yield was just beginning to really catch on. Of course, the ideas had already been around for quite a while. Baranov (1918) was the first to combine information on growth and abundance to develop a catch equation, and Russell (1931) and Graham (1935) brought the dynamic pool model to the forefront, but they were working from a base of natural history and fishery biology that had been growing for several decades.

By the late 1930s, in North America, the conservation movement was in full cry and fisheries, like other resources, were being illuminated in the glow of the Gospel of Efficiency (Hays 1969). In dozens of states and provinces, fish and game regulations were proliferated, commercial fisheries were increasingly documented, and there was a growing awareness of the necessary scientific base for management. Thompson and Bell (1934) came to the conclusion that too much fishing effort was at the heart of the halibut problem; Hile (1936) produced his classic on the cisco in Wisconsin; and the first steps were being taken to restore the Fraser River sockeye from the effects of overfishing and the Hell's Gate blockage.

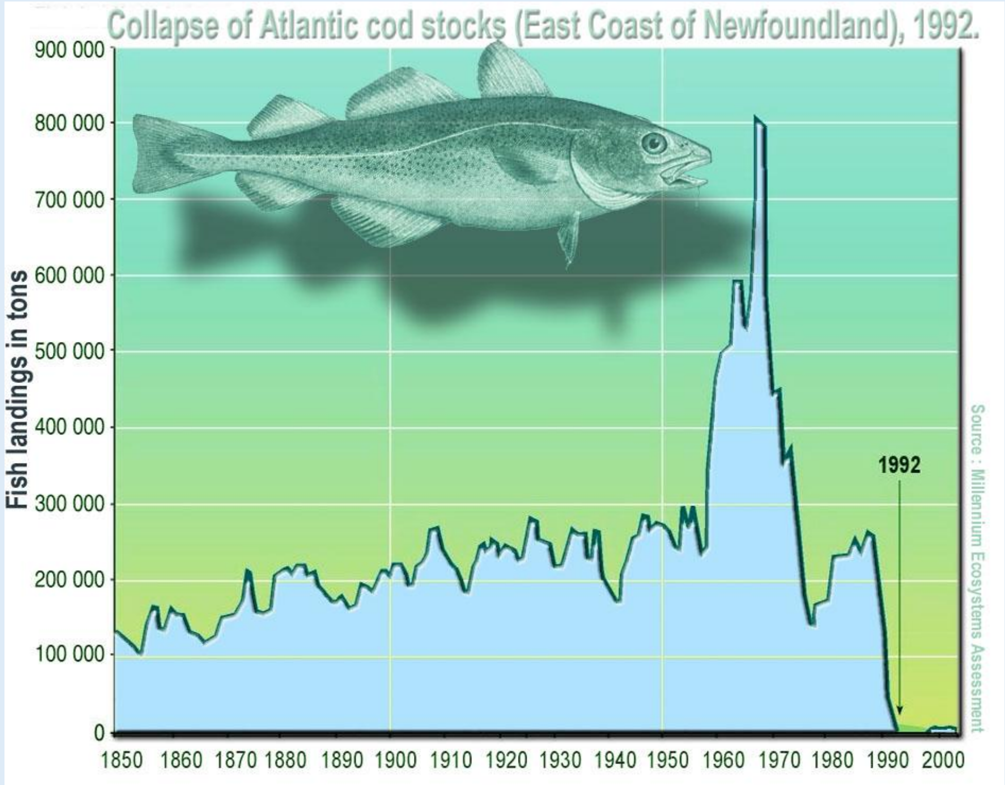
The ten years following World War II were the golden age for the concept of maximum sustained yield. Ricker (1948) produced his famous “green book,” the first version of his handbook (Ricker 1958); Fry (1947) developed the virtual population idea; and Schaefer (1954) proposed his method for estimating surplus production under nonequilibrium conditions. The literature crackled with new information and new ideas. The solidification of the concept of MSY, its application to fisheries here, there, and everywhere, was just under way. World fisheries catch was a mere 20 million tons, and there were signs in lots of places of irreligious practices such as harvesting more or less than should be harvested. In a mood of excitement about opportunities, coupled with determination to do it properly, the FAO emerged as a major actor in the international fisheries scene.

It was in consequence of this flowering of activity that the graduate students of those days had a missionary zeal about them, and as more than one wit has said, “They had a fine vocabulary of stained glass language.” Briefly, the dogma was this: any species each year produces a harvestable surplus, and if you take that much, and no more, you can go on getting it forever and ever (Amen). You only need to have as much effort as is necessary to catch this magic amount, so to use more is wasteful of effort; to use less is wasteful of food. Basically, it was a puritanical philosophy in which the supreme powers were pretty harsh on people who enjoyed themselves rather than doing precisely the Right Thing. Armed with scientific knowledge about the number of fishermen and technological advances, the

[1] Keynote address to the American Fisheries Society Annual Meetings, Dearborn, Michigan, September 19–24, 1976.

On to the present

- The challenges that caused collapses in the 50-60s have arisen numerous times since
- We are trying to grapple with these challenges still



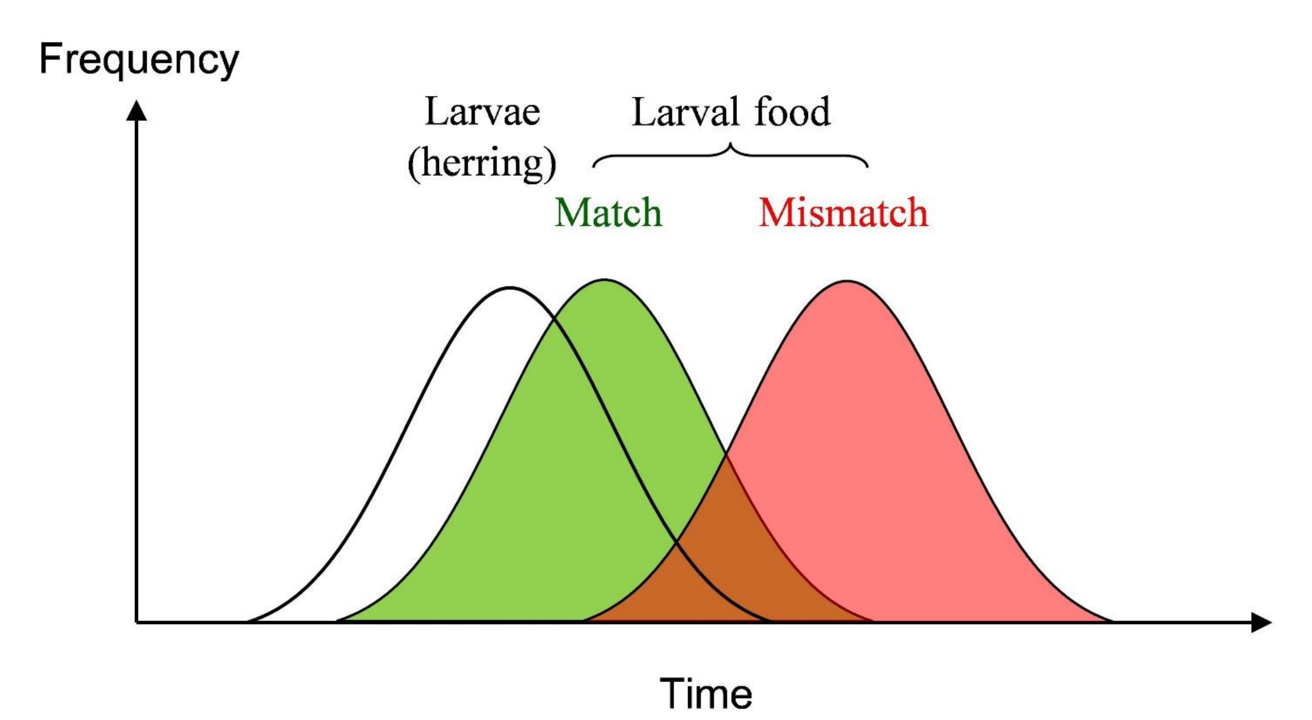
Key take-away

- This history should make clear that the knowledge created via fisheries science has been intended, since its start, to maximize the exploitation of fisheries
- Fisheries science is inherently linked to the economic and social importance of fisheries
- Population dynamics modeling serves as the primary means for determining sustainable yields

BONUS: Key Recruitment theories

Match-Mismatch Hypothesis

- Recruitment variability is driven by phenology and overlap with lower trophic level phenology
- Phenology – timing of seasonal activities
  - Feeding
  - Reproduction

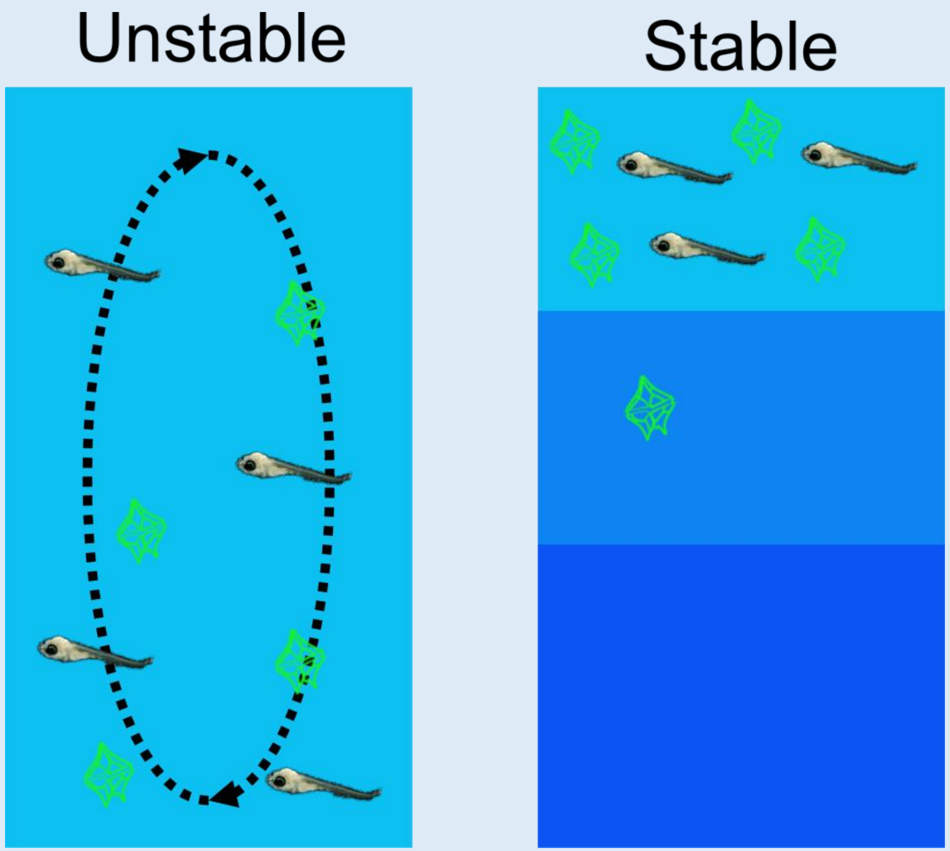


Cushing (1969); Cushing (1990)

Stable Ocean Hypothesis

- Favorable and “stable” physical and biological ocean conditions important for larval survival
- When stable, prey form concentrations in stratified ocean layers

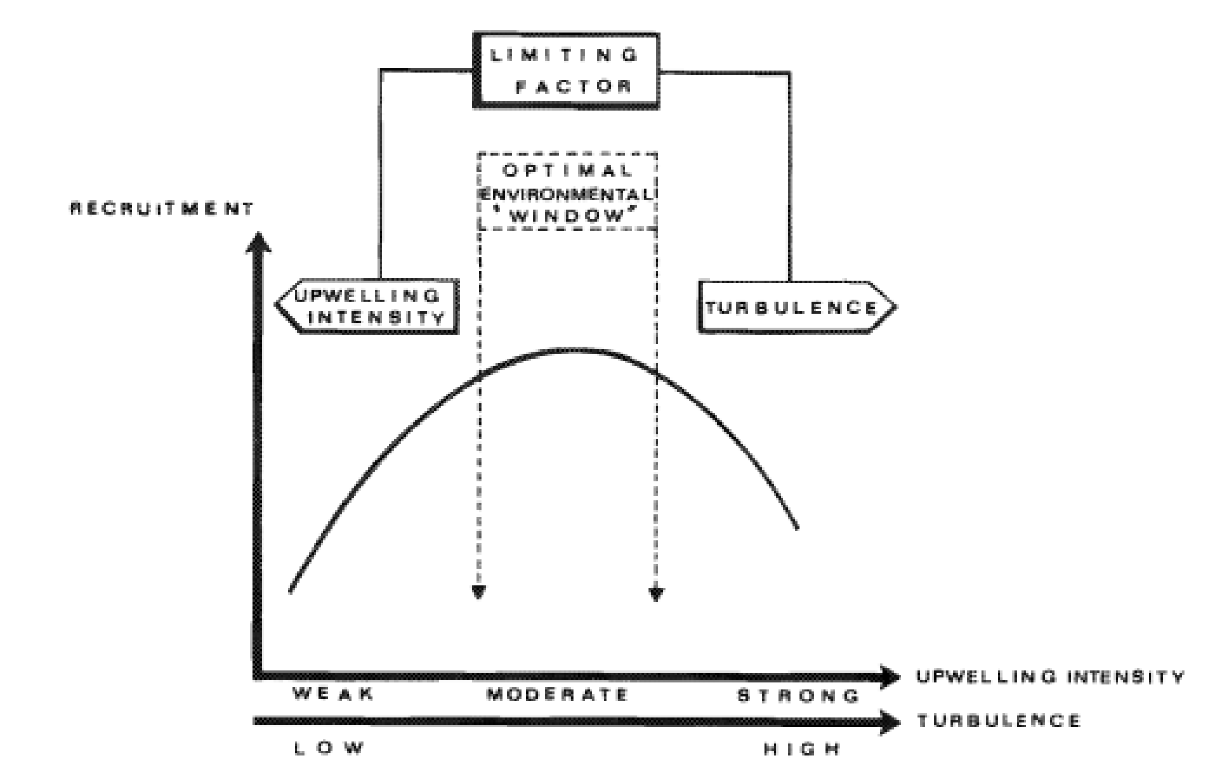
Lasker & Zweifel (1978); Lasker (1981)



Optimal environmental window

- Recruitment in upwelling ecosystems depends on upwelling intensity and turbulence
- Successful when both are moderate
  - Minimize advective losses
  - Maximize foraging success

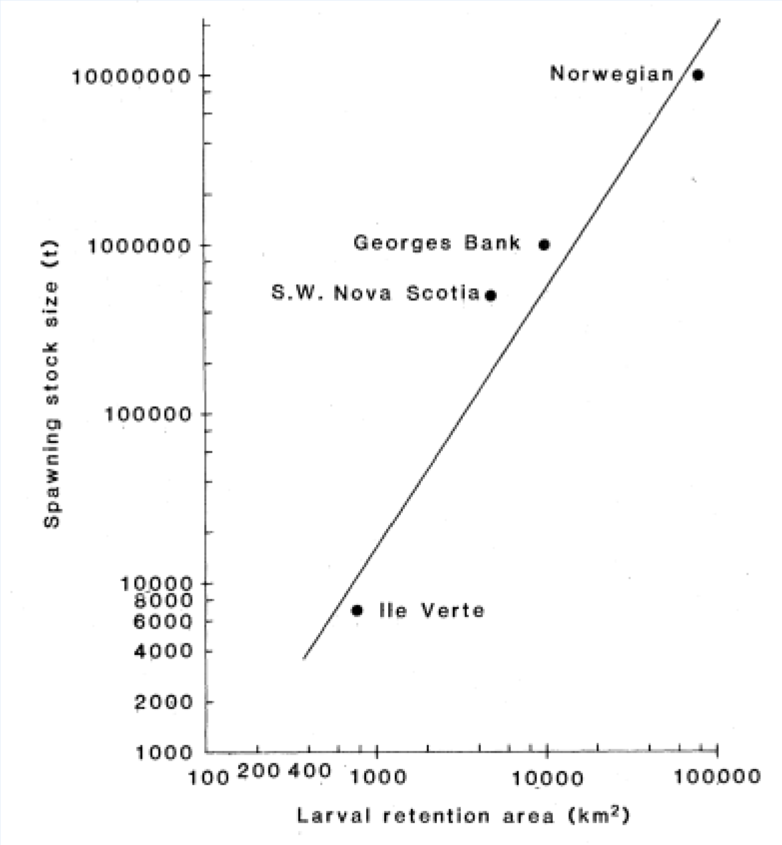
[Cury and Roy (1989)](#)



Member/Vagrant Hypothesis

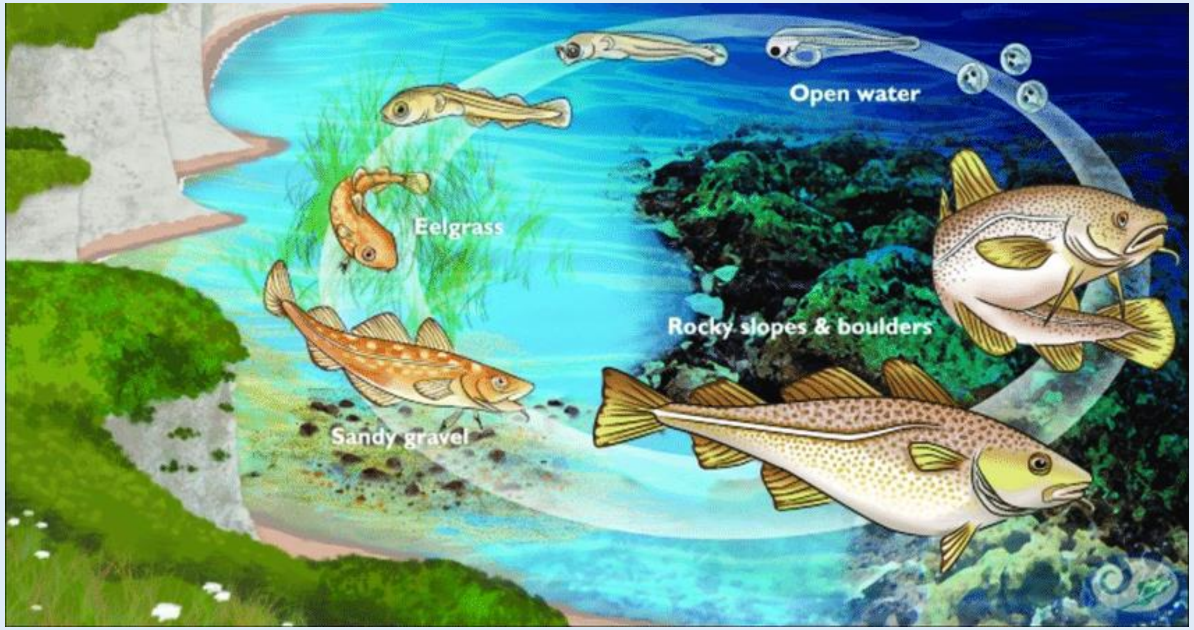
- Physical retention of early-life stages (not prey) is critical for recruitment
- Depends on adults spawning in the right place and right time
  - i.e., currents are favorable

[Iles and Sinclair (1982)](#)



Day 2 – Population growth and life history

- Density independent growth
- Density dependent growth
- Growth
- Maturity
- Mortality
- There will be equations (but fun ones?)



Learning Objectives

- General history of fisheries science
- **What are the key mathematical underpinnings of population growth theory?**
- **What biological characteristics define population growth?**
- How do we use these theories to track population dynamics?
- What are the key population dynamics currently applied?
- How do population dynamics models inform fisheries management?

How do populations grow?

- The simplest way to explain how a population changes from one year to the next is:

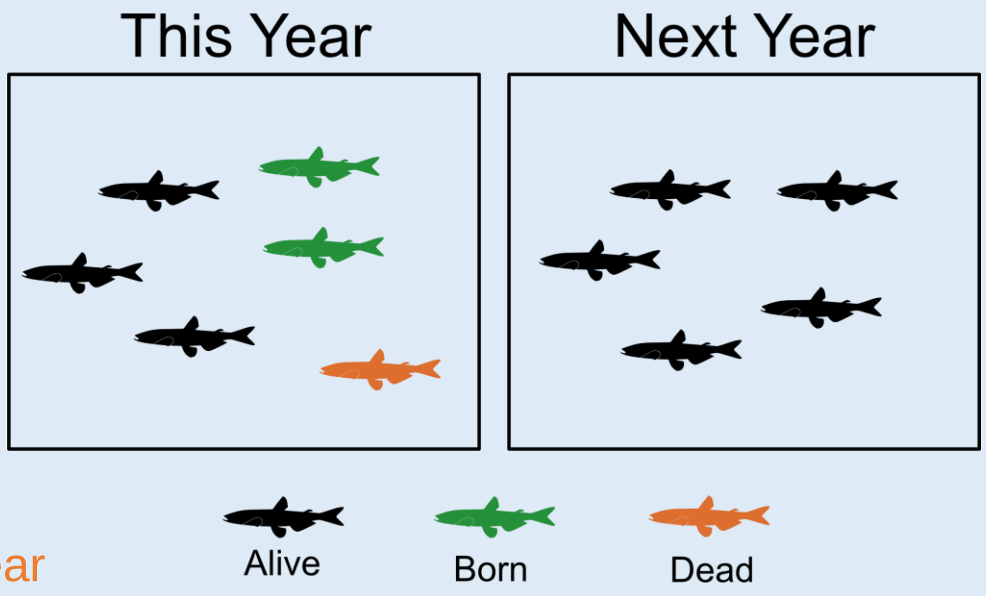
$$N_{t+1} = N_t + B_t - D_t$$

Numbers next year

Numbers this year

Births this year

Deaths this year



Per capita growth

- This basic model assumes likelihood of individuals giving birth or dying is constant over the time interval
- This is known as per capita birth or death

$$N_{t+1} = N_t + bN_t - dN_t$$

Population growth rate

- This equation can be simplified to consider the difference between per capita birth and death rates

$$N_{t+1} = (1 + b - d)N_t$$

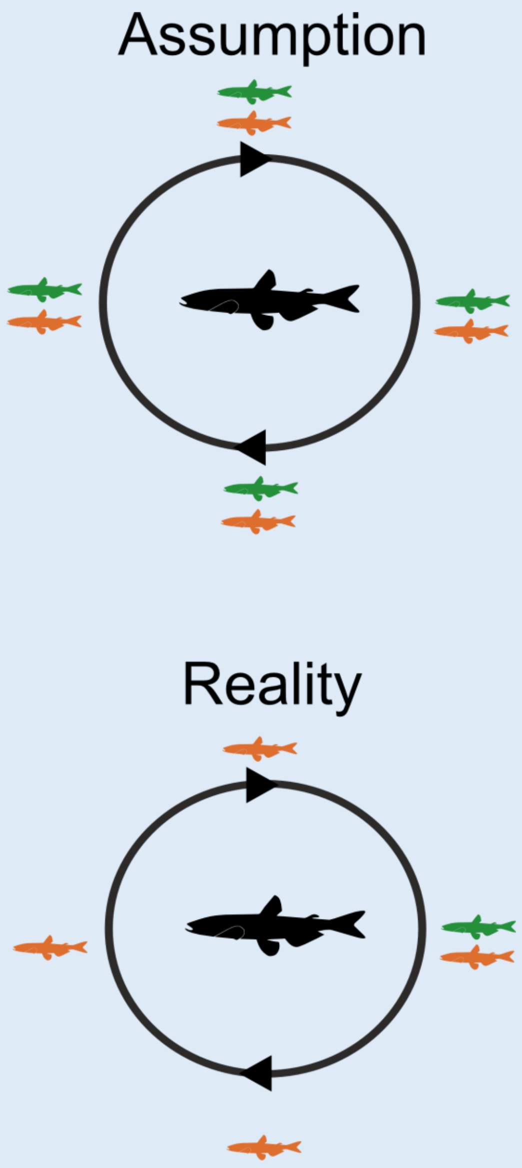
$$N_{t+1} = \lambda N_t$$

Can define growth as:

$$\lambda = N_{t+1}/N_t$$

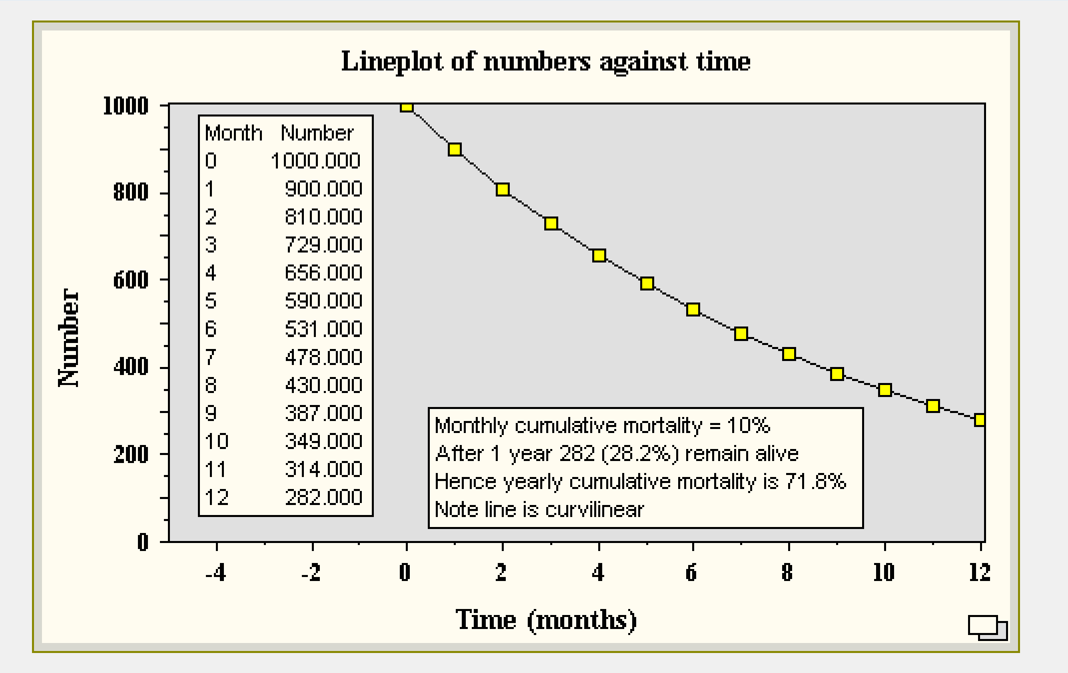
Discrete growth

- This population growth rate (λ) represents a change from one time-step to another
- Can use calculus to model these processes over small intervals using “instantaneous change” to allow processes to occur continuously



This rate or that rate?

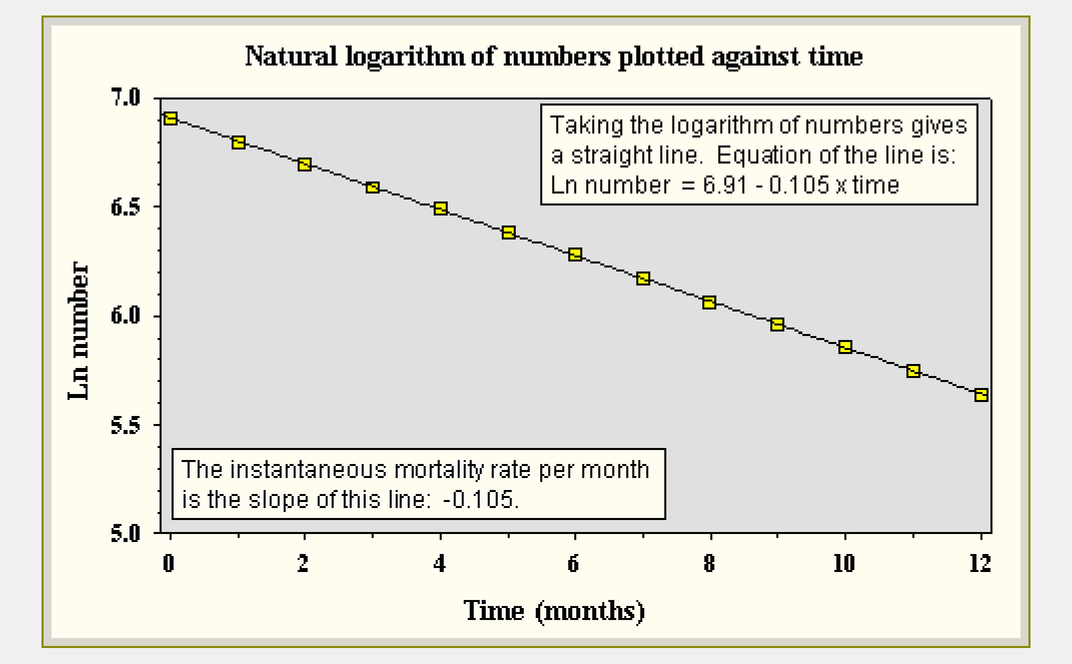
- Finite rate – proportion
  - 10% of 1000 fish die in one month = 0.1 finite mortality rate
  - Cumulative annual mortality = 718
  - Calculated based on survivors over each time period
    - Survival = $0.9^{12} = 0.2824$
    - Cumulative mortality = $1 - 0.2824$ = 0.718
- Note, you **cannot** multiply the finite rate by 12 to get a cumulative mortality rate (we would get negative fish)



Source

This rate or that rate?

- Growth rates in models are often described as being **instantaneous**
  - Rather than finite
- Instantaneous rate – probability over very short time period
  - Based on differential equations
- Finite mortality = 1-$e^{instantaneous}$
  - 1-$e^{-0.105} = 0.1$
- Note, you **can** multiply this by 12 to get an annual finite mortality rate
  - 1-$e^{-0.105*12} = 0.716$



Source

Why am I telling you this?

