Stock Assessment and Modelling Overview

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Marine Scotland Science

The Scottish Government

Fishing Into The Future: The Business Of Fishing
Thainestone House Hotel, Inverurie
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Outline

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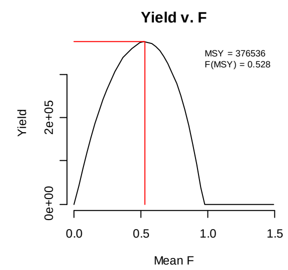
- The assessment problem
- Modelling concepts and model selection
  - Why models?
  - Cohort analysis
  - Separable models
  - Time series analysis
- MSY explained
- Ecosystem considerations
- The catch-option table



Concepts: The assessment problem

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Stonehaven GC

Source: overtherainbowhotairballoonrides.co

Concepts: Why models?

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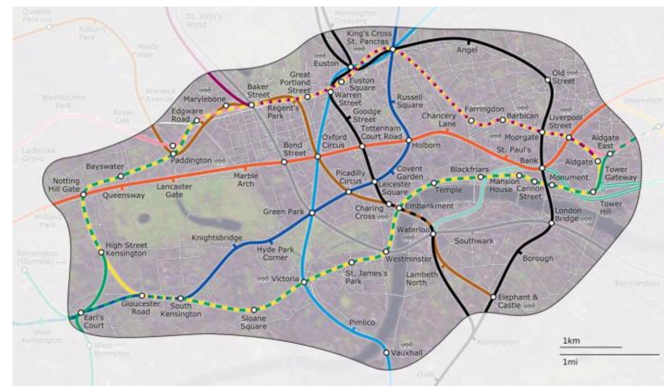

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Concepts: Why models?

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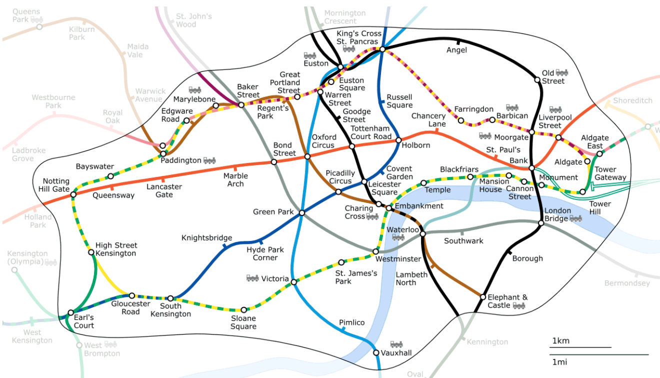

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Concepts: Why models?

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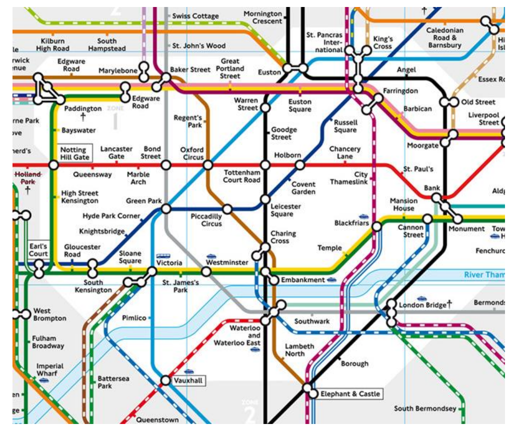
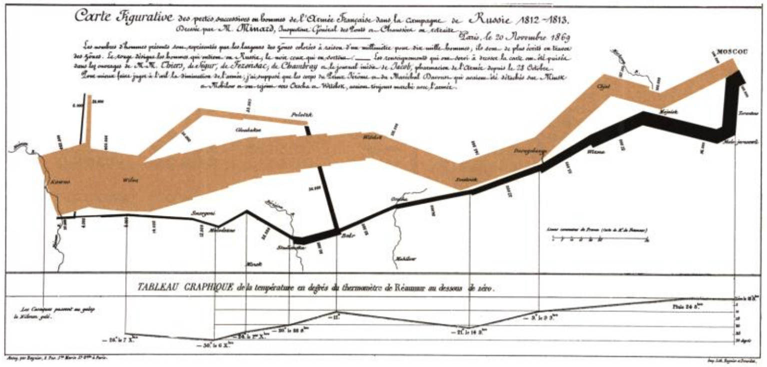
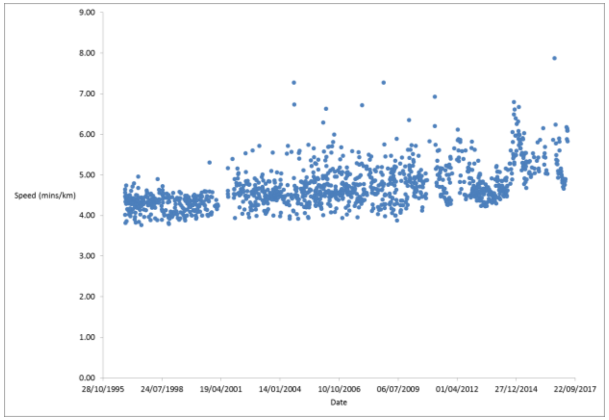


Concepts: Why models?