- You will hear people refer to natural and fishing mortality rates
  - These are instantaneous rates
- Sometimes these rates can be >1
- Because of the math behind these rates, an annual mortality rate >1 does not mean that more fish than exist died that year
- For example, if annual fishing mortality = 1
  - $1 - e^{-1} = 0.63$
  - 63% of fish would have died from fishing, not 100%

Continuous growth

- In continuous time, the equation doesn't look too different

Change in numbers

Change in time

$$\frac{\delta N}{\delta t} = bN - dN$$

$$\frac{\delta N}{\delta t} = rN$$

Can define growth as:

$$r = \frac{\delta N}{\delta N t}$$

Intrinsic rate of increase

- Continuous growth rate (r) is known as the intrinsic rate of increase
- Differs from λ because it measures per capita growth rate rather than the change in population size

Exponential growth

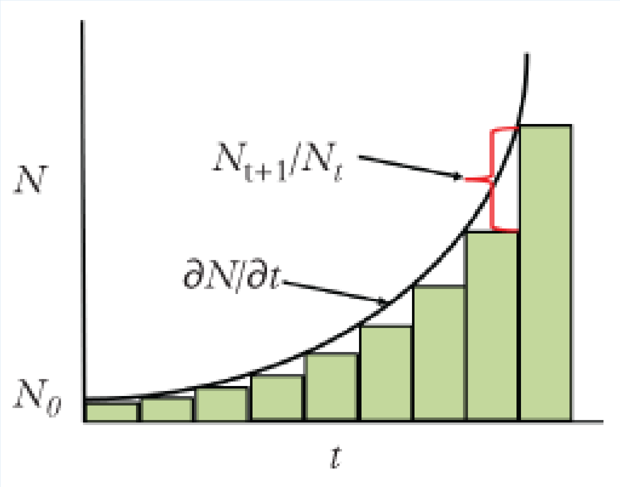
- Foundational theory of population growth
- Assumes density-independent growth: r does not change with population size (i.e., always remains at maximal level)
- Sometimes you will see this denoted as r_{max}

Exponential growth

- Described as,

$$N_t = N_0 e^{r_{max} t}$$

- N_0 is the starting population size (constant)
- r_{max} is constant
- t is time and changes



Hutchings (2021)

Try it!

- Install shiny package
- Run: shiny::runGitHub("FISH6001_apps","MatthewRobertson2452", subdir="/Exponential_growth/")
- Test different combinations of parameters to see how population growth changes

Exponential Growth

Exponential population growth is defined by the equation

$$N_t = N_0 e^{r_{max} t}$$

N_0 is the initial population size

r_{max} is the maximum rate of growth

t is the number of time steps

This growth is also defined using the differential equation:

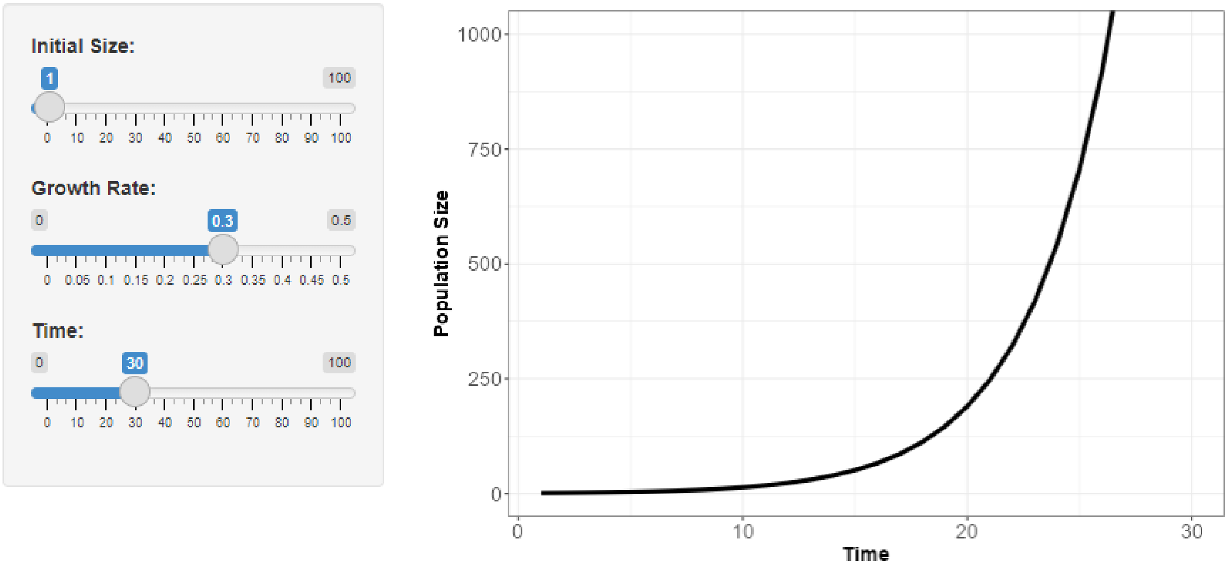
$$\frac{dN}{dt} = rN$$

$\frac{dN}{dt}$ is the population growth rate

r_{max} is still the rate of growth

N is the population size

Regardless, both equations, produce the same output:

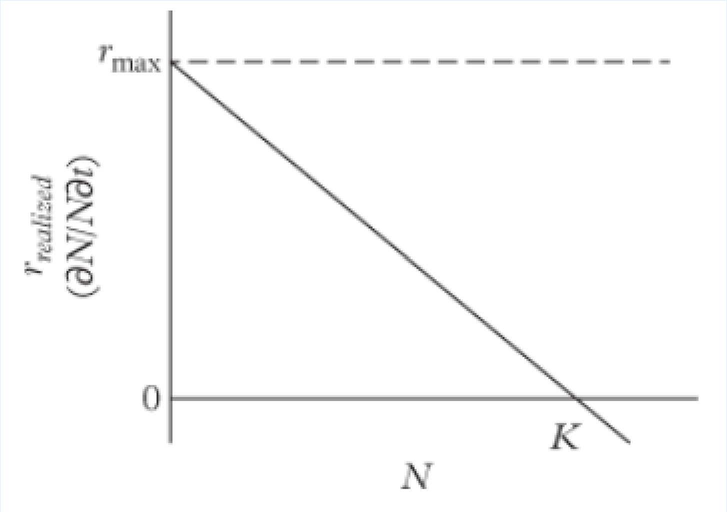


Logistic growth

- Exponential growth assumes that birth and death rates are constant
  - This can be true at small population sizes, relative to carrying capacity (K)
- However, with increasing abundance we tend to see competition for limited resources
  - Habitat
  - Food

Decreasing per capita growth

- We can consider that per capita growth is a density-dependent process
  - Growth declines with increasing population size
- Need to distinguish between r_{max} and $r_{realized}$



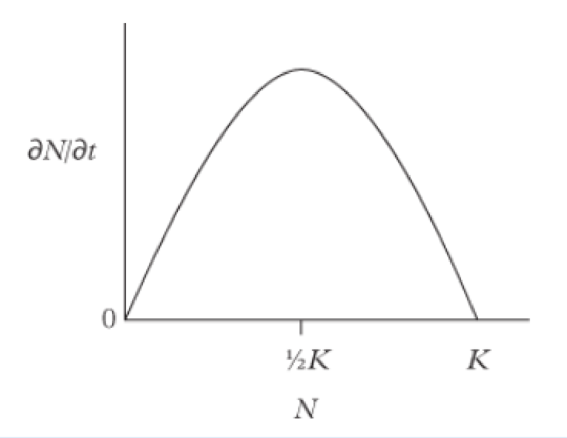
Hutchings (2021)

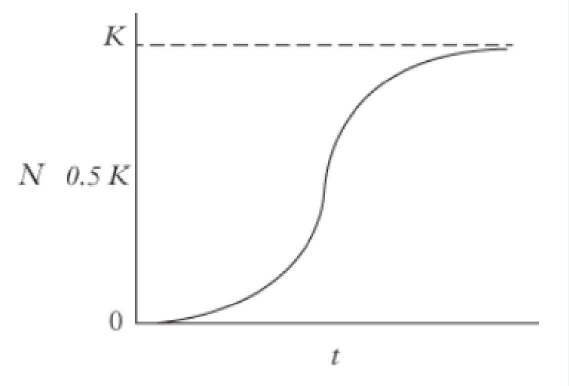
Logistic growth equation

- Described as,

$$\frac{\delta N}{\delta t} = r_{max} N\left(\frac{1-N}{K}\right)$$

- Initially, population growth rates increase with population size
- However, they reach peak growth a 0.5K and reach 0 when N=K





Hutchings (2021)

Try it!

- Run: shiny::runGitHub("FISH6001_apps","MatthewRobertson2452", subdir="/Logistic_growth/")
- What is the biggest difference between the discrete and continuous functions?
- What are the bottom plots telling us?

Logistic Growth

Logistic population growth is defined by the discrete equation

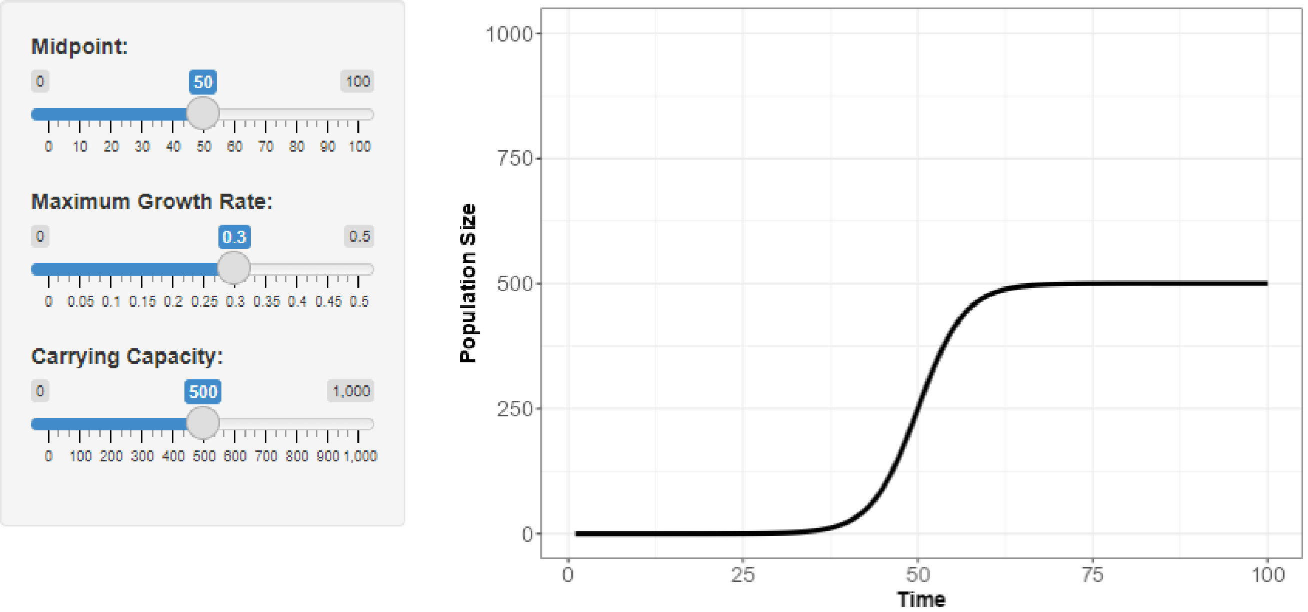
$$f(N) = \frac{K}{1 + e^{(-r_{max}(t - t_0))}}$$

K is the carrying capacity

r_{max} is the maximum rate of growth, this slows as N approaches K

t is time

t_0 is time at which the curve is at its midpoint

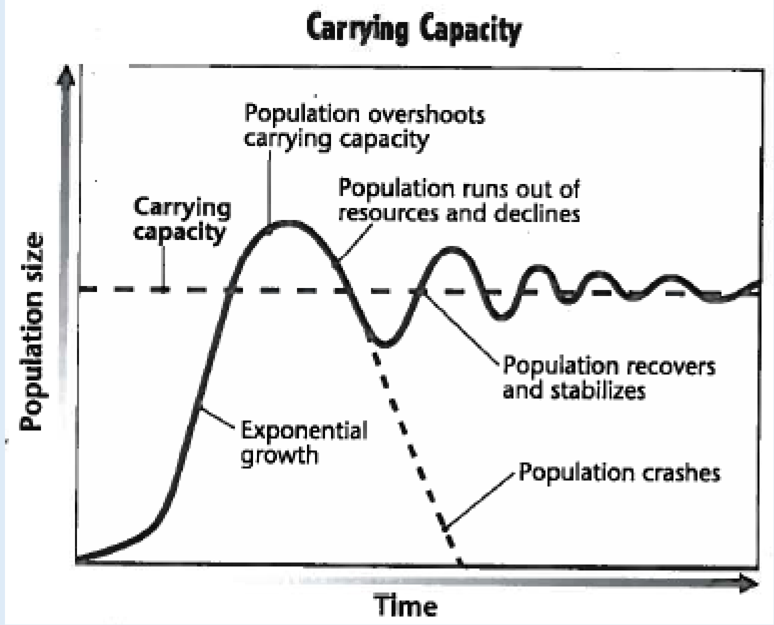


This growth is also defined using the continuous (aka. differential) equation:

$$\frac{dN}{dt} = r_{max}N(\frac{1 - N}{K})$$

Stationarity – an important point

- Carrying capacity is defined as a “stable equilibrium”



Stationarity – an important point

- Carrying capacity is defined as a "stable equilibrium"
- Ecosystems are constantly changing
  - Carrying capacity can therefore change
- This basically means that how we used to see a population grow may not be how we will continue to see a population grow

Contribution to the Symposium: *'Effects of Climate Change on the World's Oceans'*

Quo Vadimus

Climate change and non-stationary population processes in fisheries management

Cody S. Szuwalski[1,2]* and Anne B. Hollowed[3]

Modelling non-stationary natural mortality in catch-at-age models

Yan Jiao[1]*, Eric P. Smith[2], Rob O'Reilly[3], and Donald J. Orth[1]

Issues of ecosystem-based management of forage fisheries in "open" non-stationary ecosystems: the example of the sardine fishery in the Gulf of California

Andrew Bakun · Elizabeth A. Babcock · Salvador E. Lluch-Cota · Christine Santora · Christian J. Salvadeo

Provision of catch advice taking account of non-stationarity in productivity of Atlantic salmon (*Salmo salar* L.) in the Northwest Atlantic

G. Chaput, C. M. Legault, D. G. Reddin, F. Caron, and P. G. Amiro

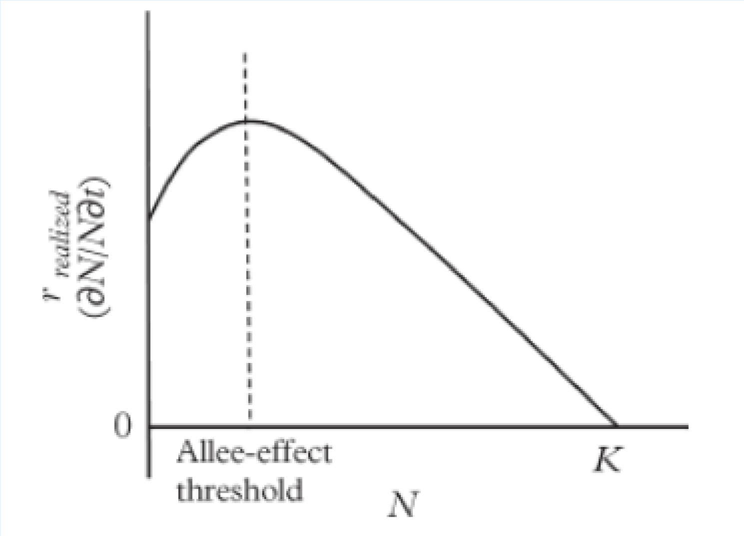
Allee effects – a caveat

- Increasing $r_{realized}$ with population size, at low population sizes
- This can be due to:
  - Predator pits
    - Less dense aggregations lead to increased predation mortality
  - Mate finding
    - When population size is too low, growth is limited due to a decreased likelihood of finding mates

Review Article

Renaissance of a caveat: Allee effects in marine fish

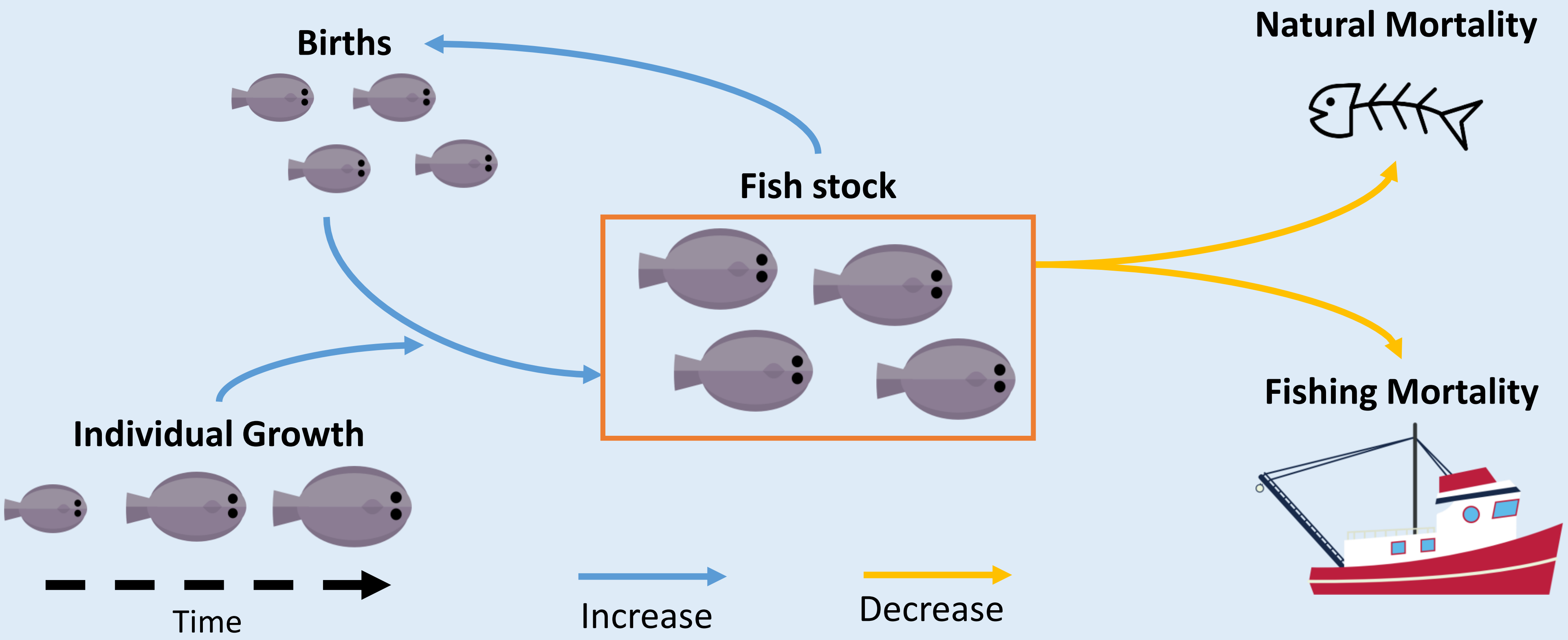
Jeffrey A. Hutchings[1,2*]



A fisheries context?

- At this point in today’s lecture we have discussed population dynamics equations that are widely applied
- But, for fisheries we want to understand the impact of fishing on populations

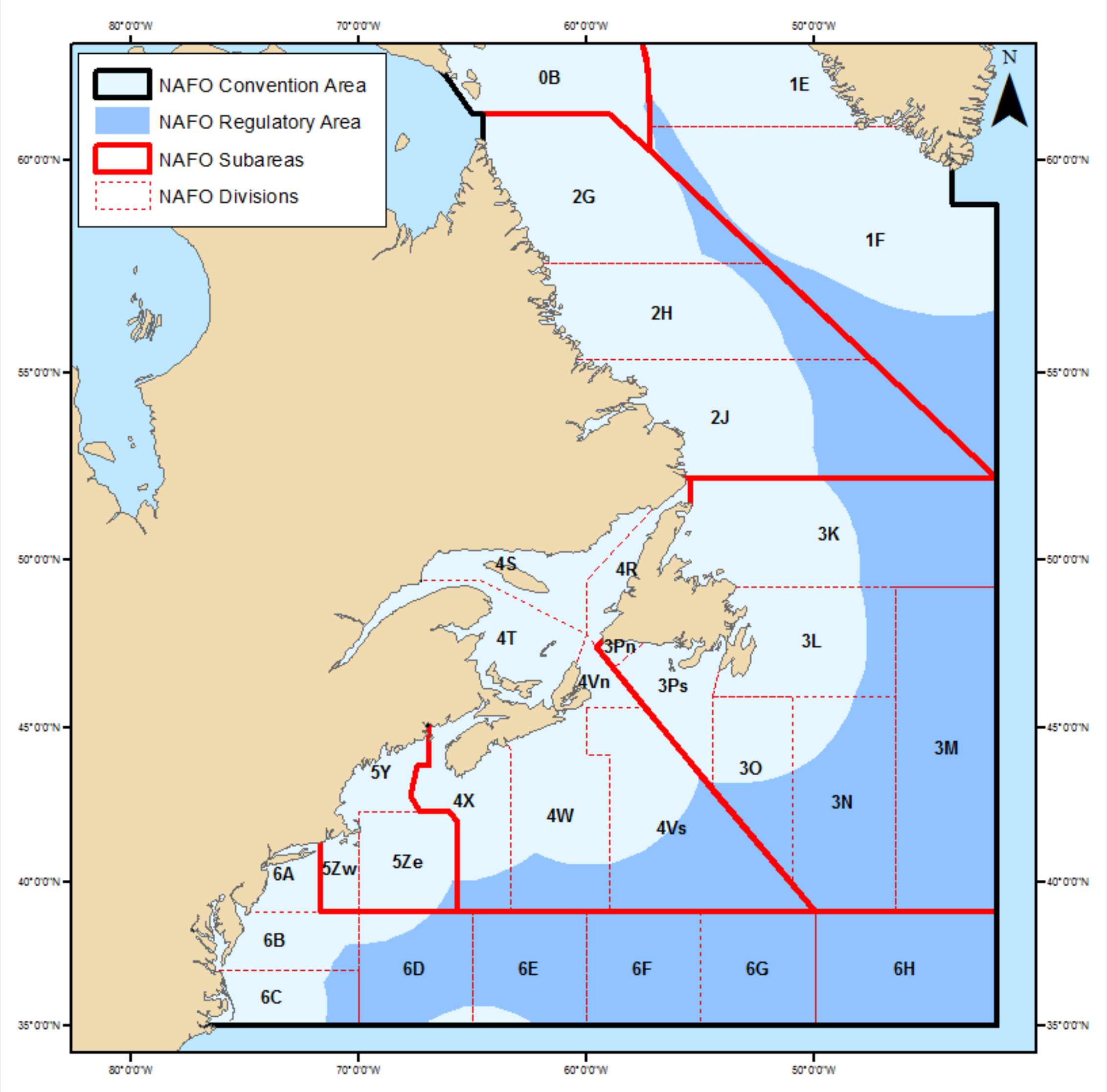
Fisheries population dynamics

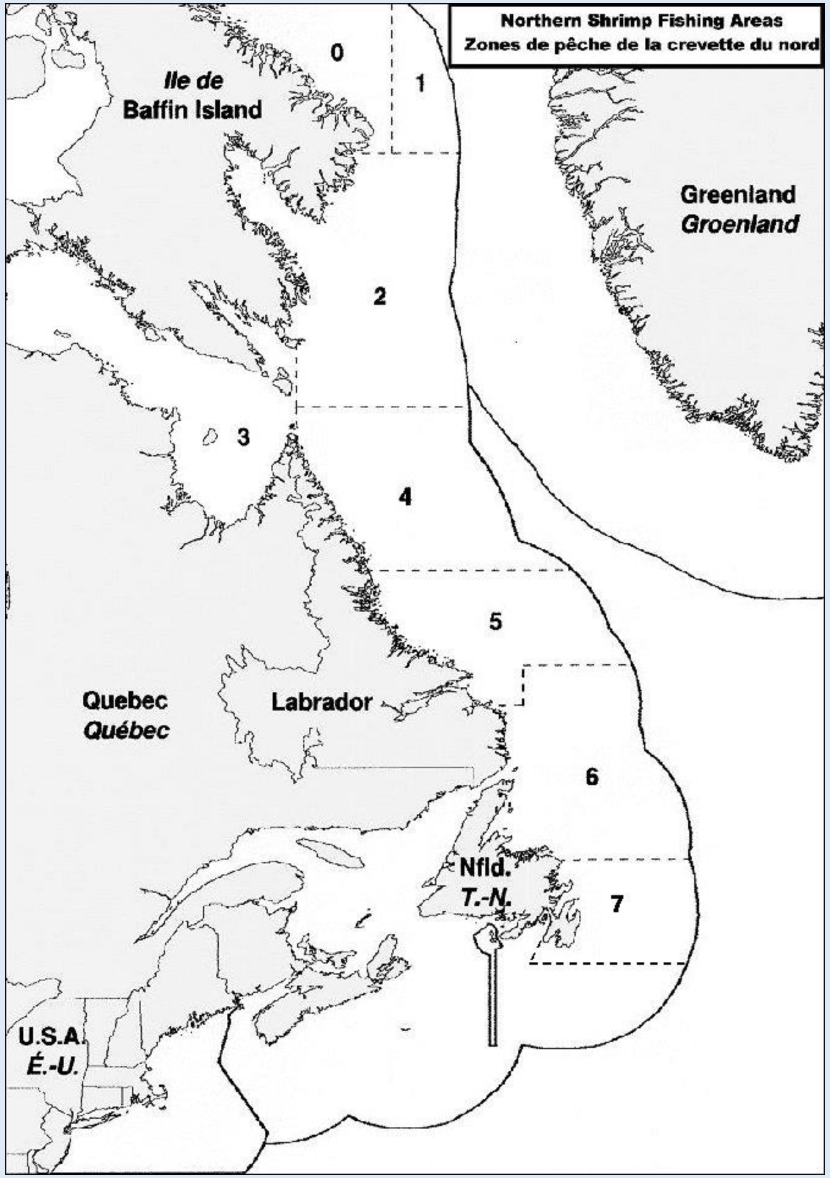


Population vs. stock

- Population: an interbreeding group of individuals
- Stock: a group of individuals geographically delimited for management purposes
  - Hope this matches a population (then less concern about migration)
- Often used interchangeably, but there can be a lot of debate about whether stock boundaries align with a population’s distribution

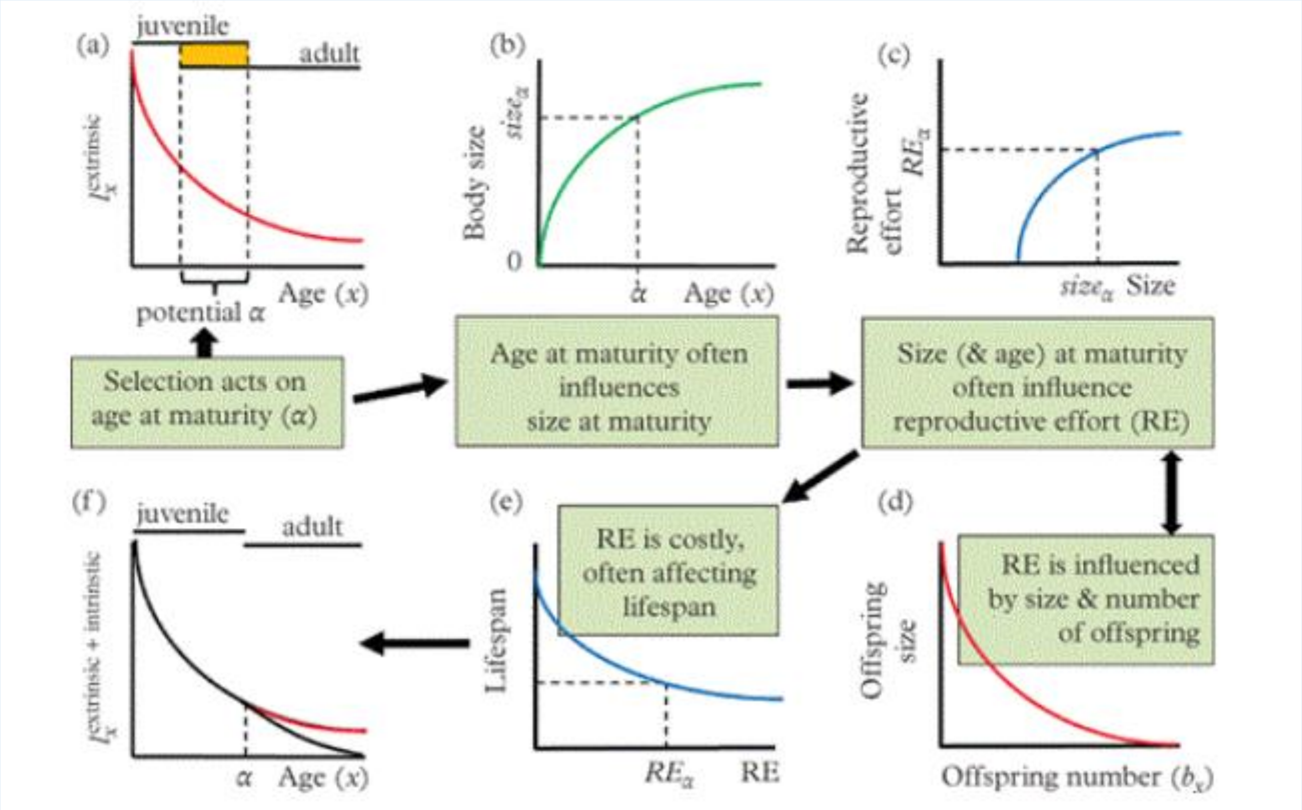
Northwest Atlantic Fisheries Organization (NAFO) Divisions





Life history traits

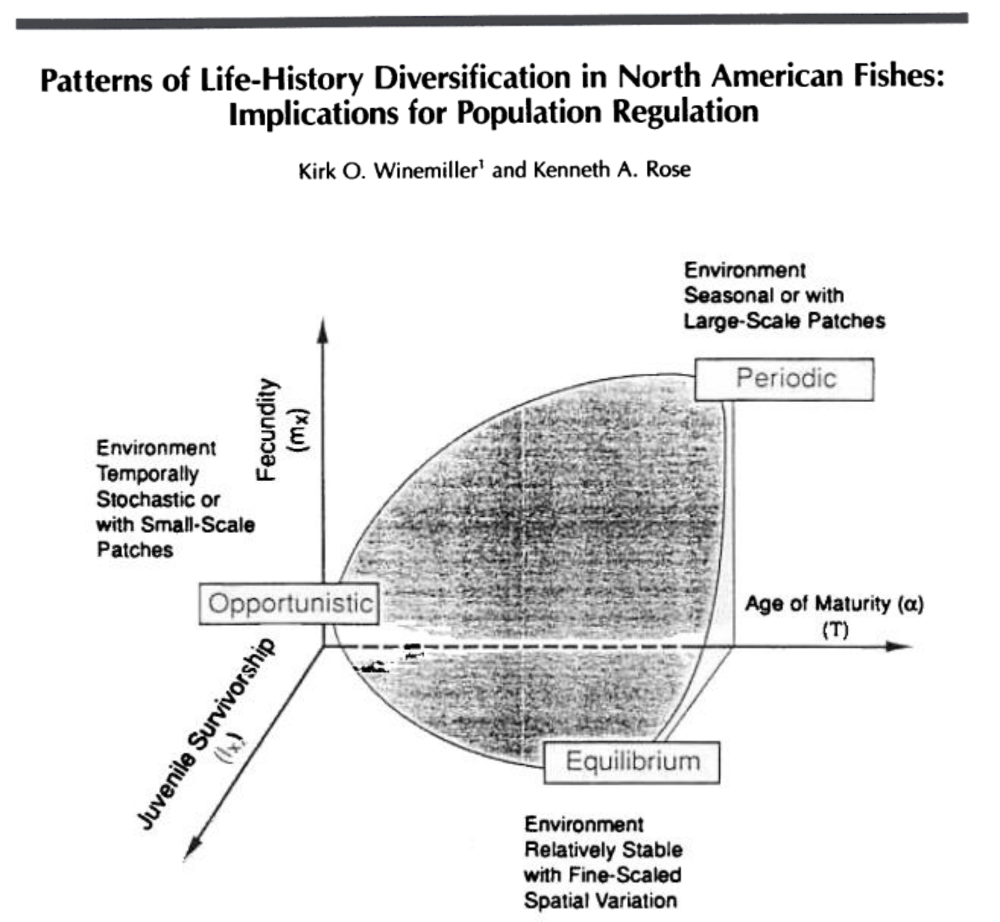
- Maturity
  - Age at maturity
  - Length at maturity
- Growth
  - Length
  - Weight
- Survival
  - Fishing mortality
  - Natural mortality



[Hutchings (2021)]

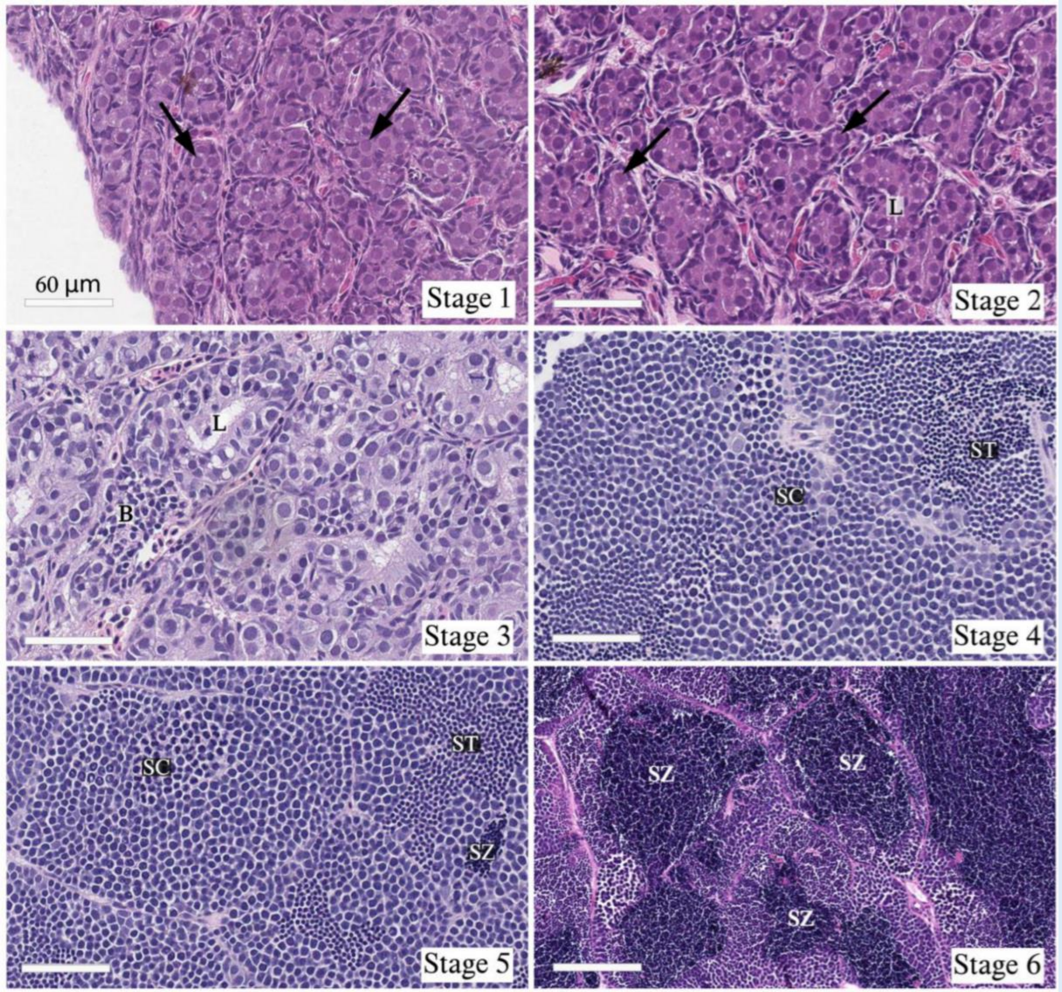
Life-history continuum

- Species may be defined based on combinations of their life-history traits (i.e., life-history strategies)
- Opportunistic
  - Small, rapid maturation, short-lived
- Periodic
  - Larger, highly fecund, long-lived
- Equilibrium
  - Intermediate size, exhibit parental care, produce few, large offspring



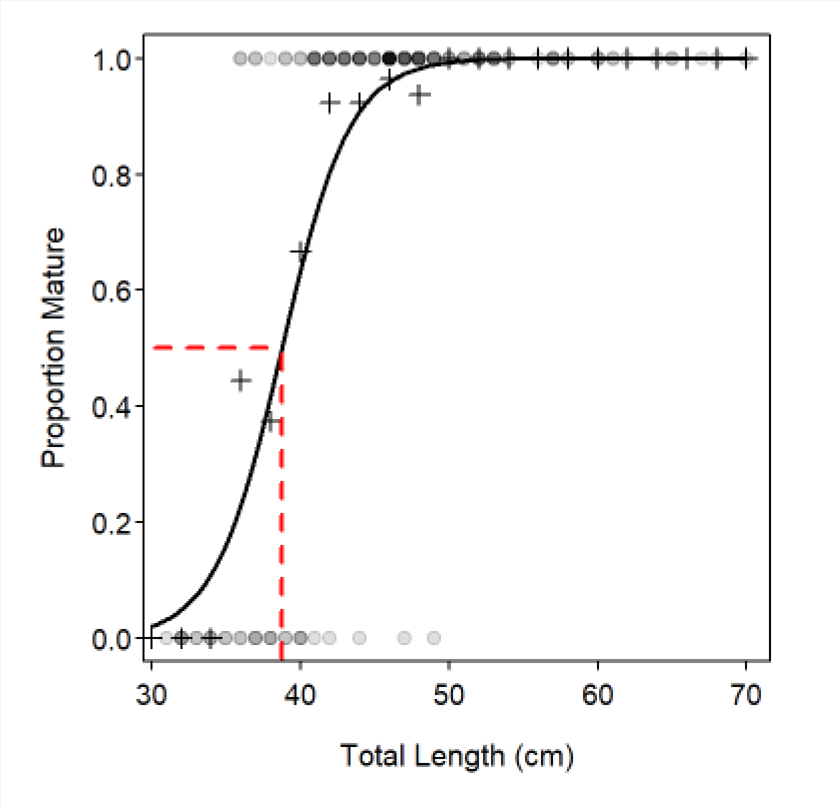
Maturity

- Fish mature as they grow, often at very different ages/sizes between sexes
- Maturity is determined via histology
  - Examination of gonads to determine whether individuals are capable of producing gametes



Maturity

- We often get data in a binary form describing whether a fish is mature (1) or immature (0)
- We use these data to calculate metrics like age or length at 50% maturity
  - When are 50% of fish mature

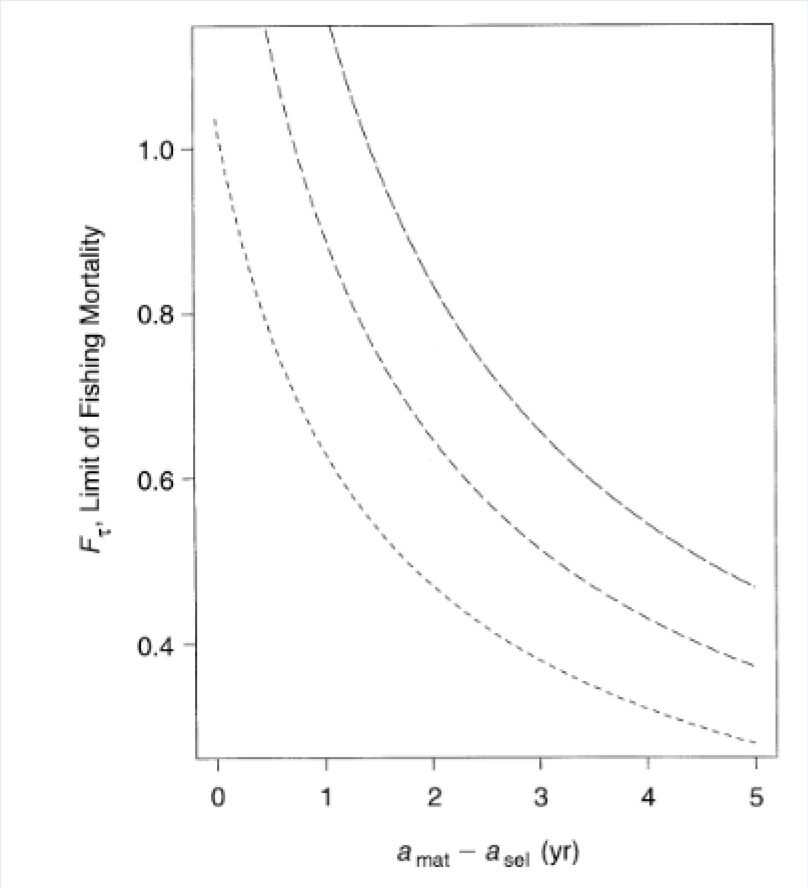


How does maturity data influence population dynamics modeling?

- Spawning stock biomass – usually defined by weight of **mature females**
  - Used for stock-recruit relationships and for understanding health of a stock
  - To get this we need to know proportion of females in the population and the age at maturity
- Some fisheries use indices of total egg production for management (see [Bernal et al. 2012])

Effect of length/age of maturity on fisheries sustainability

- Generally expected that fisheries that target immature fish are less likely to be sustainable
  - The “spawn-at-least-once” principle (see Myers & Mertz 1998)
- Allowing fish to spawn before they are selected by a fishery will limit the risk of collapsing a population



Growth

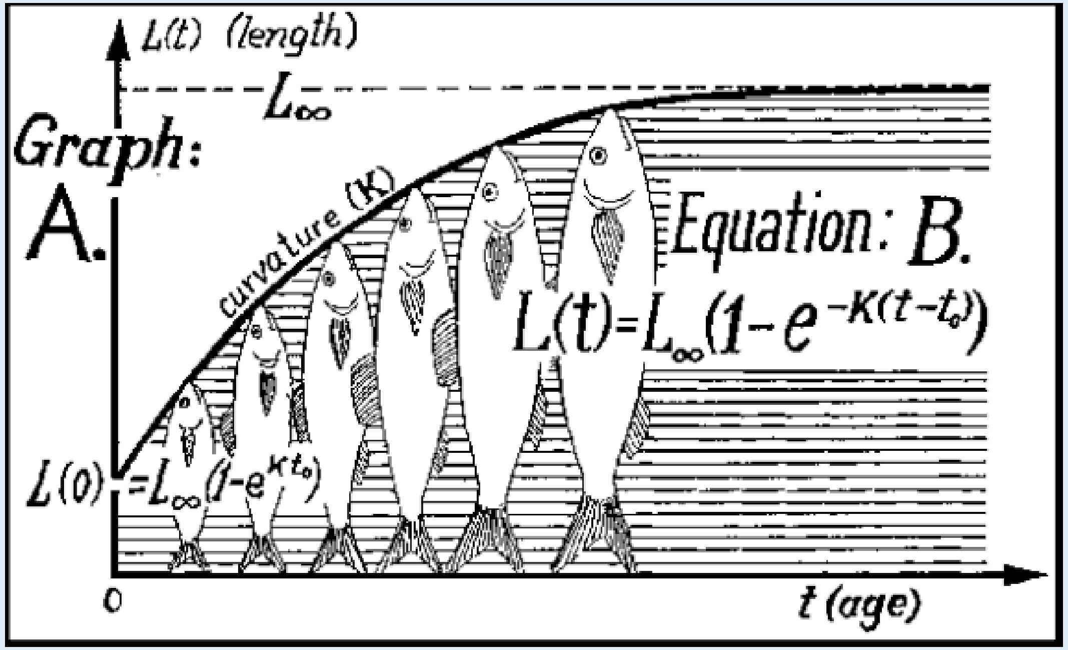
- Most common data that we have are length and age (from otoliths or scales)
- Understanding how fish grow over time influences our understanding of reproduction, mortality, and fisheries selectivity

von Bertalanffy

- Most commonly used equation for modeling length-at-age (L_a)

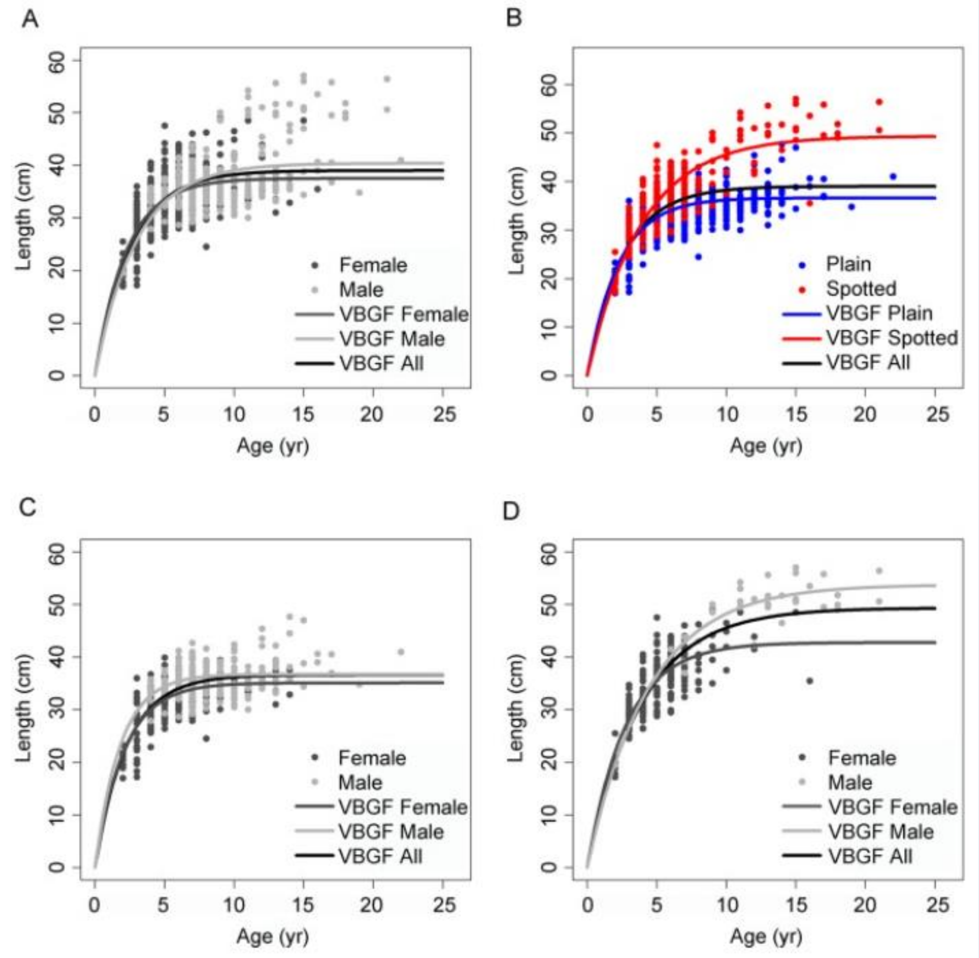
$$L_a = L_\infty(1 - e^{-K(a-a_0)})$$

- L_∞ – asymptotic maximum length
- K – growth rate
- a – age
- a_0 – hypothetical age at zero length



Understanding L_∞

- L_∞ is not the maximum possible length of an individual
  - This is a common misinterpretation
- It is the mean of maximum lengths of individuals



Length at first maturity / Size / Weight / Age

Maturity: L_m 65.4, range 31 - 74 cm

Max length : 200 cm TL male/unsexed; (Ref. 1371); common length : 100.0 cm TL male/unsexed; (Ref. 1371); max. published weight: 96.0 kg (Ref. 9988); max. reported age: 25 years (Ref. 173)

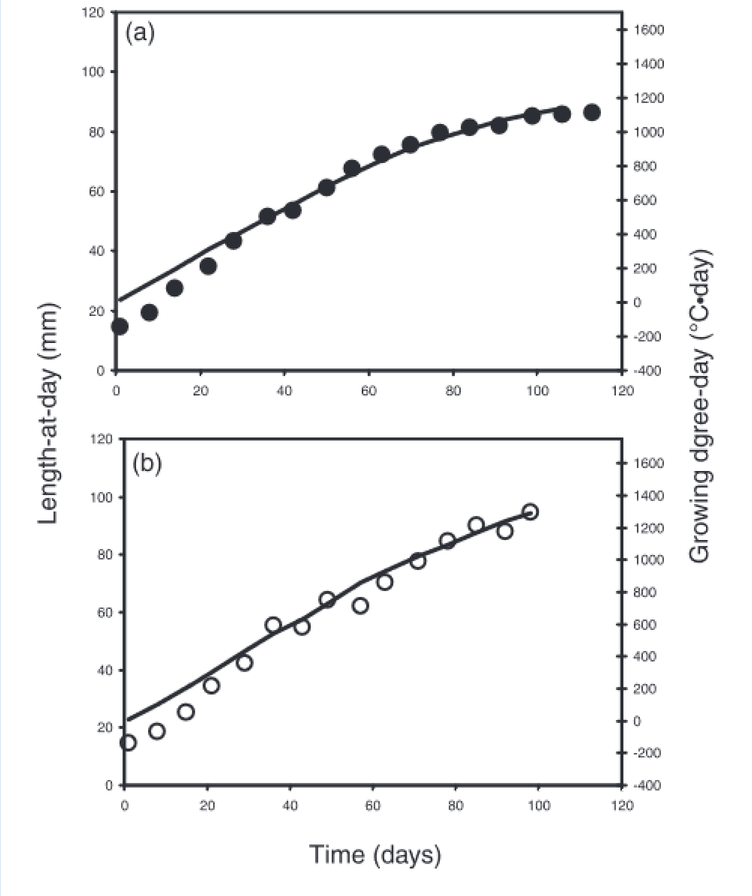
Growth research

- We know that fish growth isn't a wholly intrinsic quality
- Growth rates and asymptotic lengths vary for many reasons
    - Temperature
    - Oxygen
    - Food availability
    - Fisheries-induced selection

PERSPECTIVE / PERSPECTIVE

The growing degree-day and fish size-at-age: the overlooked metric

Anna B. Neuheimer and Christopher T. Taggart



Mortality at length

- We often have no data on natural mortality (discussed later)
- Growth modeling can help inform expectations
    - Lorenzen M - Small fish tend to have higher natural mortality rates than big fish

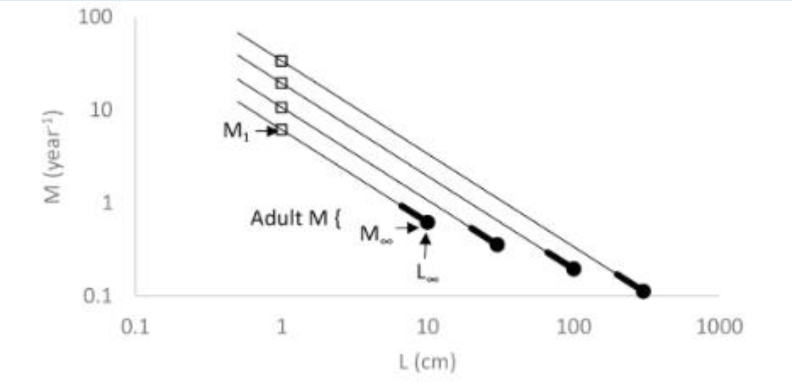

Contents lists available at ScienceDirect

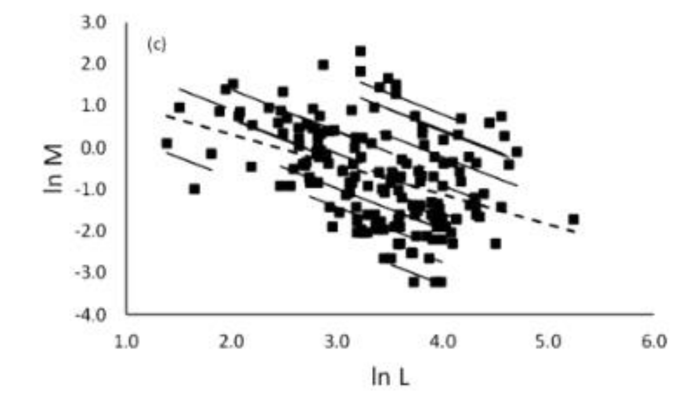
Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Natural mortality and body size in fish populations

Kai Lorenzen*, Edward V. Camp, Taryn M. Garlock





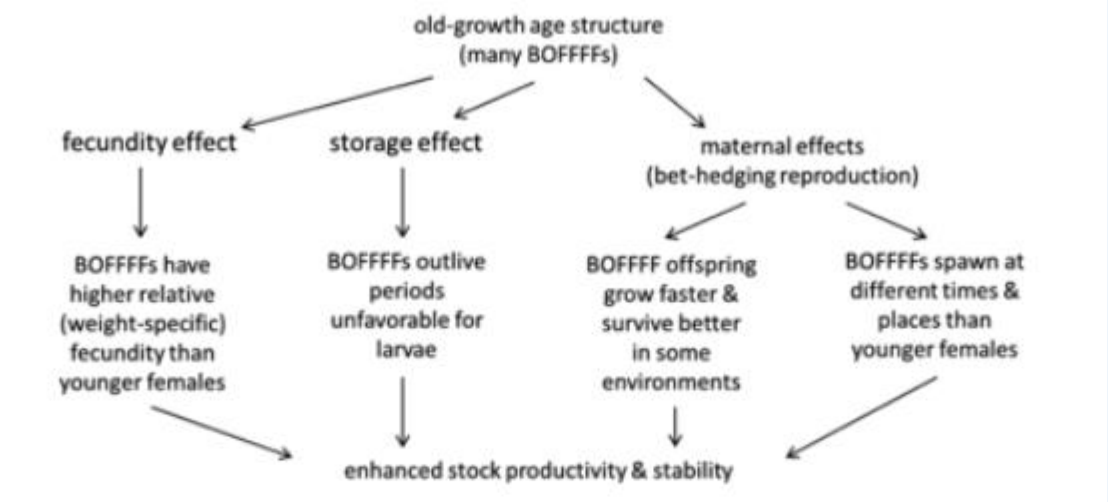
Weight-at-length

- We often care about the weight of fish in a population
- Weight affects
  - Reproductive capacity
  - Fisheries yield
  - Fish condition (mortality?)

Food for thought

BOFFFFs: on the importance of conserving old-growth age structure in fishery populations

Mark A. Hixon[1]*, Darren W. Johnson[2], and Susan M. Sogard[3]

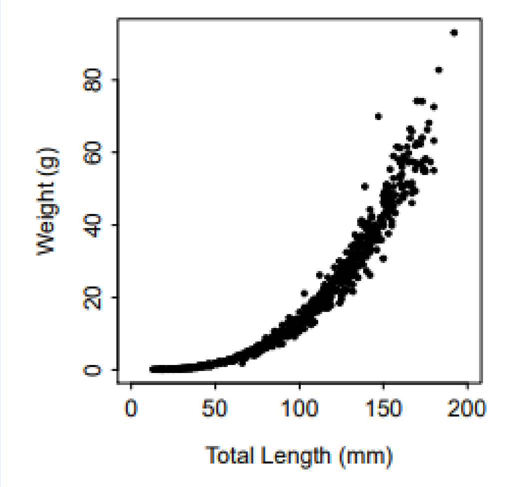


Modeling weight-at-length

- We tend to assume that fish grow allometrically
  - i.e., Weight scales directly with the length of a fish

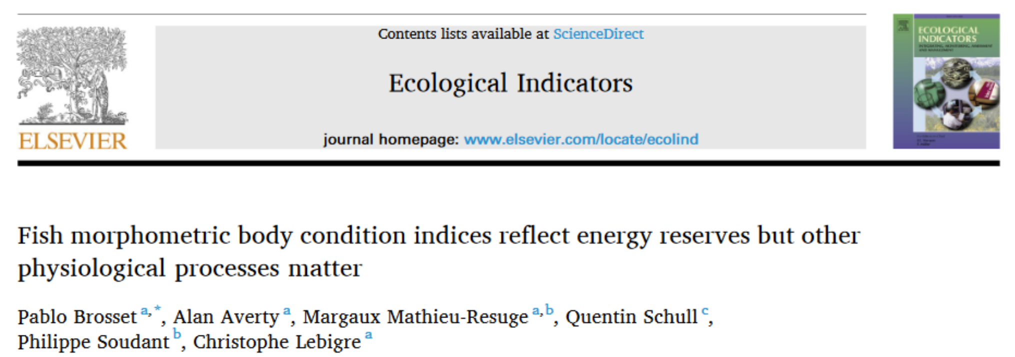
$$w = \alpha L^b$$

- α – is a constant
- b – is the allometric growth parameter (often close to 3)



Body condition

- We can assess fish body condition by examining how far they deviate from expected weight-length relationship
  - Indicative of physiological status
  - Recent feeding success
- May help inform natural mortality

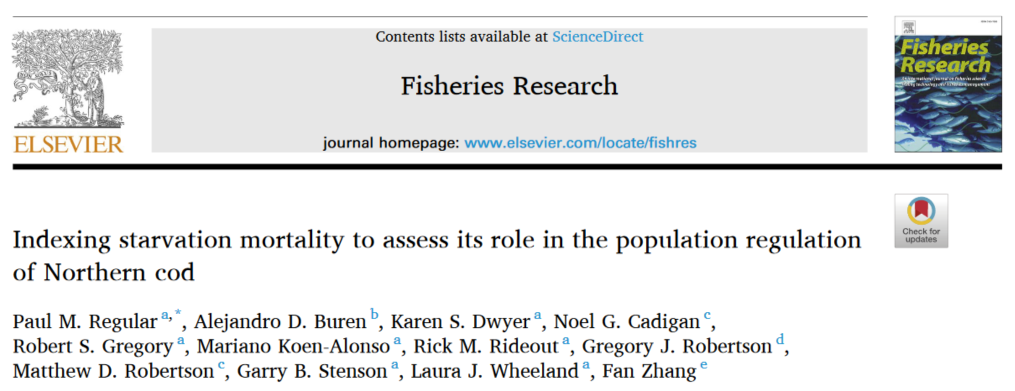

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Fish morphometric body condition indices reflect energy reserves but other physiological processes matter

Pablo Brosset[a,*], Alan Averty[a], Margaux Mathieu-Resuge[a,b], Quentin Schull[c], Philippe Soudant[b], Christophe Lebigre[a]

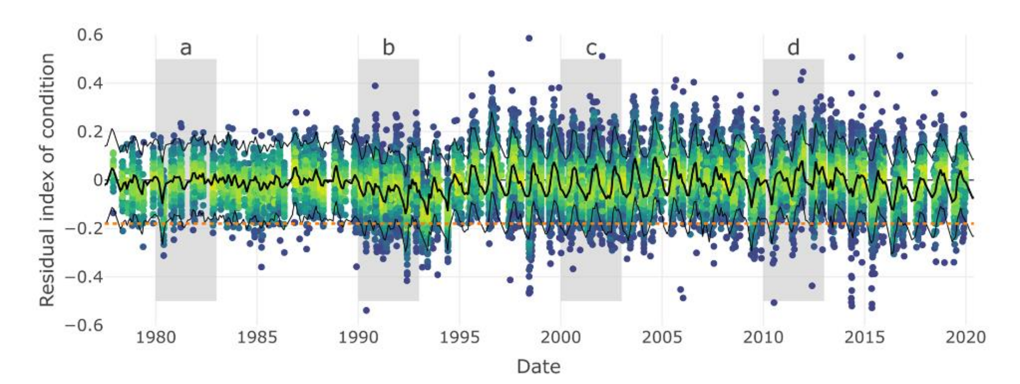

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Indexing starvation mortality to assess its role in the population regulation of Northern cod

Paul M. Regular[a,*], Alejandro D. Buren[b], Karen S. Dwyer[a], Noel G. Cadigan[c], Robert S. Gregory[a], Mariano Koen-Alonso[a], Rick M. Rideout[a], Gregory J. Robertson[d], Matthew D. Robertson[c], Garry B. Stenson[a], Laura J. Wheeland[a], Fan Zhang[e]

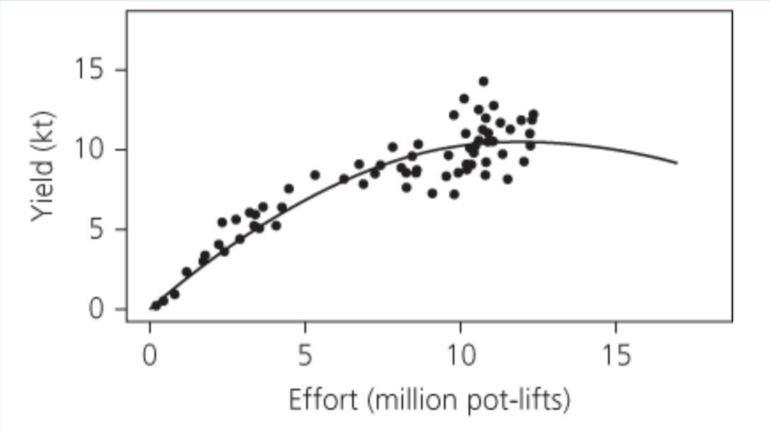


Total mortality

- Total mortality (Z) = Fishing mortality (F) + Natural Mortality (M)
- Fishing mortality is easier to estimate because, at least theoretically, we know how many fish are caught
- Natural mortality is one of the biggest unknowns
  - How can we know how many fish die in the ocean?