Concepts: Statistical model fitting



- Regression analysis

Concepts: Statistical model fitting

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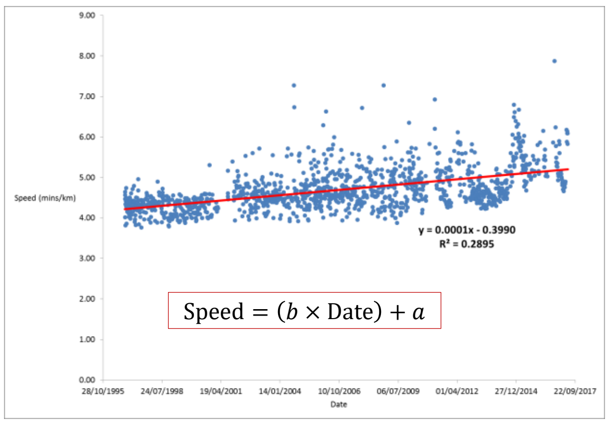

- Regression analysis
- Find a line that passes as close to as many of the points as possible
- Summarises relationship as simply as possible

Concepts: The simplest fisheries model

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Fish are born

↓

Fish grow

↓

Fish die

Concepts: The simplest fisheries model

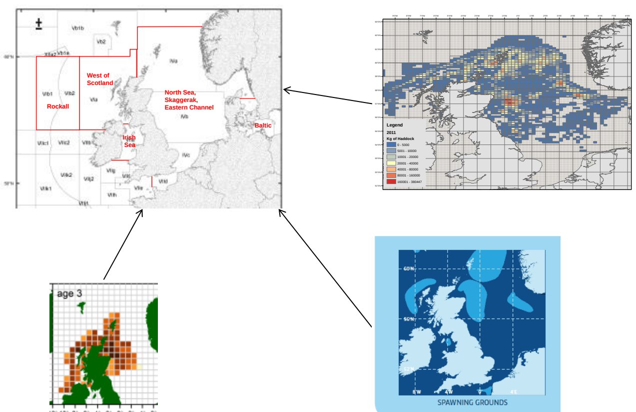
Biomass this year	=	Biomass last year	-	Deaths	+	Births	+	Growth of survivors

$$B_{y+1} = B_y - M_y + R_y + G_y$$

Concepts: Why models?

- Model:
  - A way to simplify a system so we can understand it
- Trade off:
  - Complex / realistic v. simple / understandable
- Mathematics:
  - A language in which to write models down
- Model choice:
  - Available data
  - Purpose

Concepts: What is a fish stock?



Concepts: Definitions

Spawning stock biomass (SSB) *B*

Recruitment *R*

Abundance *N*

Fishing mortality *F*

Natural mortality *M*

Concepts: Definitions

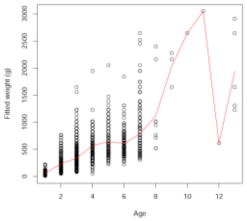
Spawning stock biomass (SSB) *B*

- The total weight of mature fish in the stock

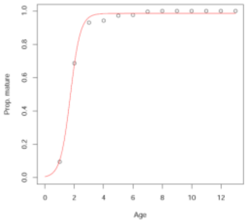
Abundance *N* x Weight *Wt* (kg) x Maturity *Mat*

Concepts: Definitions

Spawning stock biomass (SSB) *B*



North Sea haddock



Weight *Wt* (kg)

Maturity *Mat*

Concepts: Definitions

Spawning stock biomass (SSB) *B*

- The total weight of mature fish in the stock

Abundance *N* x Weight *Wt* (kg) x Maturity *Mat*

$$SSB = \sum_a N_a \times Wt_a \times Mat_a$$

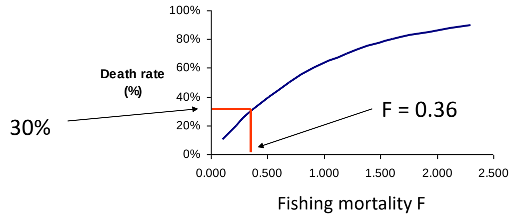
Concepts: Definitions

Recruitment *R*

- Abundance of fish entering the fishery
- Can depend on age (or size)
  - Cod large enough to be caught by age 1
  - Haddock appear in discards and bycatch by age 0 (towards the end of the year)
- Can also depend on location
  - Saithe usually stay in fjords until age 3 or 4