Fishing mortality

- The aspect of fish population dynamics that humans have control over
  - i.e., what we are trying to manage
- Product of fishing effort, catchability, population size, and time

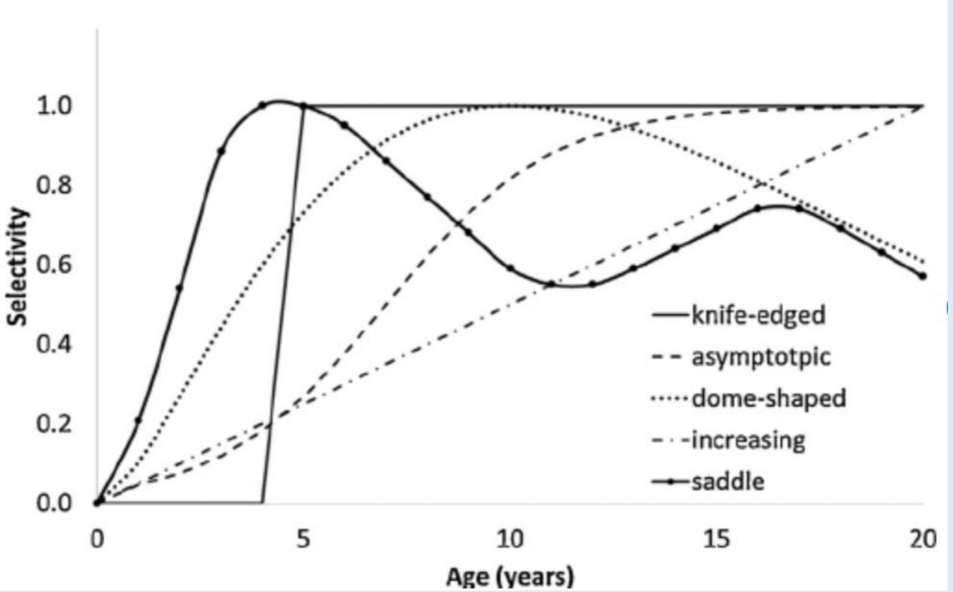


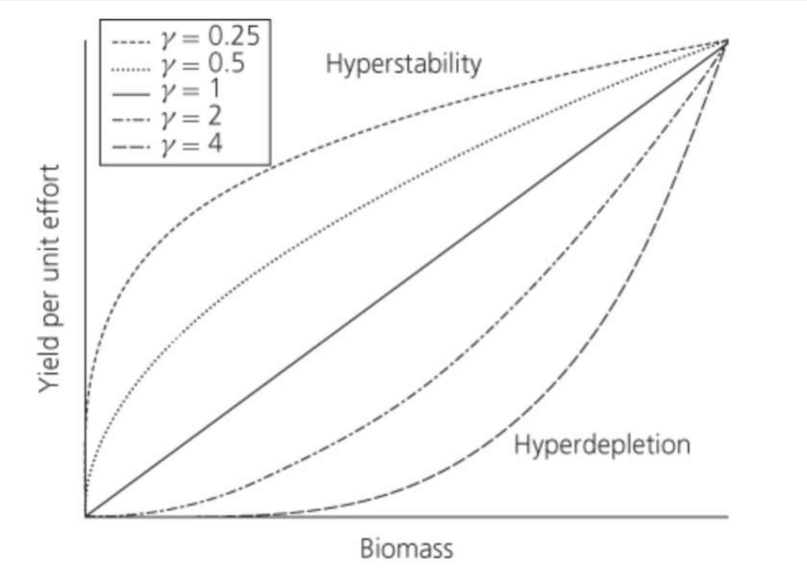
Fishing effort

- Often measured in terms of time
  - Hours or days spent fishing
- How we interpret this is completely dependent on the fishing gear that is used
- One hour of angling will produce much lower catch than one hour of bottom trawling

Catchability

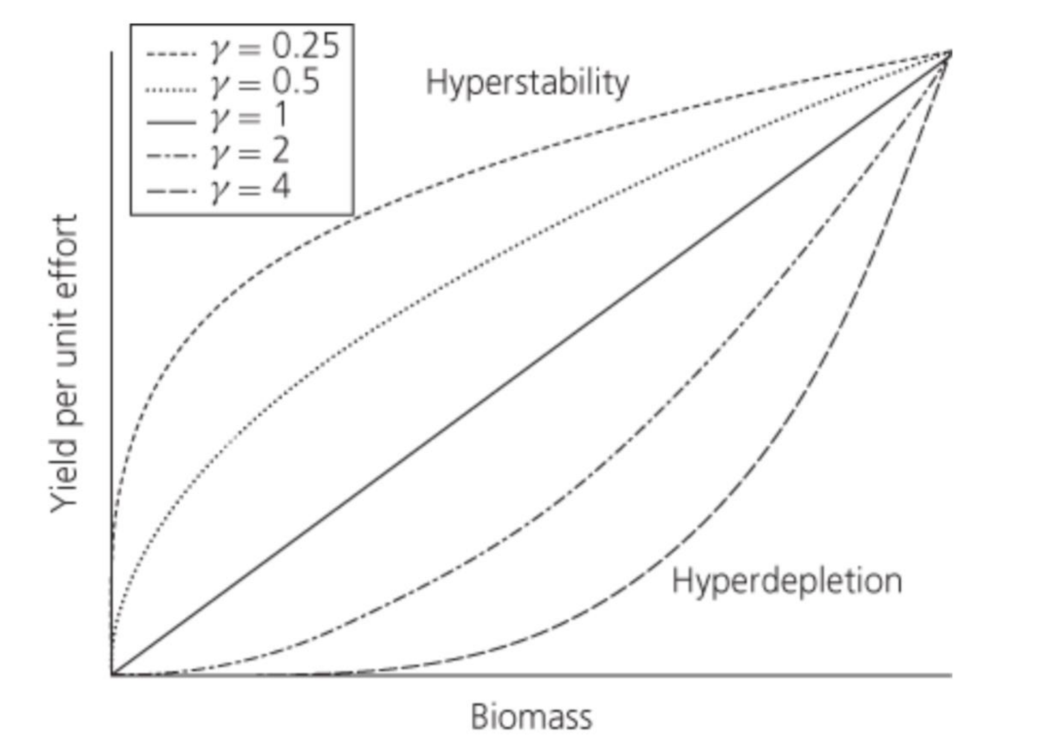
- The extent to which fish are susceptible to fishing
- Can be measured at different scales
  - Population level catchability
  - Age/length class catchability (selectivity)
- Depends on fishing gear, fish behavior, population size, and distribution





Population size/density

- Catch-per-unit-effort increases with population density
- This relationship can be nonlinear
  - Hyperstability – catch remains high even as population density declines
  - Hyperdepletion – catch declines faster than expected with decreases in population density

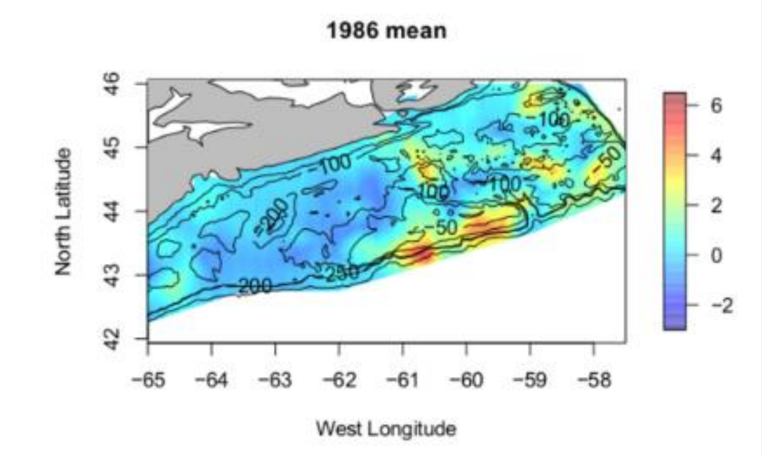


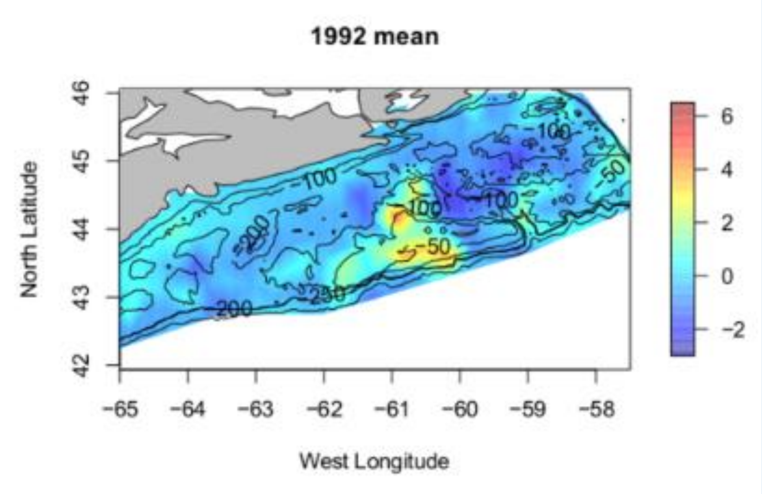
Local overfishing

RESEARCH ARTICLE

Local overfishing may be avoided by examining parameters of a spatio-temporal model

Stuart Carson[1]*, Nancy Shackell[2], Joanna Mills Flemming[1]

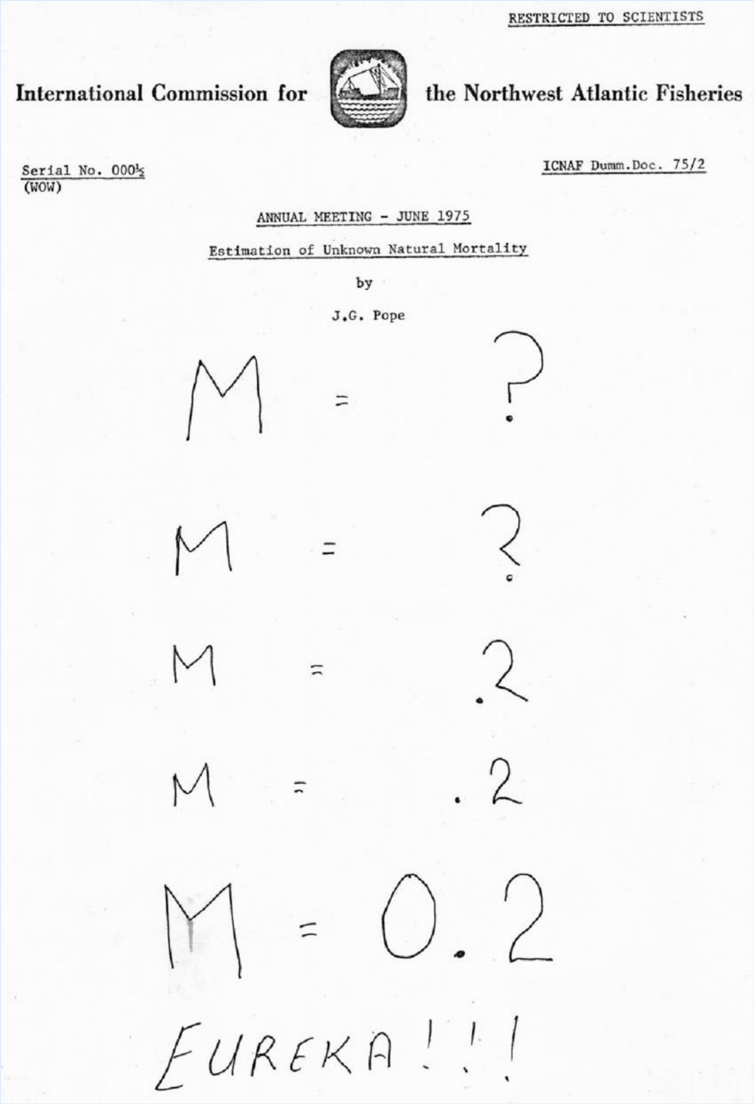




- Fish tend to occur at high concentrations with ideal resources
- Fishers learn about these areas and fish them
  - Minimize effort, maximize catch
- These ideal areas will lead to hyperstability
- May mask the actual scale of population decline

Natural mortality

- Mortality from natural causes
  - Predation
  - Starvation
  - Senescence
- Population dynamics models have often assumed that annual natural mortality rates = 0.2
  - Remembering what we learned about rates tells us that we are assuming ~18% of fish die from natural causes in a year


RESTRICTED TO SCIENTISTS

International Commission for the Northwest Atlantic Fisheries

Serial No. 000½
(WOW)

ICNAF Dumm.Doc. 75/2

ANNUAL MEETING - JUNE 1975

Estimation of Unknown Natural Mortality

by

J.G. Pope

M = ?

M = ?

M = .2

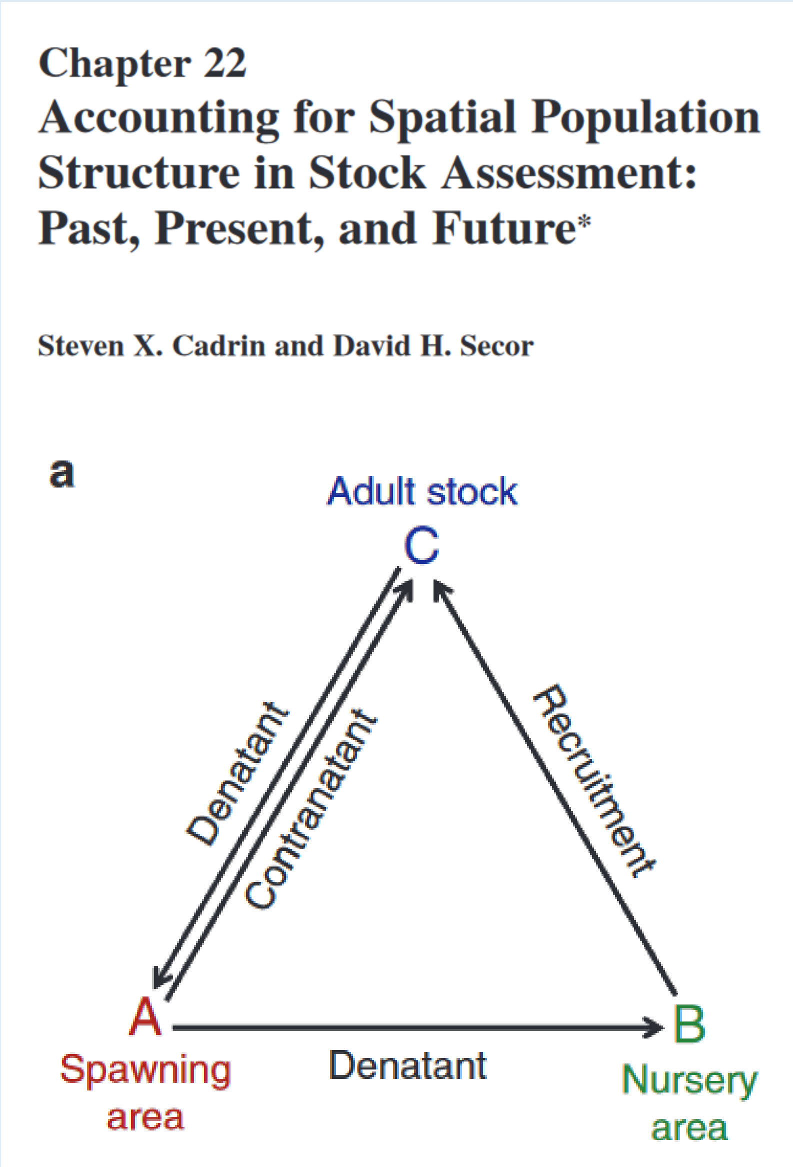
M = .2

M = 0.2

EUREKA!!!

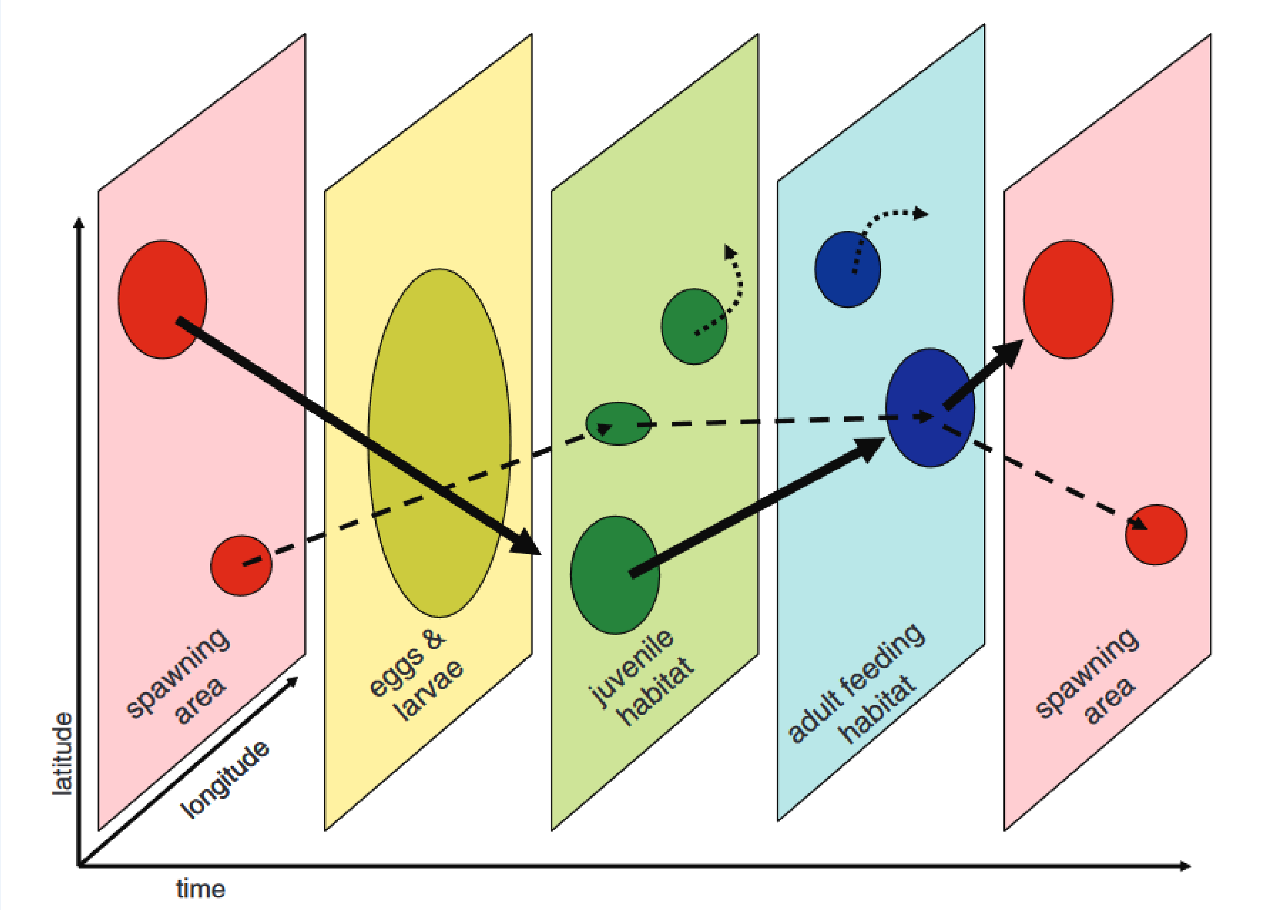
Migration?

- Immigration and emigration can also affect population dynamics
- Understanding these effects are complex and for simplicity we often assume that they are negligible



Migration?

- Immigration and emigration can also affect population dynamics
- Understanding these effects are complex and for simplicity we often assume that they are negligible



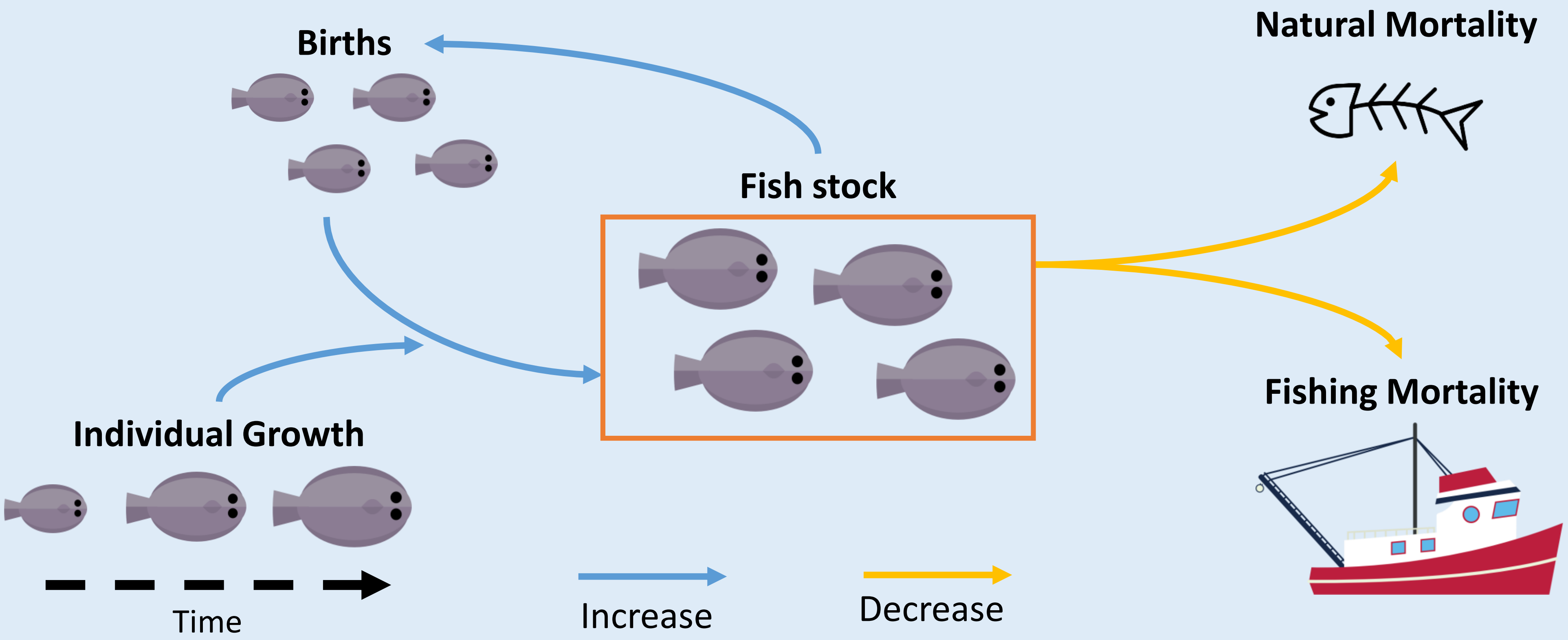
Day 3 – Population dynamics models

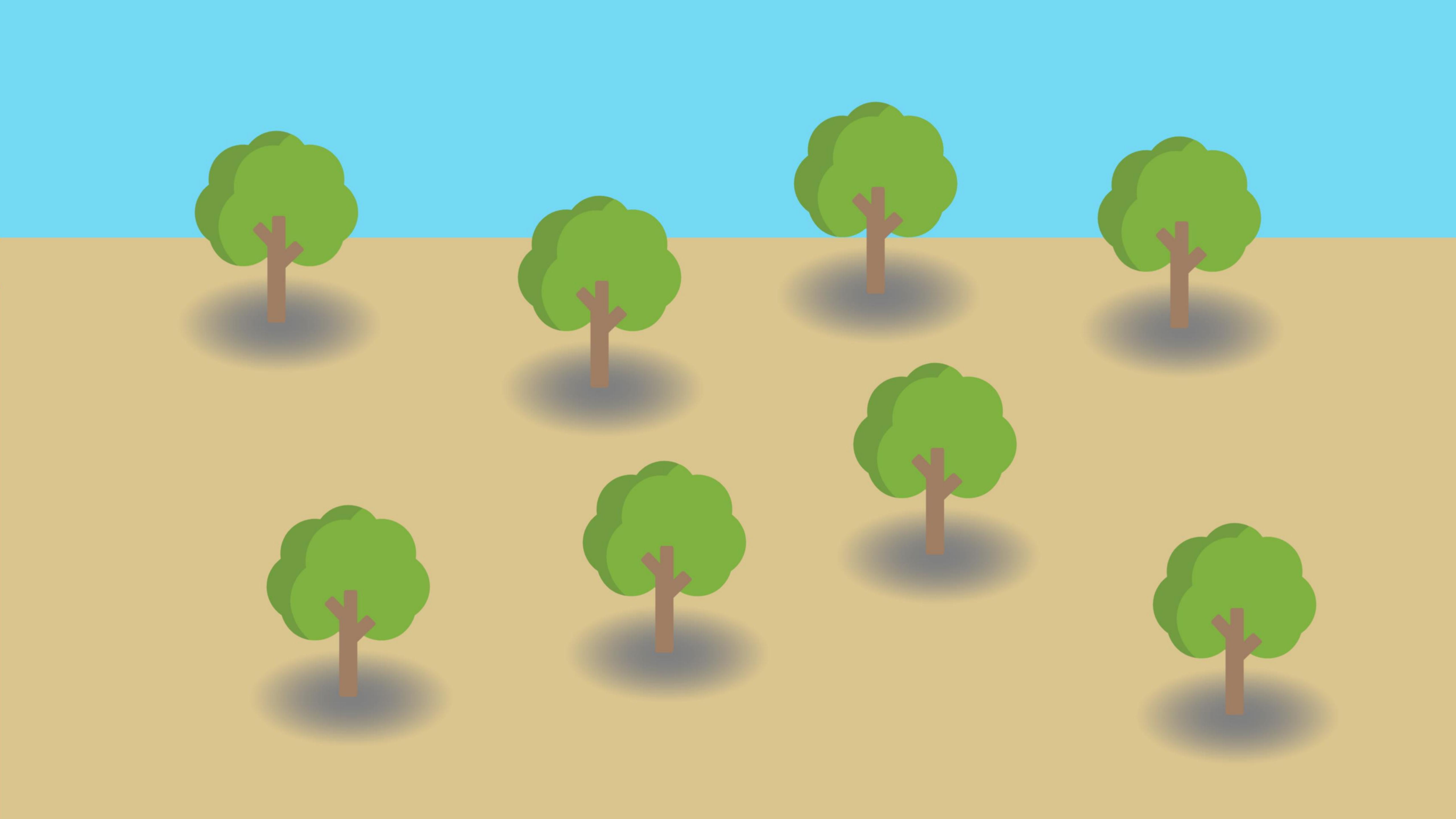
- Biomass dynamic models
- Age-structured models

Learning Objectives

- General history of fisheries science
- What are the key mathematical underpinnings of population growth theory?
- What biological characteristics define population growth?
- **How do we use these theories and biology to track population dynamics?**
- **What are the key population dynamics models?**
- How do population dynamics models inform fisheries management?

Population (stock) dynamics



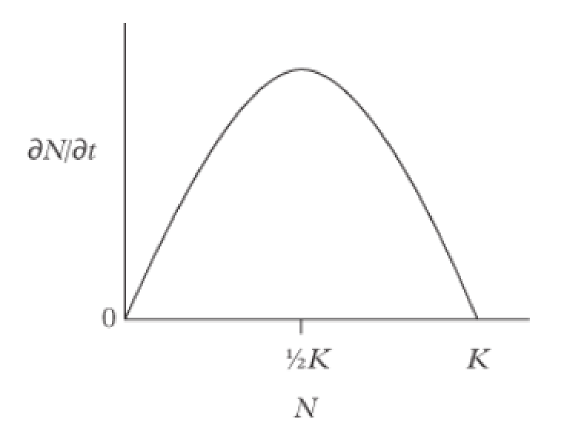


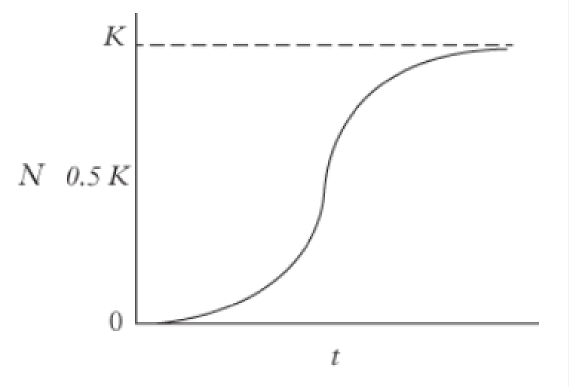
Biomass dynamic models

- One of the oldest and simplest population dynamics models
- Examine how total population size changes over time
  - No consideration of age or size structure
- These generally consider population size in terms of biomass because this is most relevant for the fishing industry
- Only require time-series of fishing effort and yield

Surplus production

- Biomass dynamic models are often referred to as surplus production models
- Recall from last class, that the logistic model assumes that growth is highest at ½ carrying capacity





Logic behind surplus production models

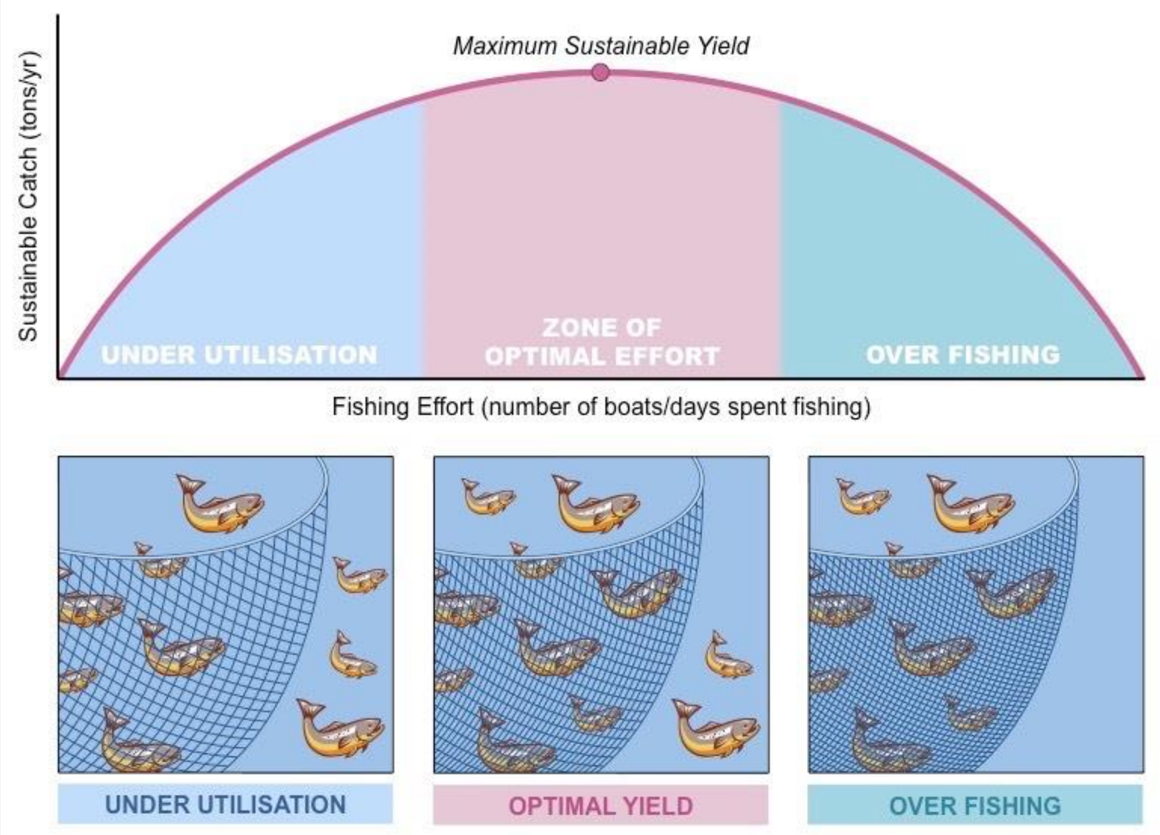
- Fish produce more offspring than needed to replenish their population annually
- Therefore, we can harvest those extra fish without risking population declines!
- Goal of the model: estimate that excess so we know how much is safe to harvest

Sustainability?

- One definition on Wikipedia: "Sustainability can be defined as the capacity to maintain or improve the state and availability of desirable materials or conditions over the long term"
- Therefore, the logic behind surplus production modeling and fishery management is, by definition, sustainable

Maximum Sustainable Yield (MSY)

- The largest catch that can be taken over an indefinite period
- To do this, population size needs to be maintained at the point of maximum growth rate
  - Only remove the number of individuals that would contribute to population size growing



Schaefer surplus production

- Start with the logistic growth equation:

$$B_{t+1} = B_t + rB_t(1 - \frac{B_t}{K})$$

Biomass at start of next year

Biomass at start of this year

Surplus production

- And then just subtract annual catches (C_t)

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{K}\right) - C_t$$

Biomass at start of next year

Biomass at start of this year

Surplus production

Catches this year

Starting the model

- How do we know how big the population was at the start of the time-series?
- We usually have no idea
- Just assume that initial biomass is = to carrying capacity
- Assumption: If we weren't fishing, then the population must have been at the maximum possible size

Catches

- Catch and effort are expected to be directly proportional to population size

$$I_t = \frac{C_t}{E_t} = qB_t$$

where I_t is an index of population size and q is catchability

Using the model to manage

- Since the model is based on logistic growth it's estimated parameters can be used to calculate maximum sustainable yield

$$MSY = \frac{r_{max}K}{4}$$

- We can also use these parameters to estimate
  - Effort at which MSY is produced (E_{MSY})
  - Biomass that has surplus production = to MSY (B_{MSY})
  - The harvest rate that will produce MSY (H_{MSY})

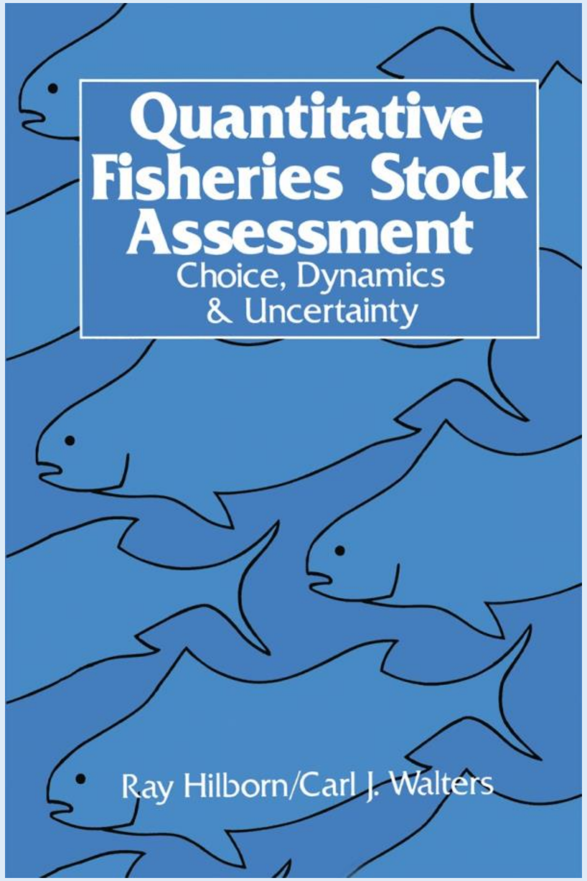
Biggest problems

- Assumes that:
    - Catch index is proportional to true biomass
    - Effort efficiency is constant
    - Population will respond instantaneously
    - Symmetric parabola
    - Age and size based biology is unimportant
- Need large ranges of fishing effort

Do people like this model?

- “Despite their rather wide use, biomass dynamic models have been looked down upon as poor cousins of age-structured analyses; indeed, in most circumstances biologists would prefer to use the age-structured tools...than rely on biomass dynamic models.”

  Hilborn & Walters (1992)



An example – 3LNO Yellowtail flounder

NOT TO BE CITED WITHOUT PRIOR REFERENCE TO THE AUTHOR(S)

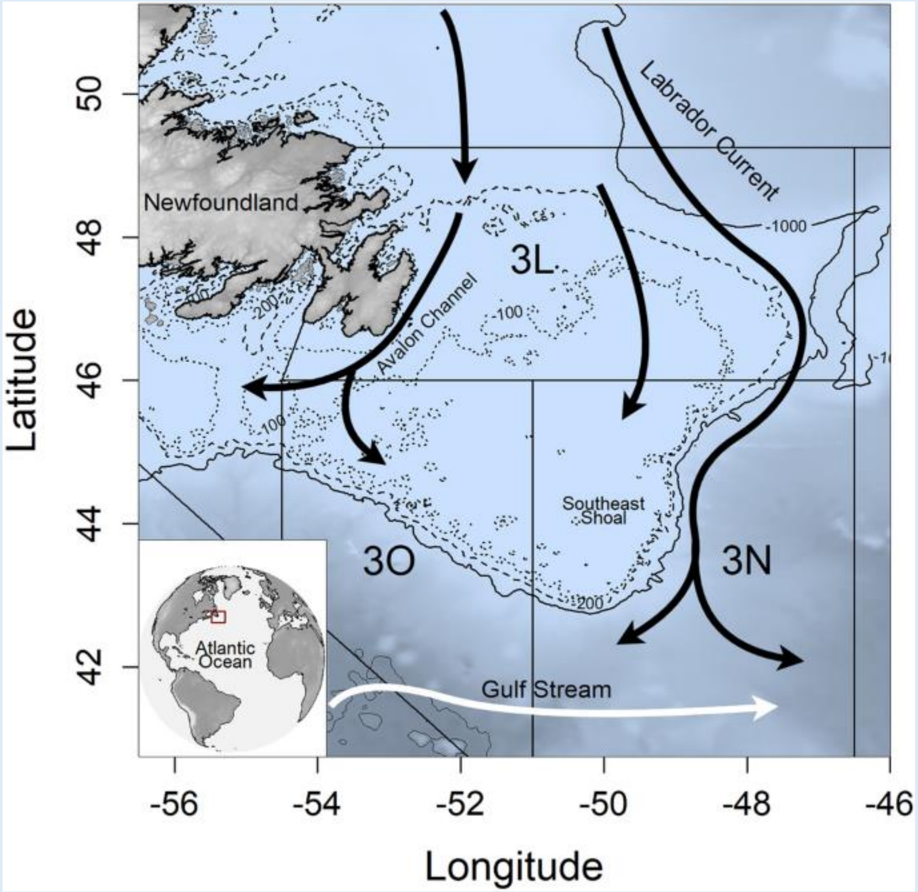
Northwest Atlantic Fisheries Organization

Serial No. 7186 NAFO SCR Doc. 21/018

SCIENTIFIC COUNCIL MEETING – JUNE 2021

2021 Assessment of Yellowtail Flounder in NAFO Divisions 3LNO using a Stock Production Model in a Bayesian Framework.

D. Maddock Parsons, R. Rideout and R. Rogers



Background

- The stock has been regulated since 1973
- Was historically captured as bycatch in cod and American plaice fisheries
- Collapsed in the late 1980s
  - Moratorium from 1994 – 1997

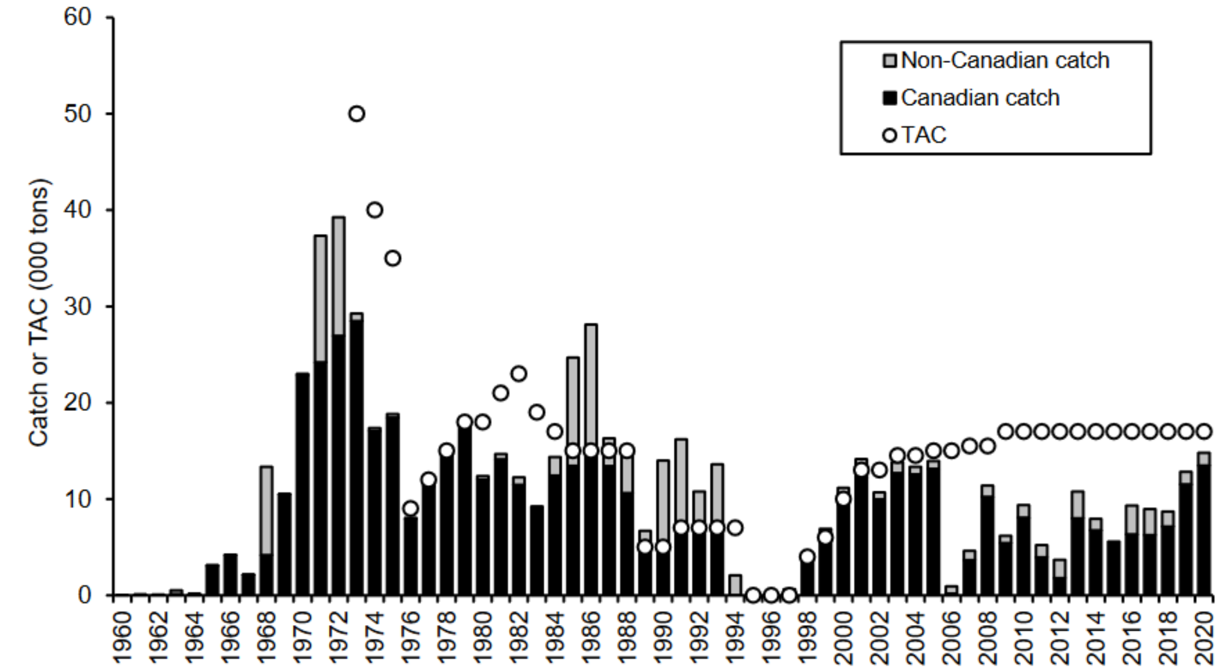


Figure 1. Catch (000t) and TAC of yellowtail flounder in NAFO Divisions 3LNO.

Research Survey Data

- Yankee survey
  - 1971 – 1982
- Russian survey
  - 1984 – 1991
- Campelen spring survey
  - 1984 – 2019
- Campelen fall
  - 1990 – 2019
- Spanish survey
  - 1995 – 2019

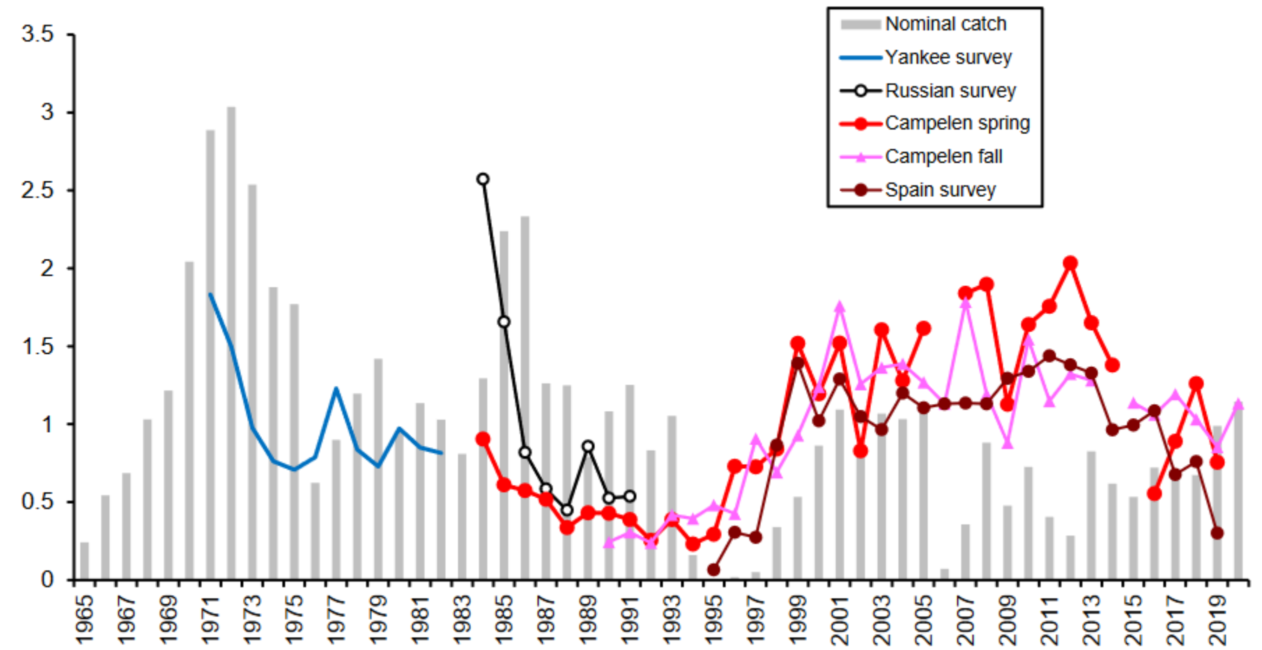
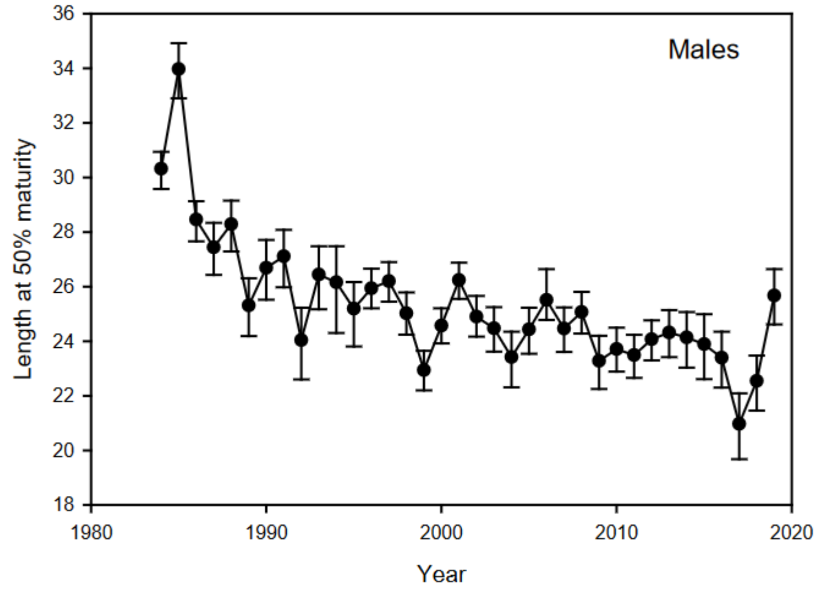


Figure 12. Nominal catch and survey series scaled to the mean for each of the indices used in the 2021 assessment of yellowtail flounder.

Additional data

- No time-series of reliable otolith ageing data
- However they do have:
  - Length
  - Weight
  - Maturity
  - Spatial distribution
- Length-weight relationship is used to calculate female SSB



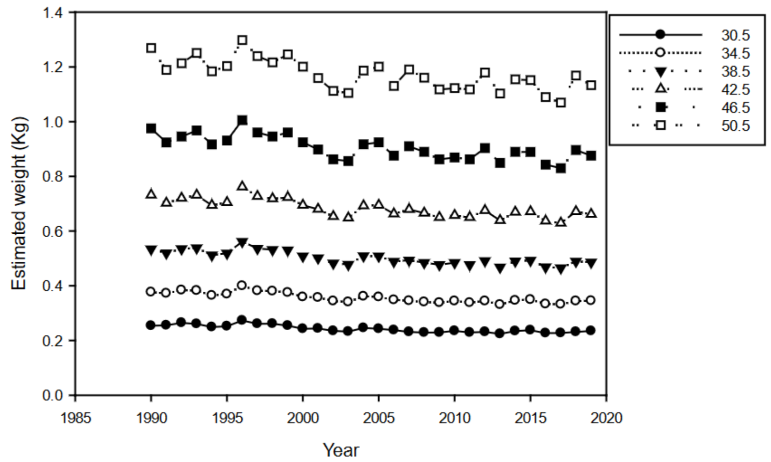


Figure 10. Estimated weight (Kg) at length (cm) for selected length groups for female yellowtail flounder in Div. 3LNO from Canadian spring surveys from 1990-2019.

Model

- Bayesian surplus production model
- Incorporated an equation to link biomass to observed survey indices
  - This is common
- Estimated biomass looks very similar to survey index biomass

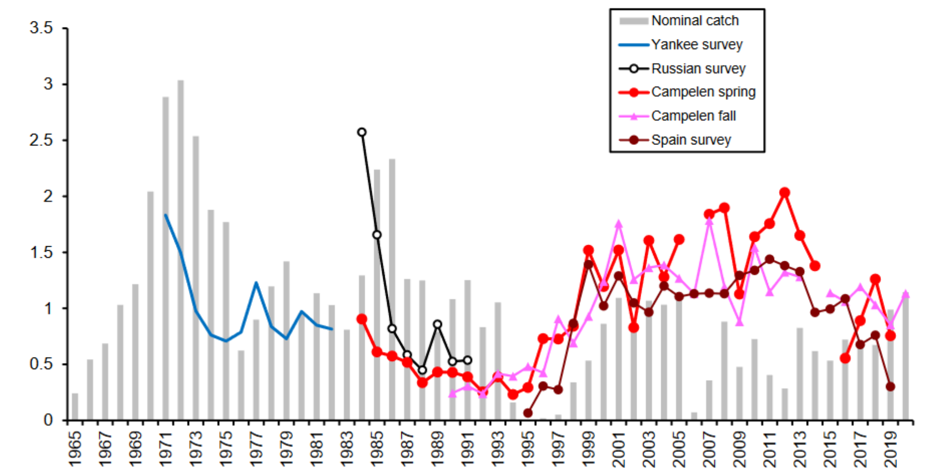
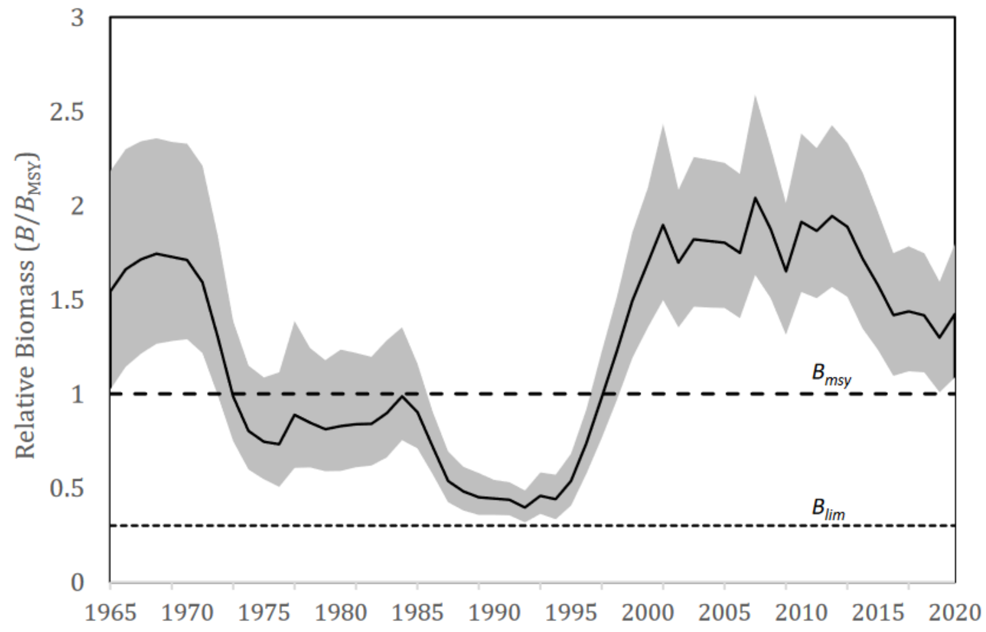


Figure 12. Nominal catch and survey series scaled to the mean for each of the indices used in the 2021 assessment of yellowtail flounder.



Fishing mortality

- Estimated that fishing mortality has been low in recent years
- Population was overfished intermittently between 1970 – 1995

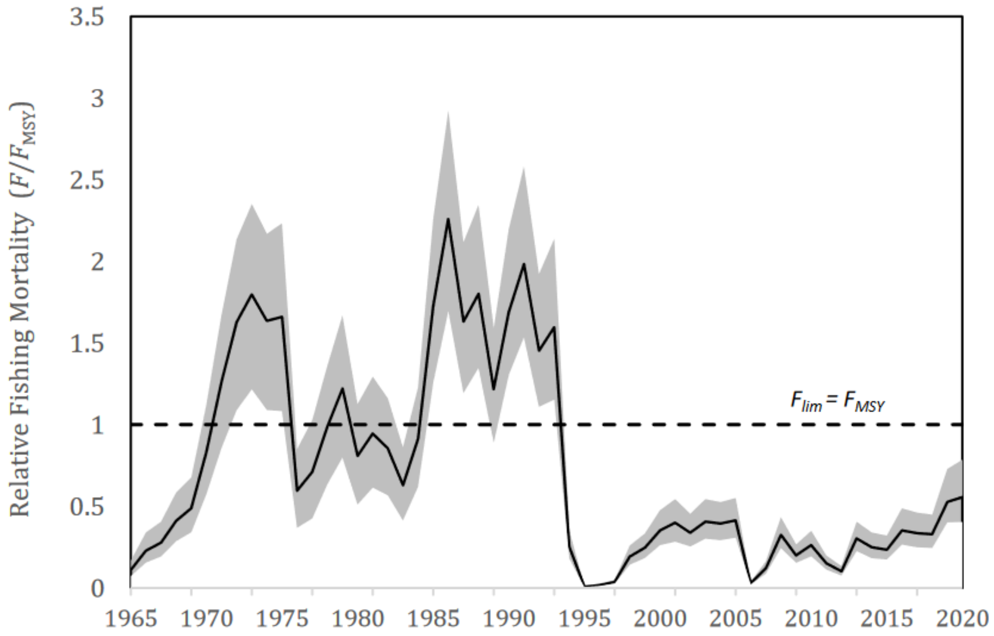
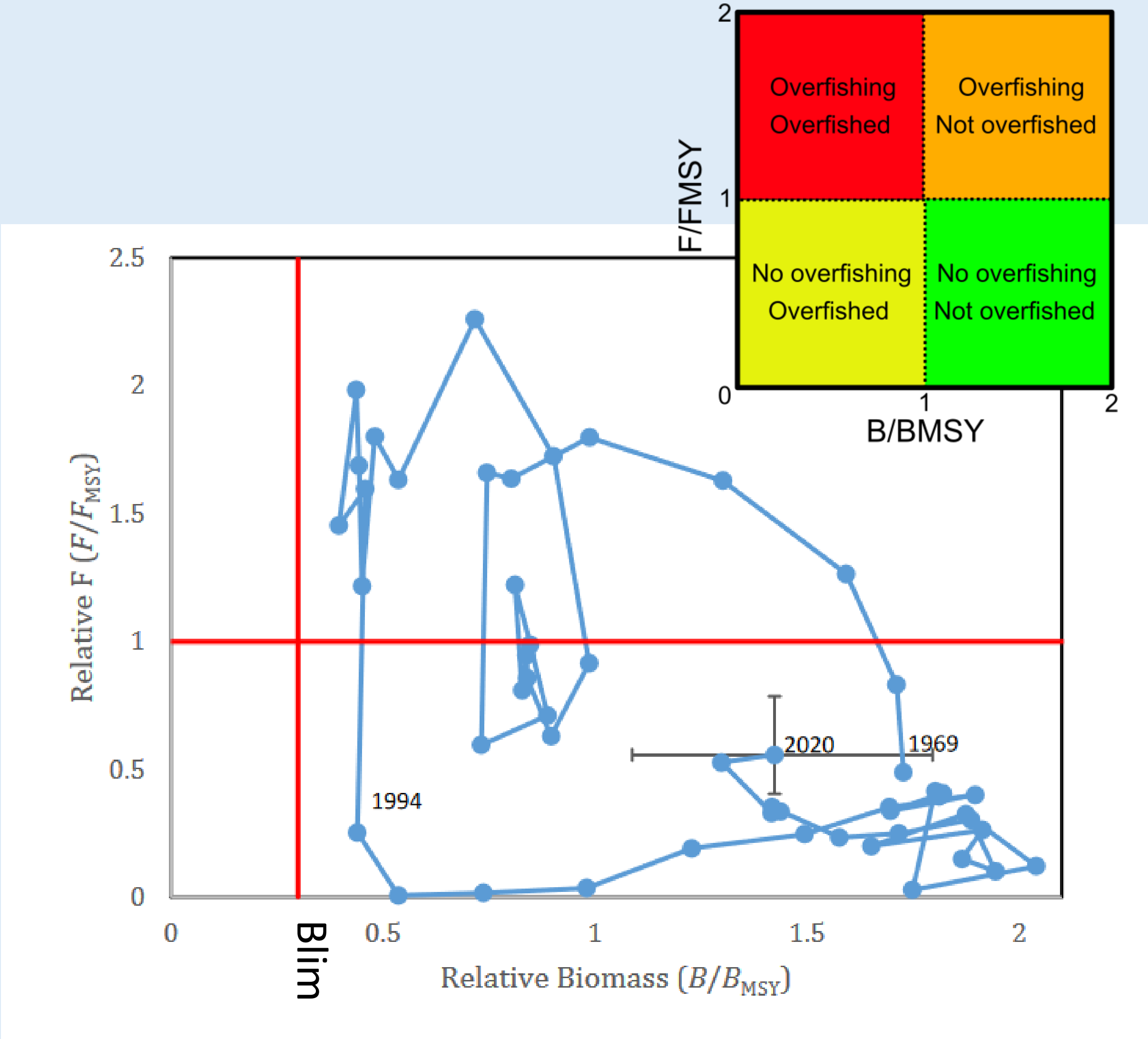


Figure 18. Yellowtail flounder in NAFO Divisions 3LNO: Relative biomass (B/B_{msy}) and relative fishing mortality (F/F_{msy}) estimates from a surplus production model in a Bayesian framework used for the 2021 assessment. 90% confidence intervals are shown.