Concepts: Definitions

Fishing mortality *F*



Concepts: The catch equation

- F. I. Baranov (1918)
  - "On the Question of the Biological Basis of Fisheries", Nauchnye Issledovaniya Ikhtiologicheskii Instituta Izvestiya

- There are 100 fish, and 30 die
- Then the death rate is 30%
- Total mortality Z is just another way of writing death rate
  - Z is fishing mortality plus natural mortality

Concepts: The catch equation

- Fish die from both fishing AND natural causes:

 =  + 

$$Z = F + M$$

Total = Fishing Natural

Concepts: The catch equation

- We can write the proportion of all deaths that are due to fishing:

$$\frac{F}{Z}$$

Concepts: The catch equation

- Suppose we also know the total number of fish:

$$N$$

Concepts: The catch equation

- If we know the proportion P that die in a year, then the number of dead fish is:

$$P \times N$$

Concepts: The catch equation

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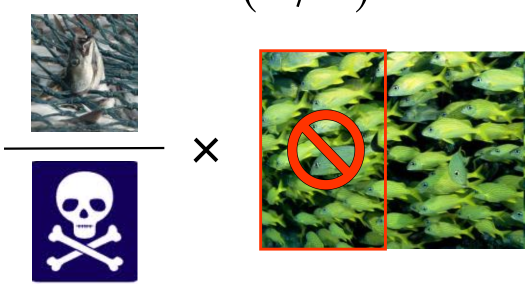
- Then the number that die due to fishing is:

$$(F/Z)\times P\times N$$



Concepts: The catch equation

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- Which we just call the catch *C*:

$$C=\left(\frac{F}{Z}\right)\times P\times N$$

Concepts: The catch equation

- IF we know catch and mortality, we can calculate abundance:

$$N = \frac{C}{\left(\frac{F}{Z}\right) \times P}$$

- But we can't easily estimate abundance and mortality at the same time!

Models: Cohort analysis

Abundance (thousands)							
	Age						
Year	1	2	3	4	5	6	7
2004	500000						
2005		150000					
2006			35000				
2007				10000			
2008					3000		
2009						1000	
2010							500

Reduction = 350000 = 70%
So Z = 1.20

Models: Cohort analysis

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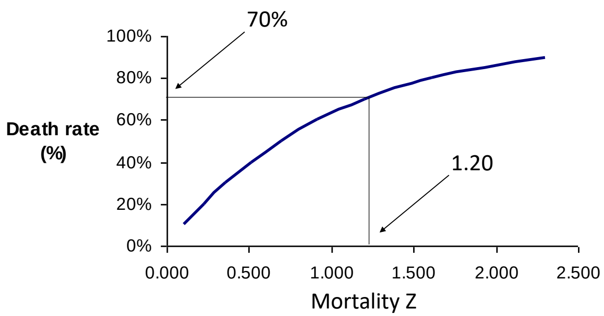

Models: Cohort analysis

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Abundance (thousands)							
	Age						
Year	1	2	3	4	5	6	7
2004	500000						
2005		150000					
2006			35000				
2007				10000			
2008					3000		
2009						1000	
2010							500

Reduction = 115000 = 77%
So Z = 1.46

Models: Cohort analysis

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Abundance (thousands)							
	Age						
Year	1	2	3	4	5	6	7
2004	500000						
2005		150000					
2006			35000				
2007				10000			
2008					3000		
2009						1000	
2010							500

Reduction = 25000 = 71%
So Z = 1.25

Models: Cohort analysis

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Abundance (thousands)							
	Age						
Year	1	2	3	4	5	6	7
2004	500000						
2005		150000					
2006			35000				
2007				10000			
2008					3000		
2009						1000	
2010							500

?