Fishing mortality

- Estimated that fishing mortality has been low in recent years
- Population was overfished intermittently between 1970 – 1995
- Currently not overfished and overfishing is not occurring



RMarkdown

Go to: https://github.com/MatthewRobertson2452/FISH6001_apps

And open the html markdown file for the surplus production model

You can also open this in R and modify the inputs to see how it changes the results

Surplus Production Model

Matt Robertson

2024-02-09

Data Setup

I am going to make a ficticious fish population and track its dynamics in response to an increasing and then stabilzing amount of fishing pressure.

To do this, we first need to define the time over which we want to track this population's dynamics as well as some basic components of this population's biology.

I am going to run a simulation for 50 years, lets say from 2000 to 2050.

```
yrs<-seq(from=2000, to=2050)
nyears<-length(yrs)
```

When we imagine that a population grows following the dynamics modeled with a surplus production model, we only need to understand the population's maximum growth rate, r_{max}, and its carrying capacity, K.

We are going to start simply and expect that $r_{max} = 1$ and $K = 1000$. Additionally, we are going to assume that our population is at carrying capacity when our simulated fishery starts.

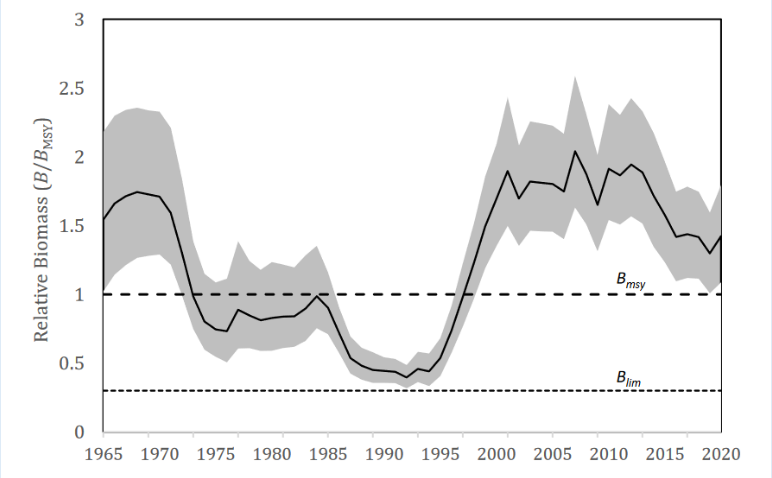
```
K<-1000

rmax<-1
```

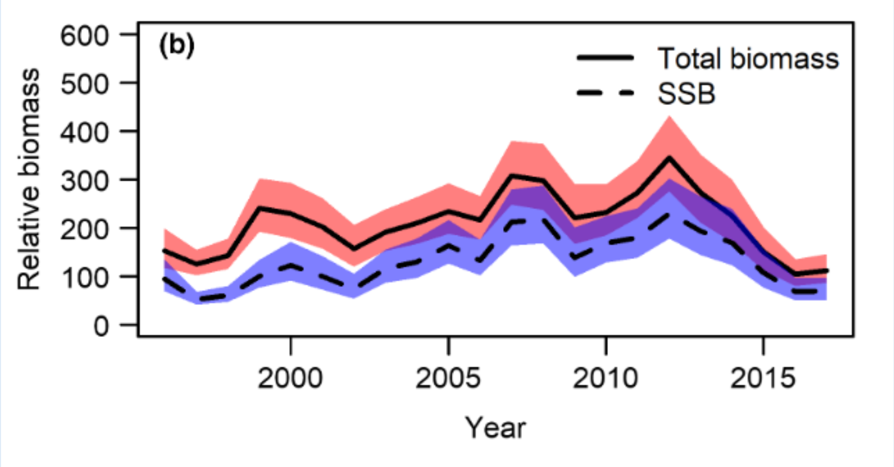
Increasing complexity

- Biomass dynamic models assume that there is no internal population structure
- We know that real populations are structured by age, length, and across space
- Structure can help inform changes in population dynamics
  - Maturity, growth, mortality, etc.

Surplus production comparison

- Age and length structured model actually indicates that yellowtail flounder biomass in recent years is similar to where it was in the 1990s (Zhang & Cadigan 2022)





Cohorts

Hjort (1914)

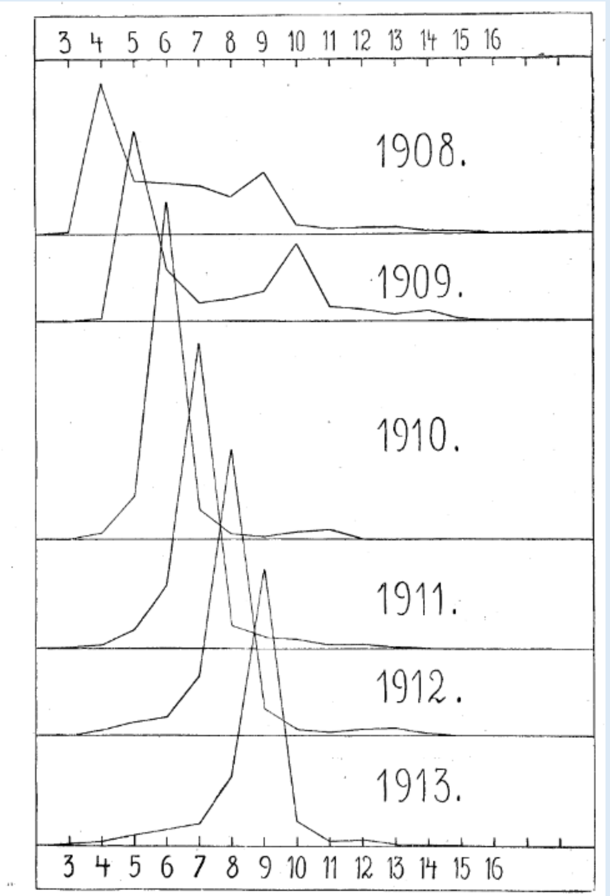


Fig. 16. Composition in point of age of spring herring, 1908—1913. 4 = 4 years old (scales showing 4 winter rings).

- Fish born in the same population in the same year
- Easily calculated by:

$$Cohort = year - age$$

  - If we measure age 3 fish in 2023 then they are from the 2020 cohort
- Benefit: The numbers in a cohort can only decline each year (assuming no migration)

Age-structured models

- Separately track the behavior of all cohorts in a population
- Explicitly allows incorporation of natural processes
  - Older fish have higher biomass
  - Older fish are more likely to be mature
  - Etc.
- As a result, these models are expected to be more biologically realistic and more accurate than biomass dynamic models

The cohort equation

- Age-structured models are essentially just a bunch of exponential decay models tied together
- Based on what is known as the cohort equation,

$$N_{t+1} = N_t e^{-Z}$$

Numbers in a cohort at the start of next year

Numbers in a cohort at the start of this year

Total mortality this year

- Mathematically describes how cohorts decline over time

Population numbers

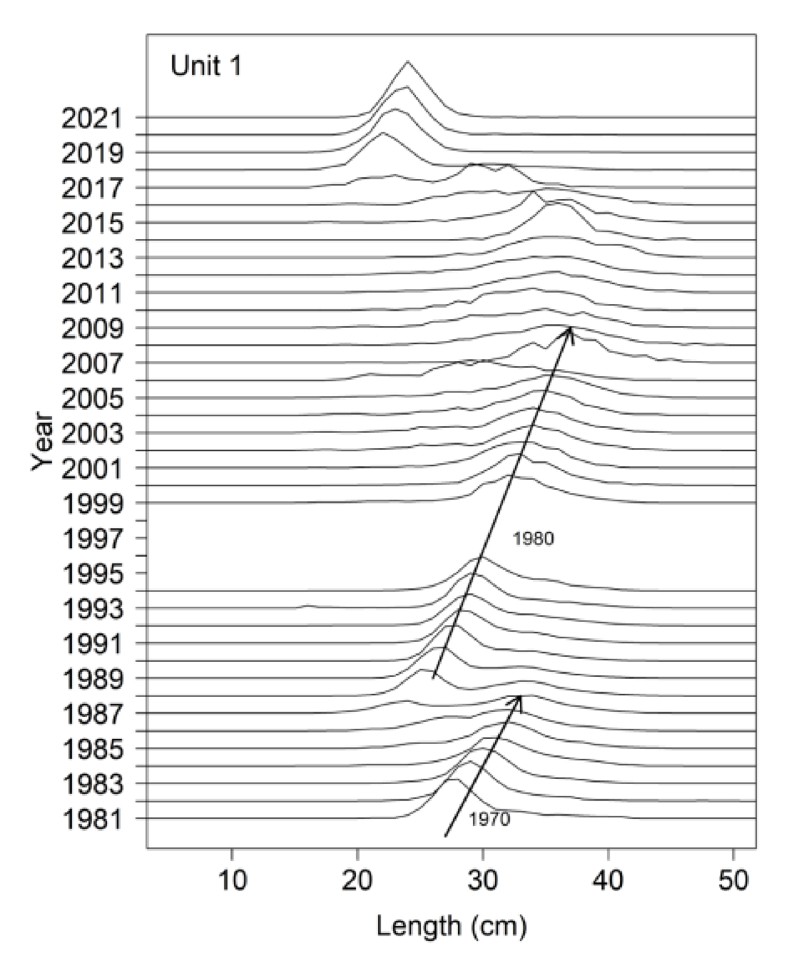
Year/Age	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7
2000	260,000						
2001		150,000					
2002			77,000				
2003				41,000			
2004					18,000		
2005						6,000	
2006							2,000

Population numbers

Year/Age	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7
2000	260,000						
2001		150,000					
2002			77,000				
2003				41,000			
2004					18,000		
2005						6,000	
2006							2,000

Length frequencies

- Cohort tracking is often visually assessed using ridge plots
- Commercial catch or surveys
- Used to identify strong cohorts
- Necessary for models to fit well because these cohorts can provide a lot of information



GSL Redfish catch length frequency

Types of age-structured models

- Virtual population analysis (VPA)
- Survey-based separable model of mortality (SURBA)
- Statistical catch at age (SCAA)
  - Stock synthesis
  - Multifan-CL
- State-space age-structured models
  - Wood’s hole assessment model (WHAM)
  - Northern cod (\s Noel Cadigan) assessment model (NCAM)
- Many others

Using these models to manage

- Can derive MSY-based reference points from age-structured models
- Can also calculate non-MSY reference points (will not spend much time describing these in this class)

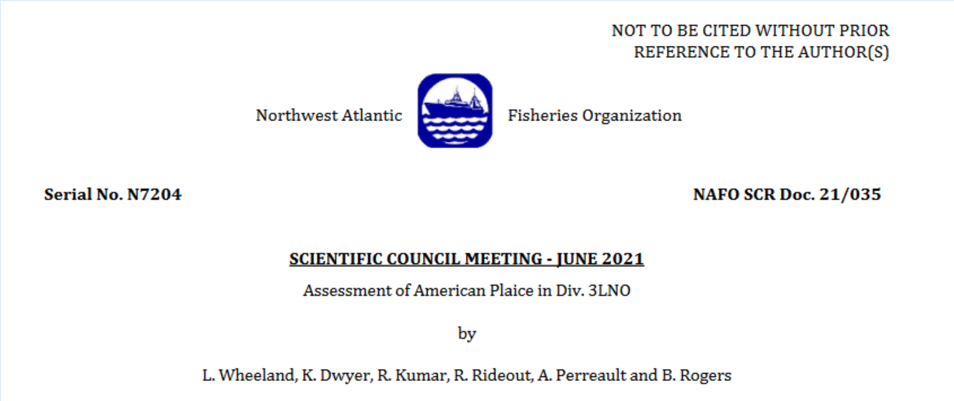
Necessary data

- Still need total catch and effort, but in addition, now need at least
  - Catch numbers-at-age for each year of the fishery
- Many more complex age-structured models, which may need:
  - Recruitment estimates
  - Stock biomass estimates
  - Length and weight information
  - Etc.

Biggest problems

- Models often require substantial amounts of data
- Assume that age describes the primary population structure
  - Do fish know how old they are?
- Many different models with different assumptions

An example – 3LNO American plaice


NOT TO BE CITED WITHOUT PRIOR
REFERENCE TO THE AUTHOR(S)

Northwest Atlantic Fisheries Organization

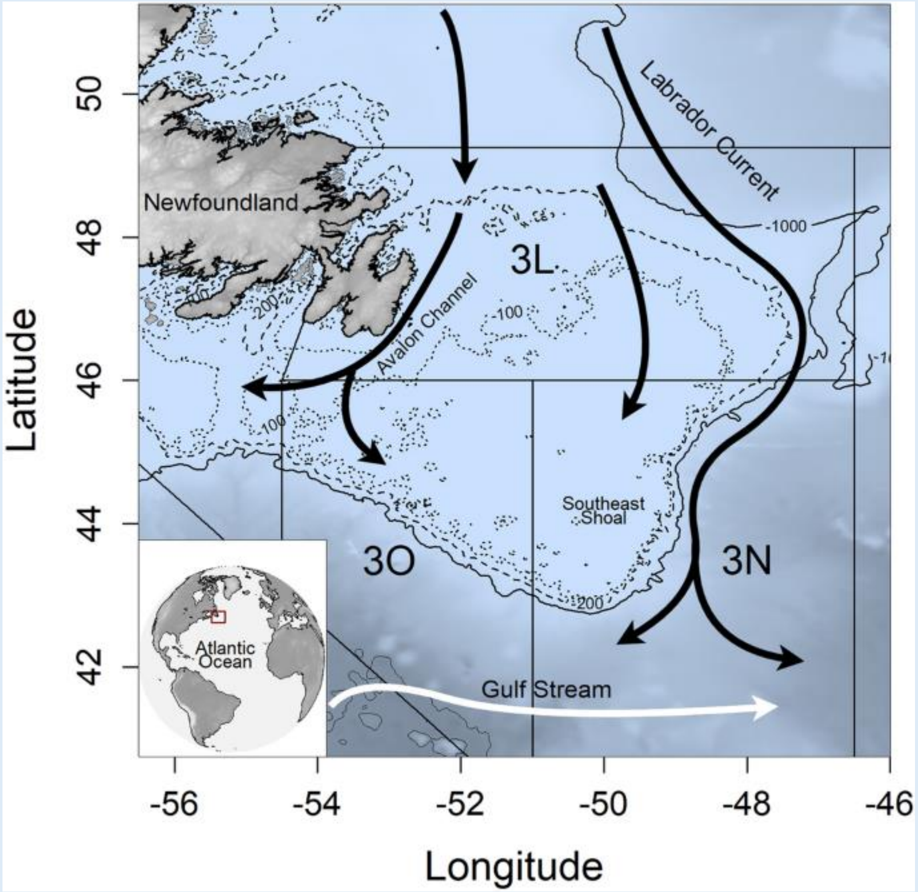
Serial No. N7204 NAFO SCR Doc. 21/035

SCIENTIFIC COUNCIL MEETING - JUNE 2021

Assessment of American Plaice in Div. 3LNO

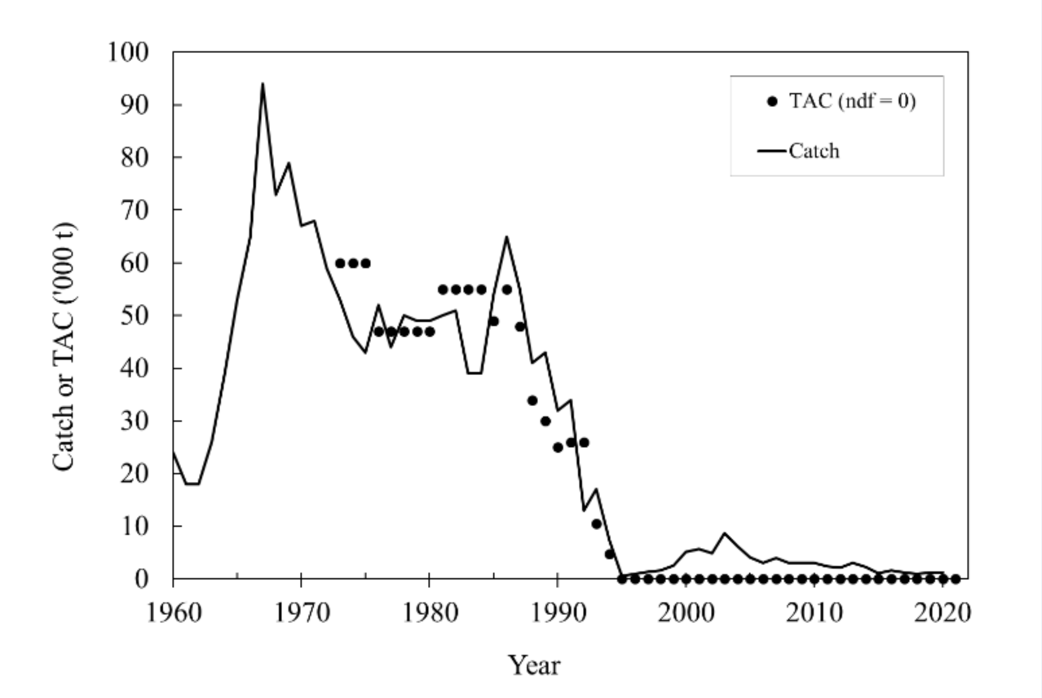
by

L. Wheeland, K. Dwyer, R. Kumar, R. Rideout, A. Perreault and B. Rogers



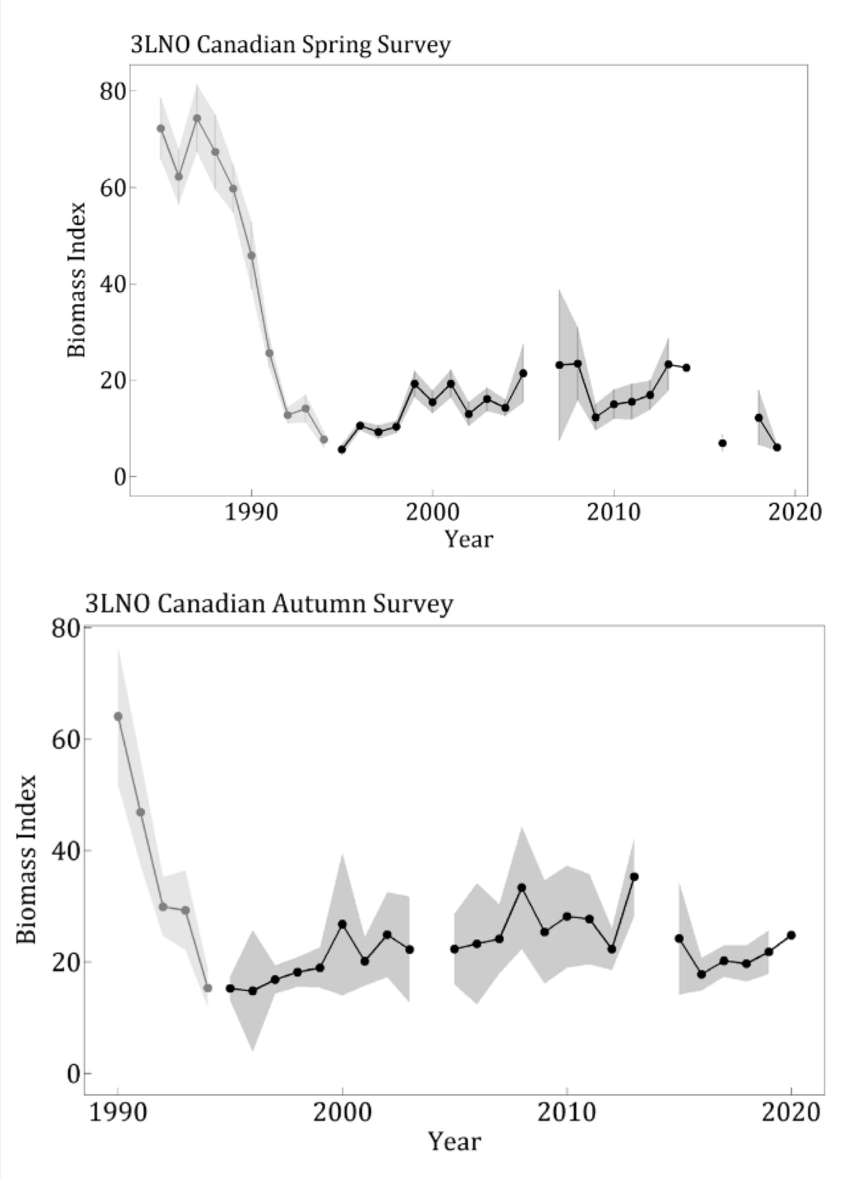
Background

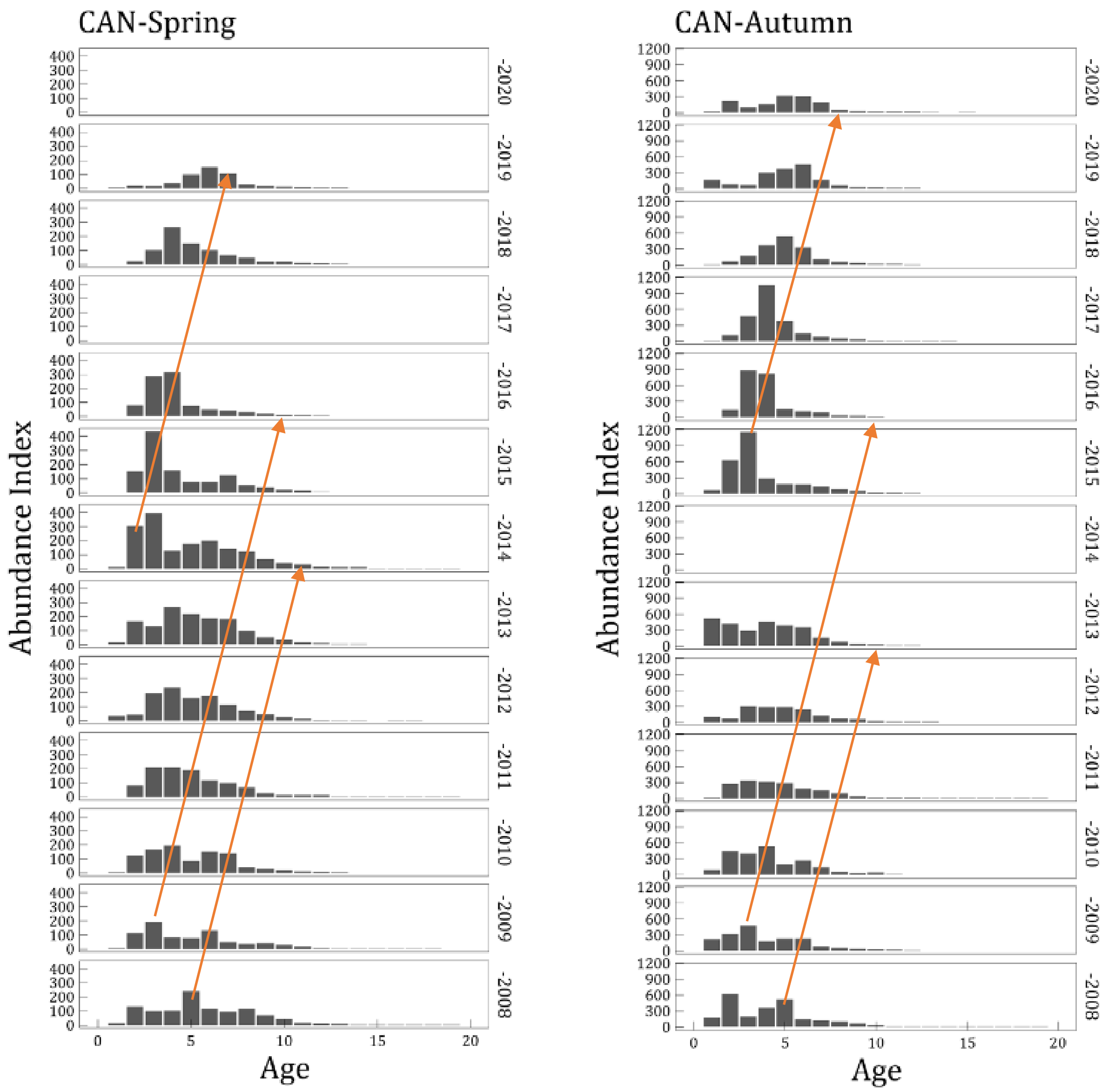
- Historically important fishery in NL
- Catches peaked in 1960s and collapsed in early-1990s
- Directed fishing moratorium in 1995
- Bycatch in yellowtail flounder, skate, and redfish fisheries since



Research survey data

- Spring bottom trawl survey
  - 1983 – 2019
- Fall bottom trawl survey
  - 1990 – 2019
- Spanish 3NO survey
  - 1995 – 2019
- Ageing data available from surveys and catches
- Also have length, weight, maturity, spatial distribution data

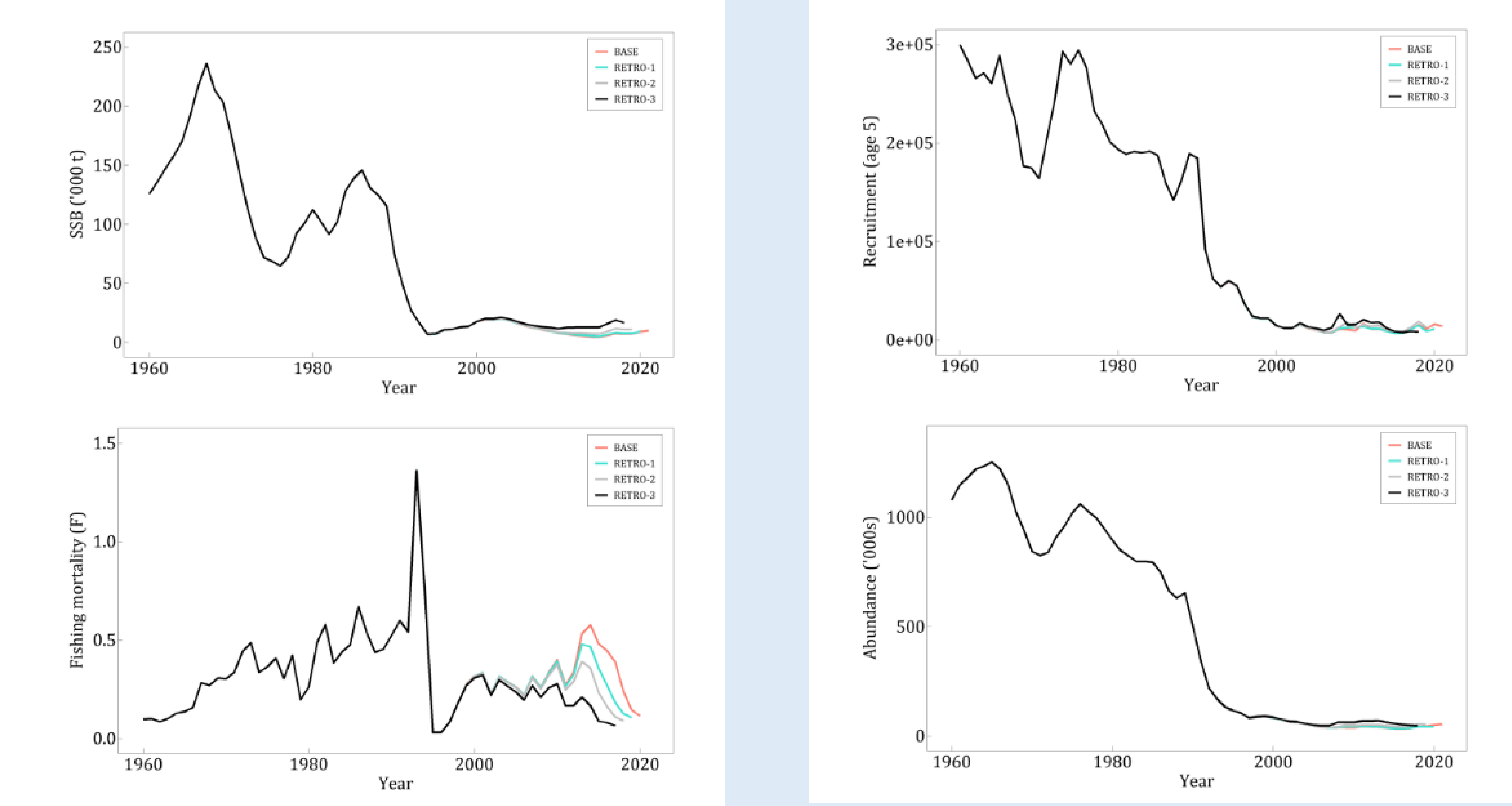



CAN-Spring
CAN-Autumn
Abundance Index
Age
-2020
-2019
-2018
-2017
-2016
-2015
-2014
-2013
-2012
-2011
-2010
-2009
-2008

Model

- Virtual population analysis (VPA)
  - No underlying statistical assumptions
  - Use algorithms to back-calculate numbers that must have been alive given how many were caught and assumptions about natural mortality
- Since this model needs fishery data for calculations, it only tracks ages that are captured by the fishery (5+)

Y/A	Age 1	Age 2	Age 3	Age 4	Age 5
2000					?
2001					?
2002					?
2003					?
2004					?
2005	?	?	?	?	?



SSB ('000 t)
Year
Recruitment (age 5)
Fishing mortality (F)
Abundance ('000s)
BASE
RETRO-1
RETRO-2
RETRO-3

RMarkdown

Go to: https://github.com/MatthewRobertson2452/FISH6001_apps

And open the html markdown file for the age structured model

You can also open this in R and modify the inputs to see how it changes the results

Age Structured Model Simulation

Matt Robertson

2024-02-09

Data Setup

I am going to make a ficticious fish population and track its dynamics in response to an increasing and then stabilzing amount of fishing pressure.

To do this, we first need to define the time over which we want to track this population's dynamics as well as some basic components of this population's biology.

I am going to run a simulation for 50 years, lets say from 2000 to 2050.

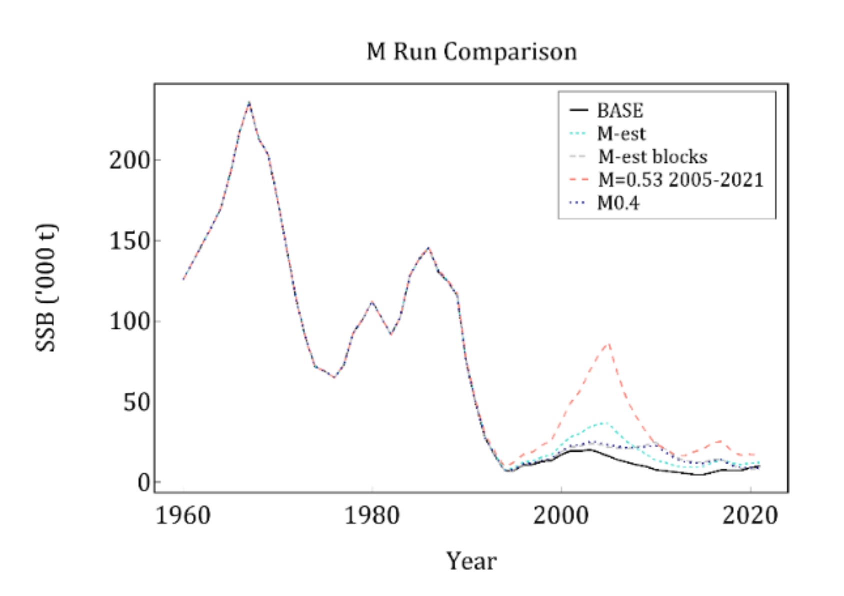
```
yrs<-seq(from=2000, to=2050)
nyears<-length(yrs)
```

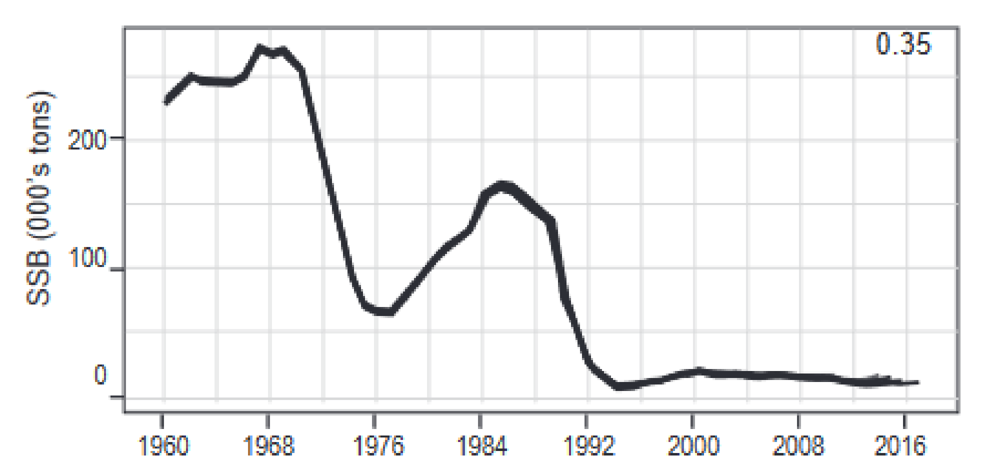
This species is going to grow to 15 years old and have an L_{inf} of 100 cm. You can modify these values if you'd like. However, this simulation relies on some very specific assumptions and any changes you make could lead to a rapid population decline or increase.

```
nages<-15
linf<-100
laa<-rep(NA, nages)
for(i in 1:15){
laa[i]<-linf*(1-exp(-0.25*(i-0.01)))
}

plot(laa~seq(from=1, to=nages, by=1), pch=19, xlab="Age", ylab="Mean Length (cm)", las=1)
lines(laa~seq(from=1, to=nages, by=1))
```

VPA Comparison

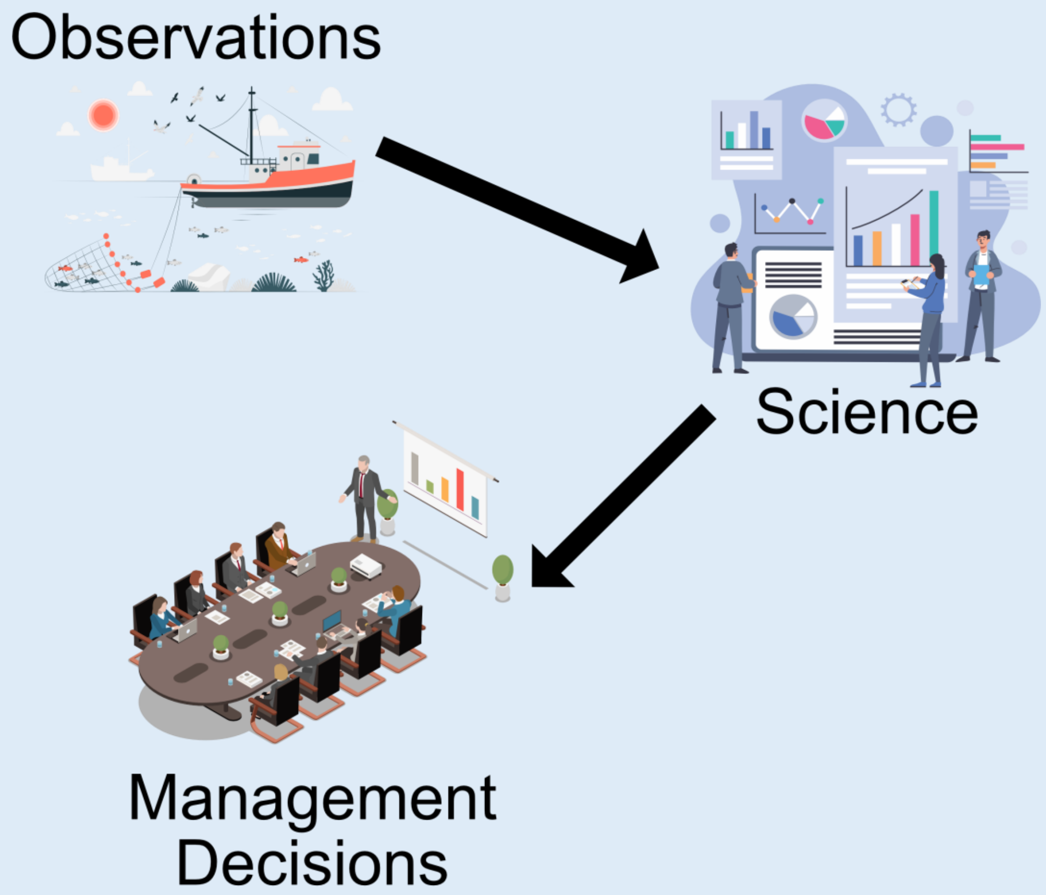
- Natural mortality assumptions seem to have a huge impact on SSB estimates
- A lot of uncertainty in landings data which VPAs cannot account for
- Other models can do a better job of handling these issues





Day 4 – Scientific advice for fisheries management

- Canada’s management system
- Precautionary approach
- Reference points
- Stock assessments
- Management strategy evaluations



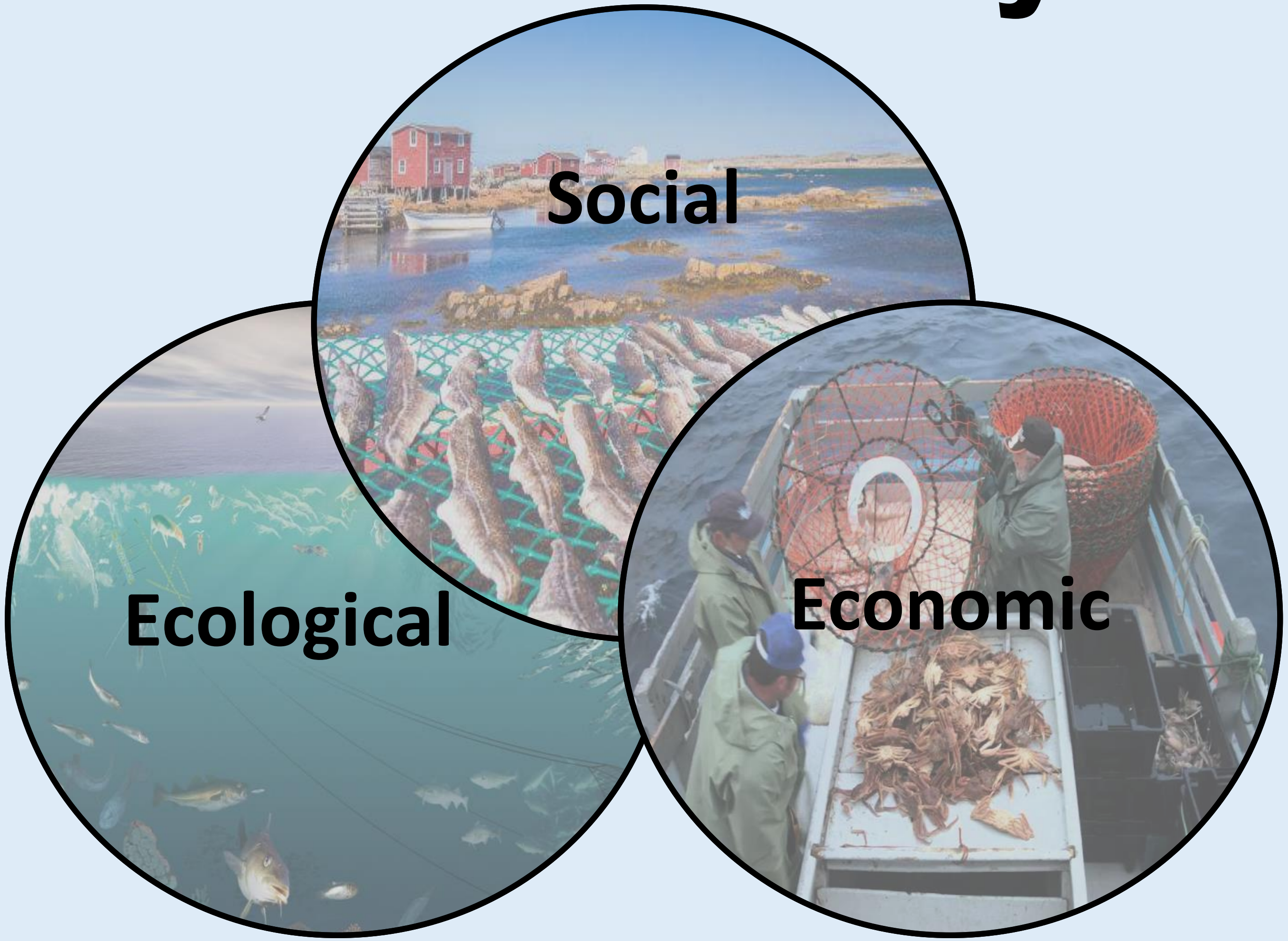
Learning Objectives

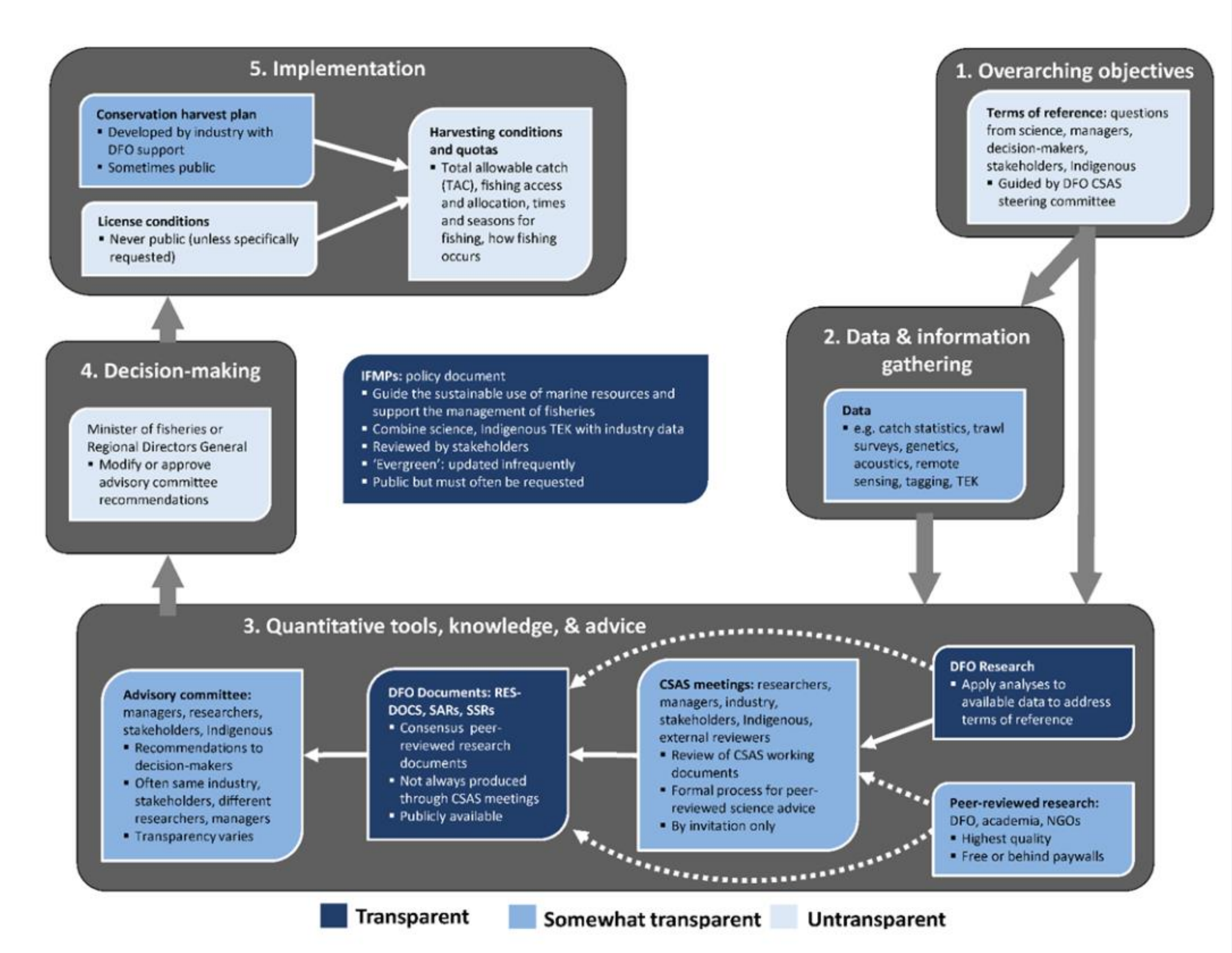
- General history of fisheries science
- What are the key mathematical underpinnings of population growth theory?
- What biological characteristics define population growth?
- How do we use these theories to track population dynamics?
- What are the key population dynamics currently applied?
- **How do population dynamics models inform fisheries management?**

Objectives of fisheries management

- "The over-riding goal of fisheries management is the long-term sustainable use of the fisheries resources. Achieving this requires a proactive approach and should involve actively seeking ways to **optimise the benefits** derived from the resources available." – Cochrane, FAO
- Fisheries management is not about managing the fish, but about managing people

Pillars of sustainability

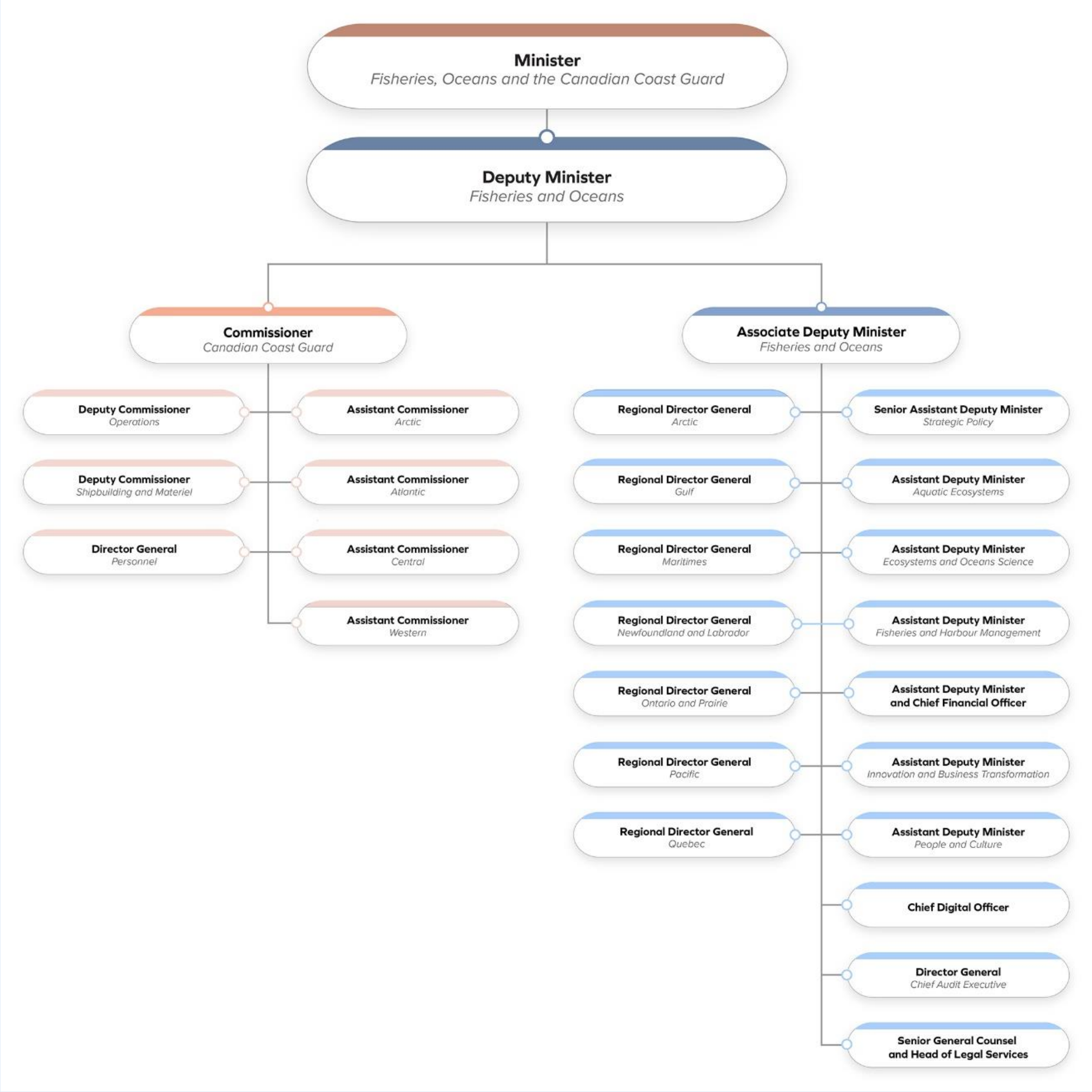




Boyce et al. 2020

Who makes decisions?

- Ultimate discretion for management decision-making falls to the fisheries minister
- Many management actions are made by regional authorities (e.g., regional directors general)



Who makes decisions?

- Ultimate discretion for management decision-making falls to the fisheries minister
- Many management actions are made by regional authorities (e.g., regional directors general)

Minister of Fisheries
Diane Lebouthillier

NL Regional Director General
William McGillivray

Kevin Anderson's Old Position

Canadian Fisheries Act

Fish Stocks

Measures to maintain fish stocks

6.1 (1) In the management of fisheries, the Minister shall implement measures to maintain major fish stocks at or above the level necessary to promote the sustainability of the stock, taking into account the biology of the fish and the environmental conditions affecting the stock.

Limit reference point

(2) If the Minister is of the opinion that it is not feasible or appropriate, for cultural reasons or because of adverse socio-economic impacts, to implement the measures referred to in subsection (1), the Minister shall set a limit reference point and implement measures to maintain the fish stock above that point, taking into account the biology of the fish and the environmental conditions affecting the stock.

Publication of decision

(3) If the Minister sets a limit reference point in accordance with subsection (2), he or she shall publish the decision to do so, within a reasonable time and with reasons, on the Internet site of the Department of Fisheries and Oceans.

Plan to rebuild

6.2 (1) If a major fish stock has declined to or below its limit reference point, the Minister shall develop a plan to rebuild the stock above that point in the affected area, taking into account the biology of the fish and the environmental conditions affecting the stock, and implement it within the period provided for in the plan.

First Session, Forty-second Parliament,
64-65-66-67-68 Elizabeth II, 2015-2016-2017-2018-2019

STATUTES OF CANADA 2019

CHAPTER 14

An Act to amend the Fisheries Act and other Acts in consequence

---

ASSENTED TO

JUNE 21, 2019

BILL C-68

Canadian Fisheries Act

Considerations

Considerations for decision making

2.5 Except as otherwise provided in this Act, when making a decision under this Act, the Minister may consider, among other things,

(a) the application of a precautionary approach and an ecosystem approach;

(b) the sustainability of fisheries;

(c) scientific information;

(d) Indigenous knowledge of the Indigenous peoples of Canada that has been provided to the Minister;

(e) community knowledge;

(f) cooperation with any government of a province, any Indigenous governing body and any body — including a co-management body — established under a land claims agreement;

(g) social, economic and cultural factors in the management of fisheries;

(h) the preservation or promotion of the independence of licence holders in commercial inshore fisheries; and

(i) the intersection of sex and gender with other identity factors.

First Session, Forty-second Parliament,
64-65-66-67-68 Elizabeth II, 2015-2016-2017-2018-2019

STATUTES OF CANADA 2019

CHAPTER 14

An Act to amend the Fisheries Act and other Acts in consequence

ASSENTED TO

JUNE 21, 2019

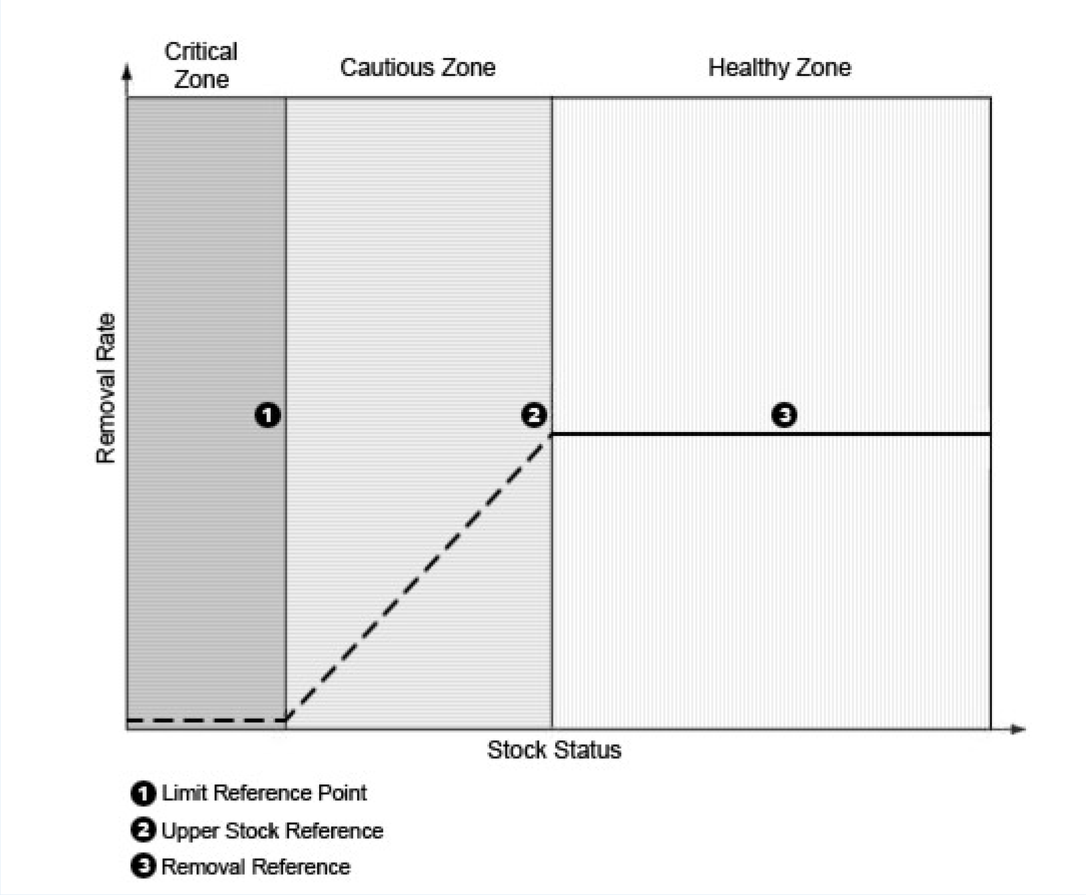
BILL C-68

Precautionary approach

- "... in general, about being cautious when scientific information is uncertain, unreliable or inadequate and not using the absence of adequate scientific information as a reason to postpone or fail to take action to avoid serious harm to the resource."
- Includes:
  - Reference points linked to stock and ecosystem indicators
  - Objectives for desirable resource and fishery outcomes
  - Resource use strategies to scale resource use to its condition in a manner that avoids undesirable outcomes

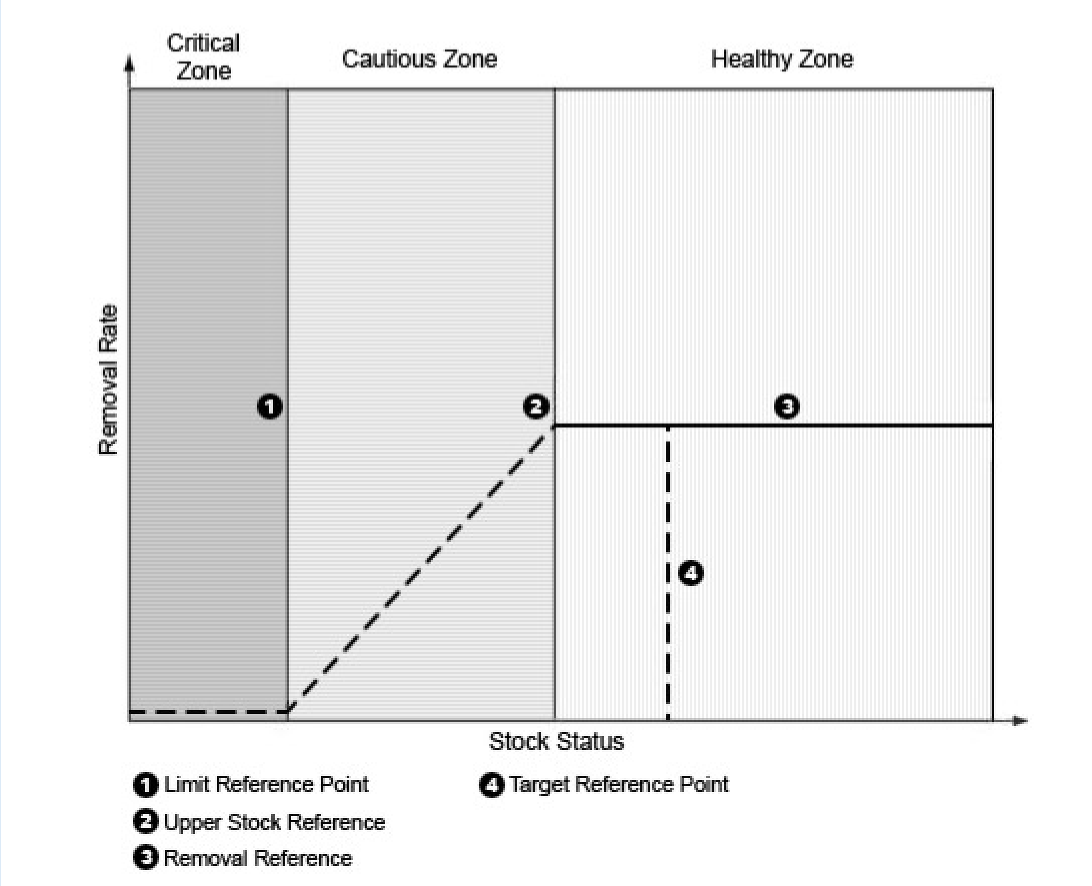
Reference points and stock status

- Reference Point (RP)
  - Define stock status
- Limit reference point (LRP)
  - Stock status below this point causes serious harm
- Upper stock reference (USR)
  - Below this point, removals must be reduced progressively until LRP



Reference points and stock status

- Reference Point (RP)
  - Define stock status
- Limit reference point (LRP)
  - Stock status below this point causes serious harm
- Upper stock reference (USR)
  - Below this point, removals must be reduced progressively until LRP
- Target reference point
  - Must be ≥ USR (often = USR)
- Removal reference is maximum acceptable removal rate (e.g., F)
  - Must be ≤ F_{MSY}



Harvest control rules

- Harvest control rule
  - Tactic used to achieve desired stock and fishery objectives
- Status-based rules:
  - Removal rate (F) determined using a function with estimated stock status
- Risk-based rules:
  - Acceptable probability of future stock decline is based on stock status and recent change in status (i.e., increasing, stable, decreasing)

Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences

Canadian Science Advisory Secretariat (CSAS)

Research Document 2013/080

National Capital Region

Current Approaches for the Provision of Scientific Advice on the Precautionary Approach for Canadian Fish Stocks: Harvest Decision Rules

A.R Kronlund[1], K.R. Holt[1], P.A. Shelton[2] and J.C. Rice[3]

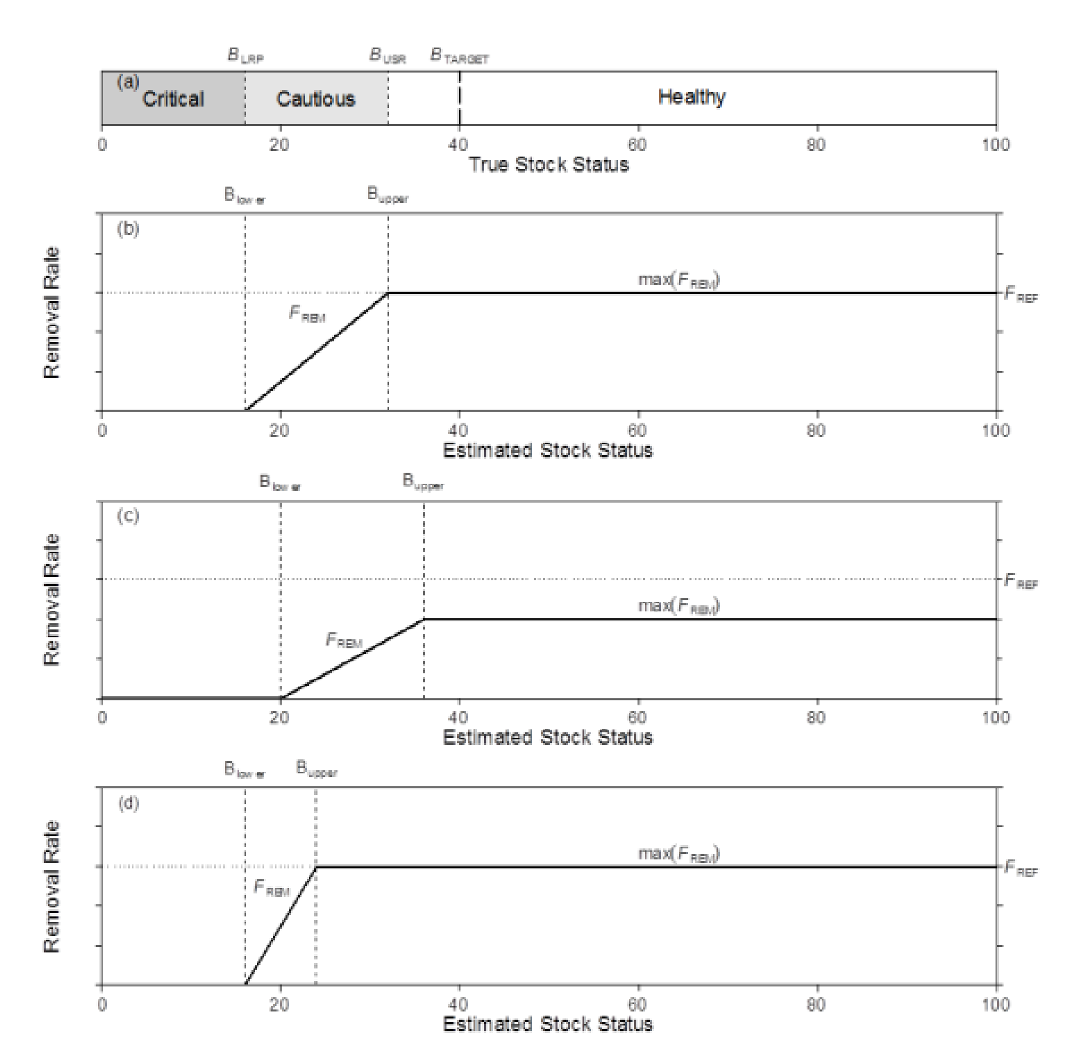
[1]Fisheries and Oceans Canada
Pacific Biological Station
Nanaimo, British Columbia V9T 6N7

[2]Fisheries and Oceans Canada
NAFC, P.O. Box 5667
80 East White Hills Road
St. John's, NL A1C 5X1

[3]Fisheries and Oceans Canada
200 Kent Street
Ottawa, ON K1A 0E6

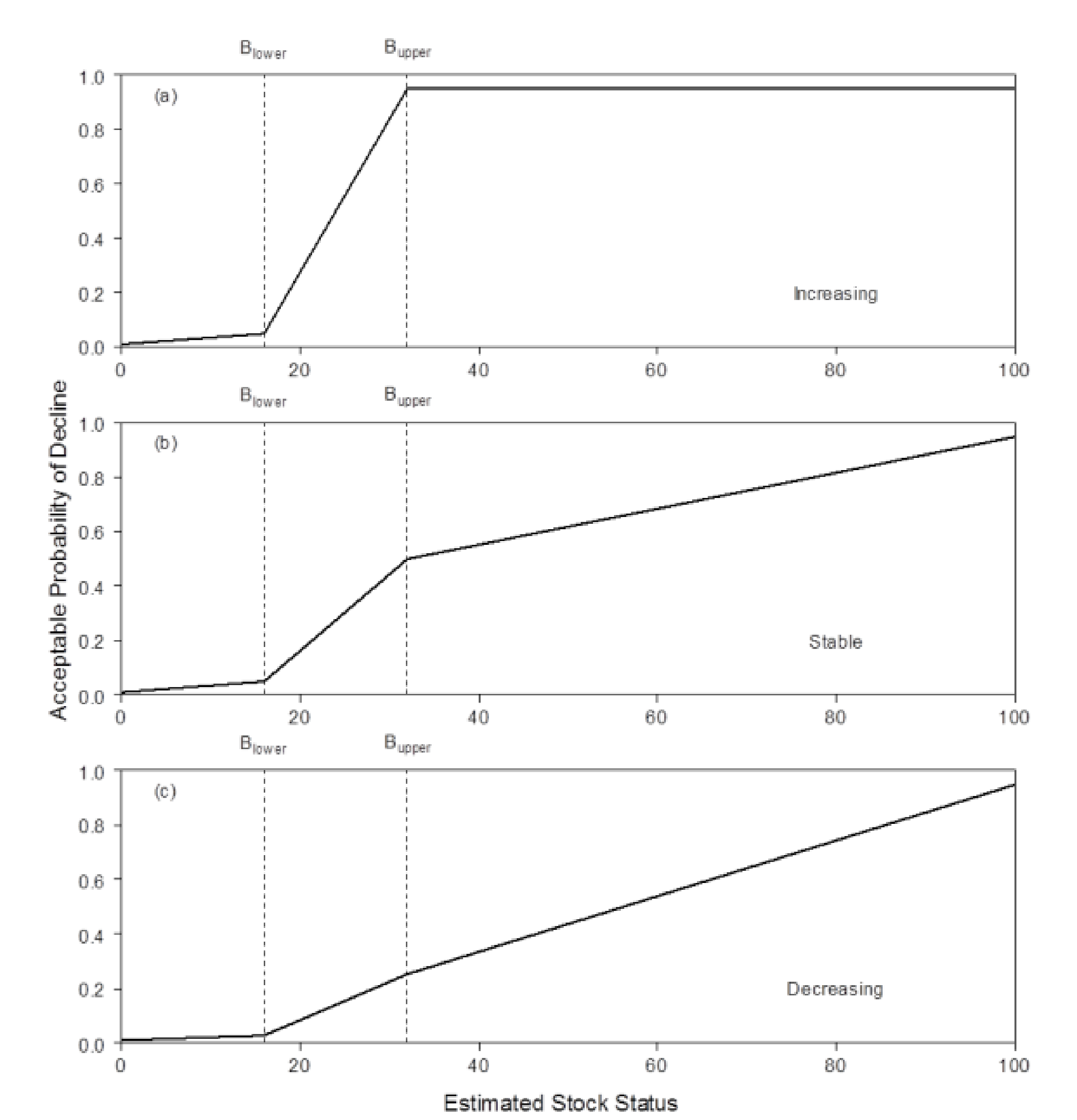
Status-based rules

- Rules are often defined based on reference points, such that:
  - $\max(F_{REM})$ must be ≤ F_{REF}
  - $B_{lower} = B_{LRP}$
  - $B_{upper} = B_{USR}$
- But these could also be specified differently



Risk-based rules

- Rules are based on a combination of:
  - Current stock status
  - Recent rate of change in status
  - Projected probability of future decline based on a specified harvest level
- Where the specified harvest level is the amount where the projected probability of future decline does not exceed the **acceptable probability of future decline**



Rebuilding plans

- “when a stock has reached the Critical Zone, a rebuilding plan must be in place with the aim of having a high probability of the stock growing out of the Critical Zone within a reasonable timeframe” – DFO PA policy
- Need to be developed within 24 months of minister learning about stock declining below LRP

Interim management

- While a rebuilding plan is being developed:
  - Conservation considerations must prevail
  - Removals from all sources are at lowest possible level
  - No tolerance for preventable decline
  - Management actions must promote stock growth

Elements of a rebuilding plan

- Must at minimum rebuild above the LRP
- Timeline must be $<3\ T_{min}$
  - T_{min} - The time to rebuild with no fishing

A. Introduction and context;

B. **Stock status and stock trends;**

C. **Probable causes for the stock's decline;**

D. **Measurable objectives aimed at rebuilding the stock;**

   i. **Rebuilding target and timeline;**

   ii. **Additional measurable objectives and timelines;**

E. **Management measures aimed at achieving the objectives;**

F. Socio-economic analysis;

G. **Method to track progress towards achieving the objectives;**

H. **Periodic review of the rebuilding plan;**

I. References

The role of science


Marine Policy 121 (2020) 104161
Contents lists available at ScienceDirect
Marine Policy
journal homepage: http://www.elsevier.com/locate/marpol
ELSEVIER

Impediments to fisheries recovery in Canada: Policy and institutional constraints on developing management practices compliant with the precautionary approach

Anna-Marie Winter [a,b], Jeffrey A. Hutchings [c,d,e,*]

1. Definition of quantifiable criteria (e.g., reference points) for scientific judgement of management objectives (e.g., stock status, total allowable catch)
2. Analysis of risks
3. Evaluation of what actions (harvest rules) will meet objectives
4. Peer-review to ensure use of best available evidence
5. Transparent science advisory process

Winter & Hutchings (2020)

Stock assessment models

- Statistical and mathematical models that make quantitative predictions about the reactions of fish populations to alternative management choices
- The goal is to provide advice to managers to help them make choices about dynamic fishery systems in the face of uncertainty – Hilborn & Walters (1992)

Stock assessment meeting

- Peer-review of stock assessment context, data, models, and the resultant scientific advice that will be provided to fishery managers

Fisheries and Oceans Canada | Pêches et Océans Canada

Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Newfoundland and Labrador Region

Canadian Science Advisory Secretariat
Science Advisory Report 2022/041

STOCK ASSESSMENT OF NORTHERN COD (NAFO DIVISIONS 2J3KL) IN 2021

Image: Atlantic Cod (Gadus morhua).

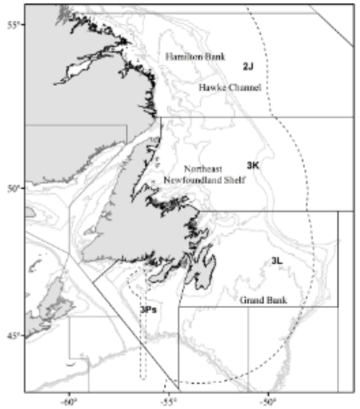
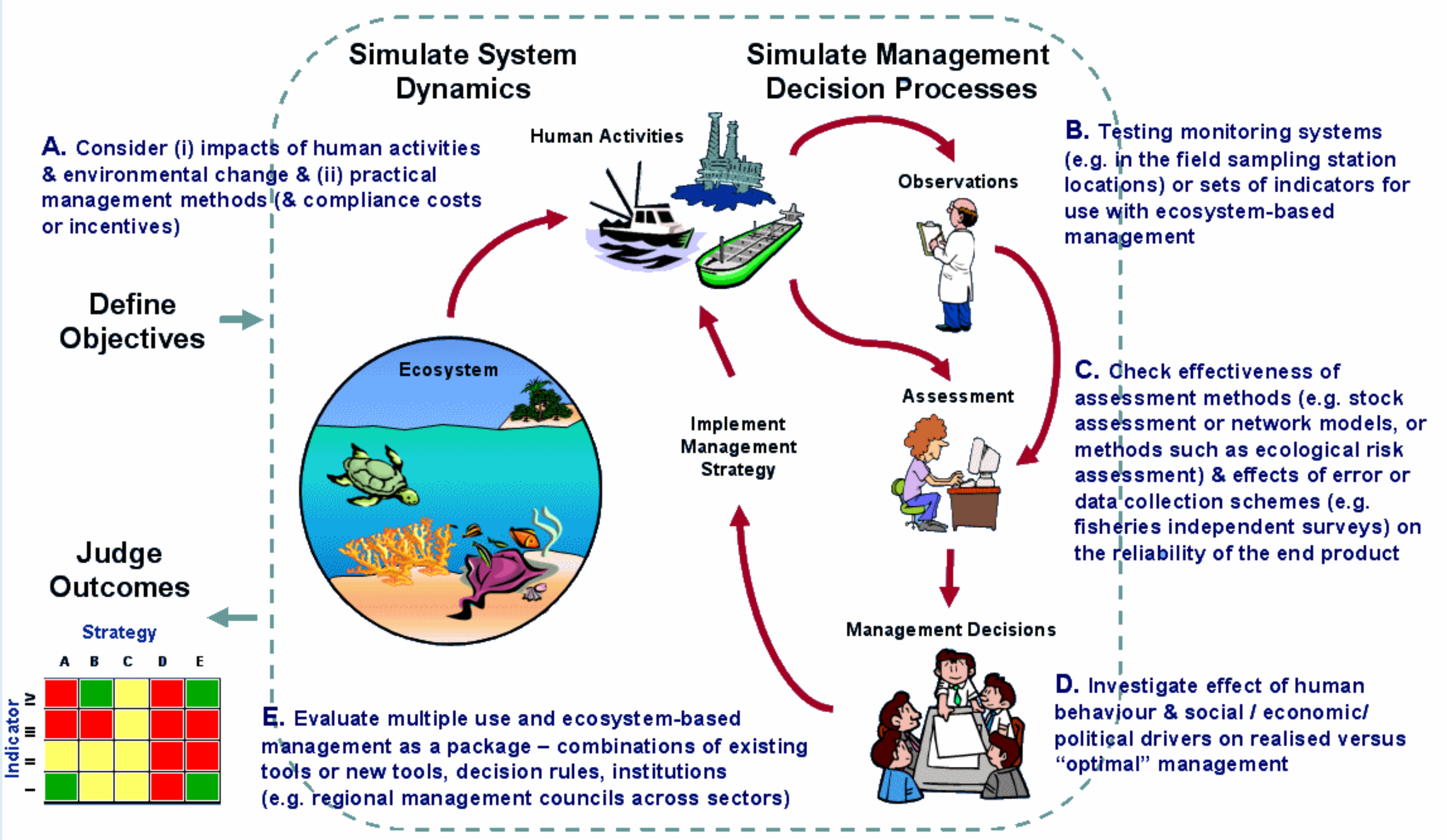


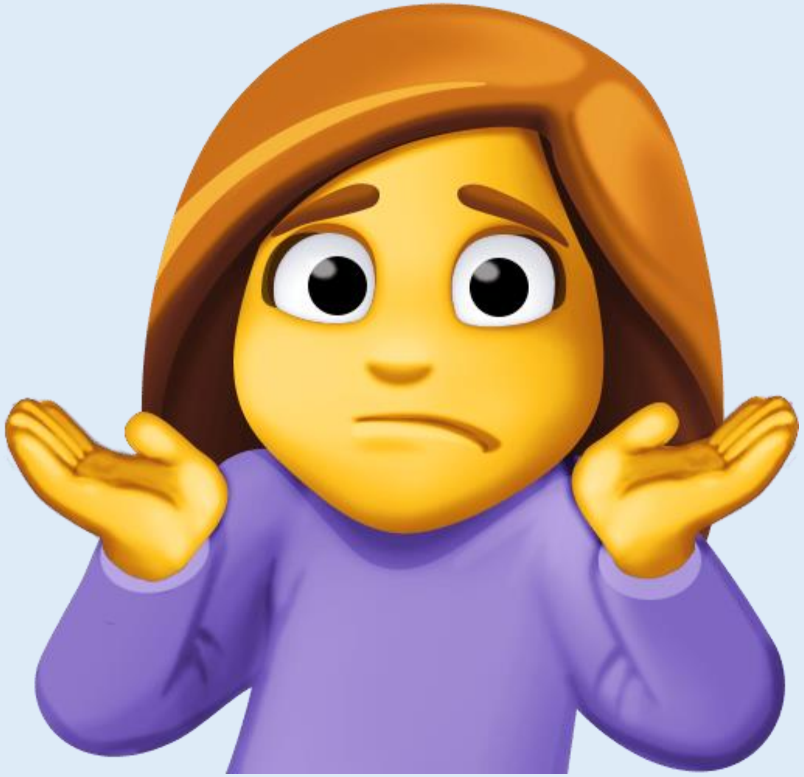
Figure 1: Stock area of Northern (2J3KL) cod. The dashed line indicates Canada's 200 nautical mile Exclusive Economic Zone (EEZ).

Management strategy evaluation



CSIRO

Does any of this actually work?



Returning to a slide from Day 1

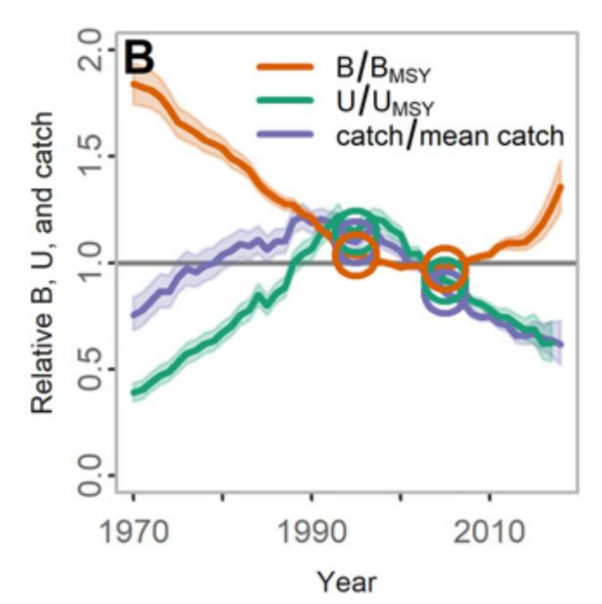
- Confidence in these new tools and the communication between scientists and regulators was at an all time high in the 1950s
- However, it was not too last
- Many fisheries collapsed in the 1950s and 1960s, due to:
  - **Catch efficiency improvements**
  - **Political interventions limiting uptake of suggested regulations**
  - **Inability to understand complex socioecological systems**

Does any of this actually work?

- Examined stocks that are scientifically assessed (~50% of global marine catch)
- On average, abundance is increasing and at proposed target levels
- Regions with less developed fisheries management have, 3x greater harvest rates and ½ the abundance

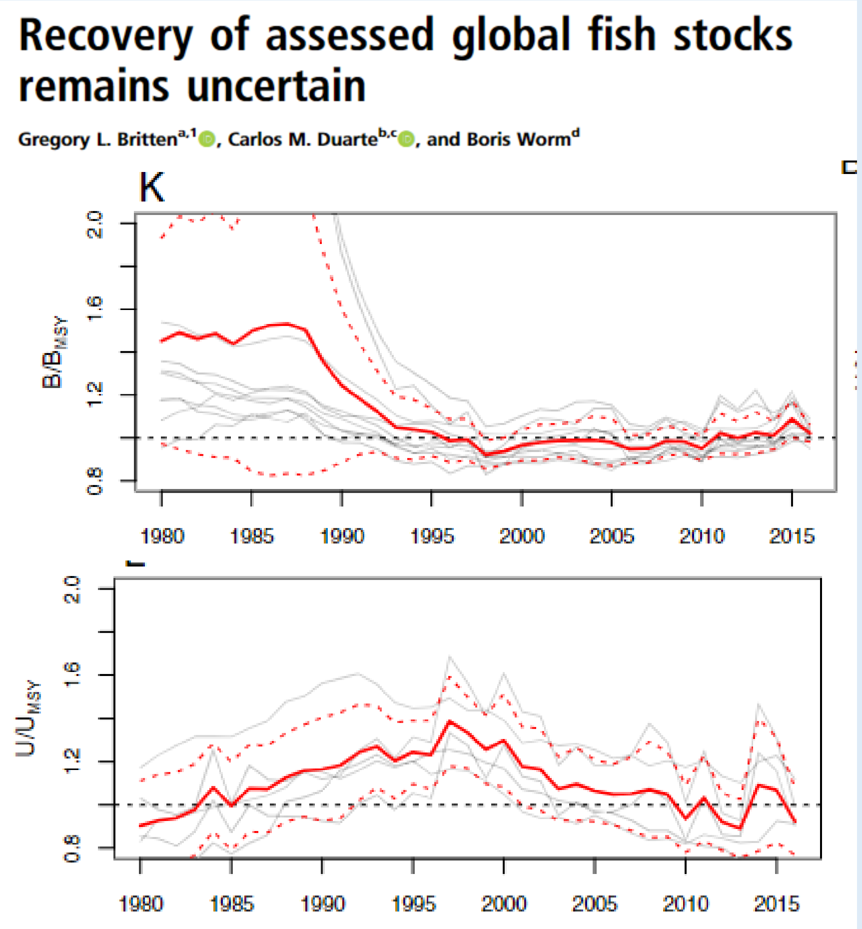
Effective fisheries management instrumental in improving fish stock status

Ray Hilborn[a,1], Ricardo Oscar Amoroso[a], Christopher M. Anderson[a], Julia K. Baum[b], Trevor A. Branch[a], Christopher Costello[c], Carryn L. de Moor[d], Abdelmalek Faraj[e], Daniel Hively[a], Olaf P. Jensen[f], Hiroyuki Kurota[g], L. Richard Little[h], Pamela Mace[i], Tim McClanahan[j], Michael C. Melnychuk[a], Cóilín Minto[k], Giacomo Chato Osio[l,m], Ana M. Parma[n], Maite Pons[a], Susana Segurado[o], Cody S. Szuwalski[c], Jono R. Wilson[c,p], and Yimin Ye[q]



Does any of this actually work?

- Re-examined the data that Hilborn examined but used different averaging techniques
- Found that different methods produced different results
- Up to 48% of stocks remain below biomass reference points
- Up to 40% are exploited above sustainable levels



Canadian challenges

- Canada's science advisory process is less structured and transparent
- Potential for this structure to "obfuscate... science leading to an erosion of credibility and accountability of fisheries management decisions."

Marine Policy 121 (2020) 104161

Contents lists available at ScienceDirect

Marine Policy

journal homepage: http://www.elsevier.com/locate/marpol

Impediments to fisheries recovery in Canada: Policy and institutional constraints on developing management practices compliant with the precautionary approach

Anna-Marie Winter[a,b], Jeffrey A. Hutchings[c,d,e,*]

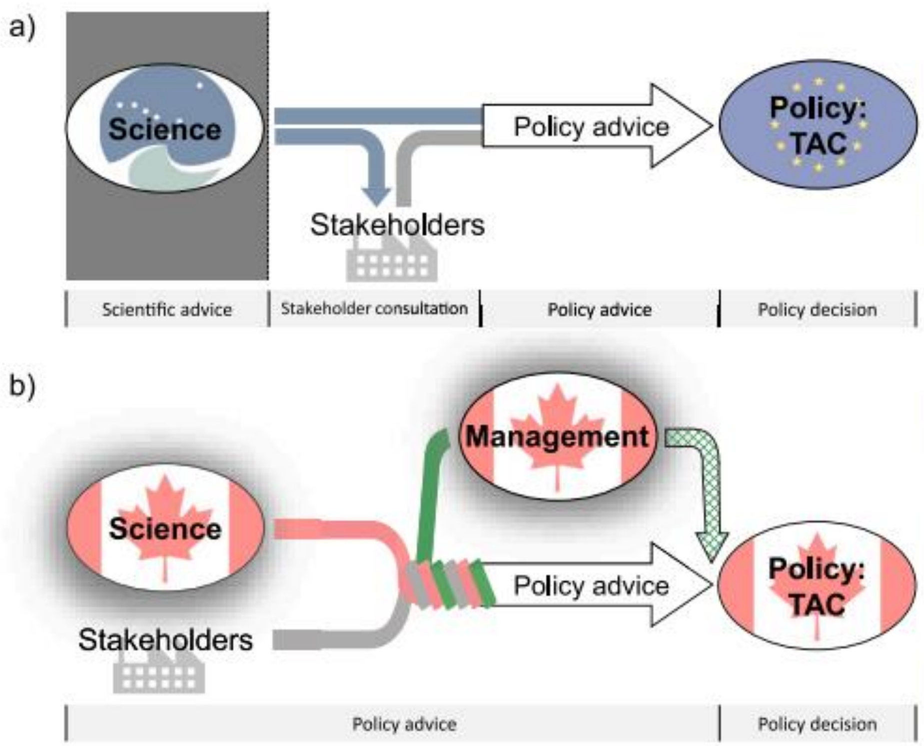


Fig. 2. The decision-making process for determining total allowable catch, TAC, in the European Union (EU) (a) and in Canada (b). In the EU, ICES (International Council for the Exploration of the Sea) provides science advice to the European Council (DG MARE). Stakeholders are asked for consultation via Advisory Councils. DG MARE's policy advice is then sent to the Council of the EU which decides on the TAC. Each step of the consecutive decision-making process is transparent (published) and accountable. Science has a defined role, distinct and publicly distinguishable from stakeholder advice. In Canada, science is facilitated by the Department of Fisheries Oceans' in-house Canadian Science Advisory Secretariat (CSAS). Science advice is less transparent because of the inseparable stakeholder involvement and management considerations that influence the entire advisory process. In some cases (e.g. harvest control rules), management decisions need not be based on science advice (hatched arrow). The policy advice published by CSAS is presented to the Minister who has discretion to base all, part, or none of her/his TAC decision on science. As a consequence, the role of science is not as well defined or publicly distinguishable in Canada as in the EU; the different steps of the decision-making process are less transparent, limiting the accountability of the decision-making process.

5

NL challenges

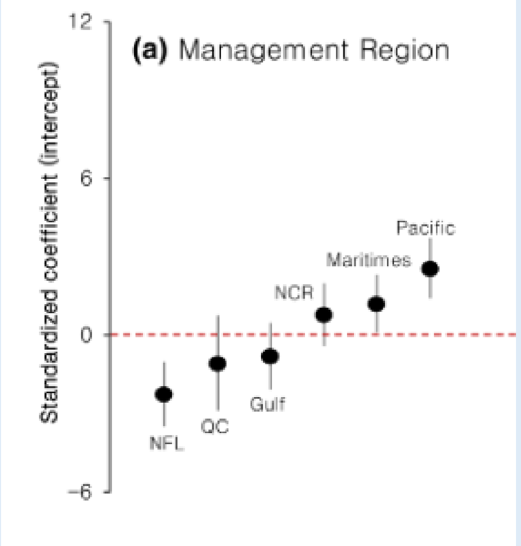

Received: 31 October 2023 | Revised: 21 December 2023 | Accepted: 15 January 2024
DOI: 10.1111/faf.12815

ORIGINAL ARTICLE

FISH and FISHERIES WILEY

Learning from positive deviants in fisheries

Laurenne Schiller[1] | Gregory L. Britten[2,3] | Graeme Auld[1] | Boris Worm[4]



- NL stocks are in worse shape and have more uncertainty than any other Canadian region
- Due to fishing industry and environmental changes, but also

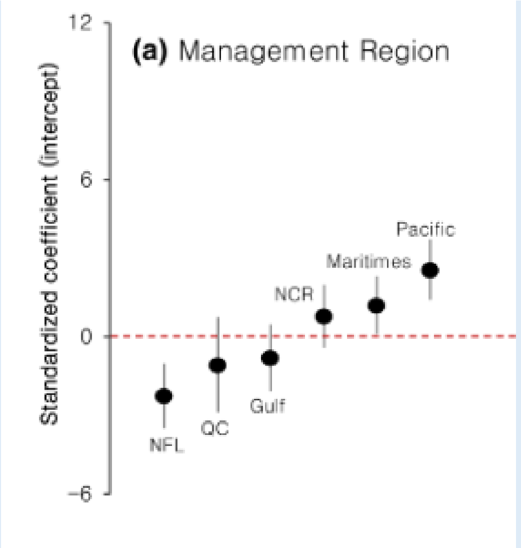
NL challenges

- NL stocks are in worse shape and have more uncertainty than any other Canadian region
- Due to overfishing and environmental changes
- But also, may be influenced by lobbying having an effect on the process

Received: 31 October 2023 | Revised: 21 December 2023 | Accepted: 15 January 2024
DOI: 10.1111/faf.12815
FISH and FISHERIES WILEY
ORIGINAL ARTICLE

Learning from positive deviants in fisheries

Laurenne Schiller[1] | Gregory L. Britten[2,3] | Graeme Auld[1] | Boris Worm[4]



NL

DFO scientists' union says members' work in N.L. undermined by industry and political interference

'Interference with scientific work is commonplace,' writes Judith Leblanc

Todd O'Brien · CBC News · Posted: Jan 24, 2022 6:00 AM NST | Last Updated: January 25, 2022

Assignment Overview

- Using an Rmarkdown simulation, examine theoretical population dynamics for your fish stock
  - Find the necessary traits as inputs to run the population dynamics model (8 points)
  - Identify differences between your stock and a pre-defined stock (5 points)
  - Determine whether your stock maintains a more sustainable fishery than a pre-defined stock (2 points)

Running the assignment

- Download the following files from the “Assignment” folder on this module’s github repository (https://github.com/MatthewRobertson2452/FISH6001_apps/tree/main):
  - Population_dynamics_module_assignment.Rmd
  - simulated_pop_dy.RData
- The markdown file will need the Rdata file to be in the same folder
- Make changes and write your answers in the markdown file
- Submit the markdown file and the knitted pdf output to my email