Models: Cohort analysis

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Total mortality Z							
	Age						
Year	1	2	3	4	5	6	7
2004	1.20						
2005		1.46					
2006			1.25				
2007				1.20			
2008					1.10		
2009						0.69	
2010							0.69

Models: Cohort analysis

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Natural mortality							
	Age						
Year	1	2	3	4	5	6	7
2004	0.80						
2005		0.35					
2006			0.25				
2007				0.20			
2008					0.20		
2009						0.20	
2010							0.20

Models: Cohort analysis

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Fishing mortality							
	Age						
Year	1	2	3	4	5	6	7
2004	0.40						
2005		1.11					
2006			1.00				
2007				1.00			
2008					0.90		
2009						0.49	
2010							0.49

Models: Cohort analysis

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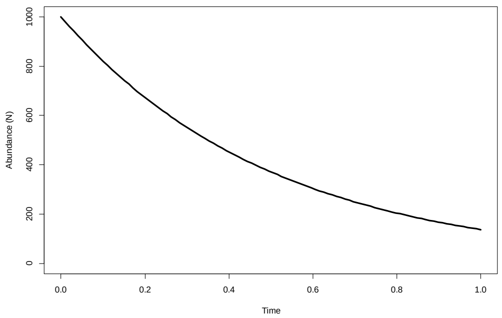
- So if we know
  - Catch
  - Abundance
  - Natural mortality
- Then we can calculate fishing mortality
  - Except for the last year!
- But we **don't** know abundance…

Concepts: Exponential decline

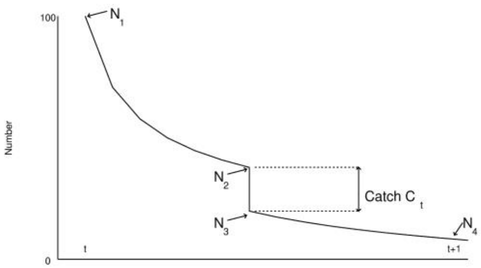
- A cohort is assumed to decline exponentially:

$$N_{a+1,t+1} = N_{a,t}\exp(-Z_{a,t})$$



Concepts: Exponential decline

- Key simplifying assumption:
  - Assume all catch taken at once
  - *Pope's cohort approximation*



Models: Cohort analysis

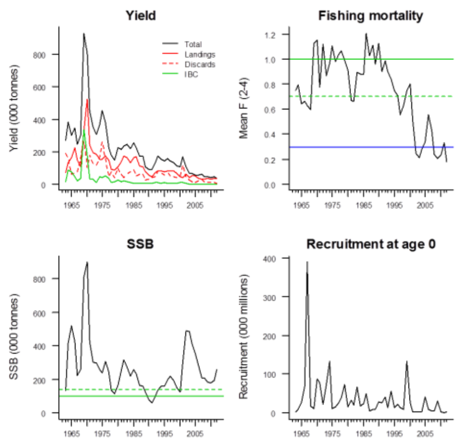
- So we **can** do an assessment with catch data only
- Pros:
  - Many samples
- Cons
  - Fishermen follow fish
  - Some catch data may be missing
  - Difficult to estimate some *F*s
- Survey data can help to address these problems

Models: Cohort analysis

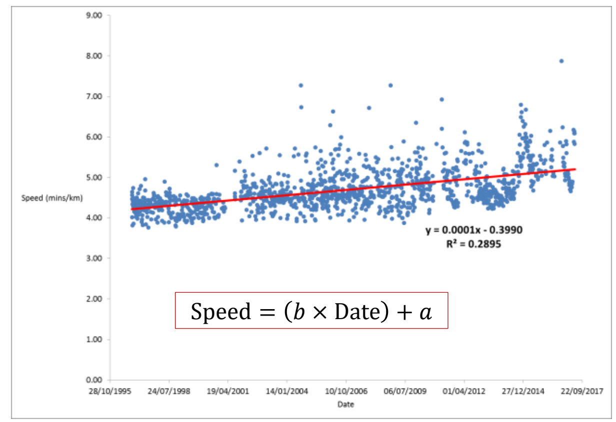
- The key features of cohort analysis are:
  - Work backwards from last year
  - Add up catches
  - Add fish removed by natural mortality
  - "Tune" using surveys (if available)
  - Results in an estimate of the number of fish there must have been at the start of the cohort
- No statistical parameter estimation
  - Hence no estimates of uncertainty

Models: Cohort analysis

- Example: XSA applied to NS haddock (ICES 2013):



Models: Separable model



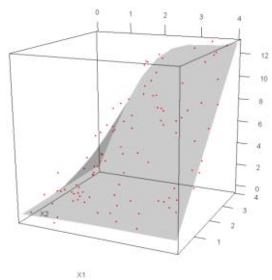
- Regression analysis
- Find a line that passes as close to as many of the points as possible
- Summarises relationship as simply as possible

Models: Separable model

- An analogy in fisheries is a **separable model**
  - Two dimensional catch data (age and year)
  - Find a **surface** that passes as close to as many of the points as possible
  - Separable constraint:

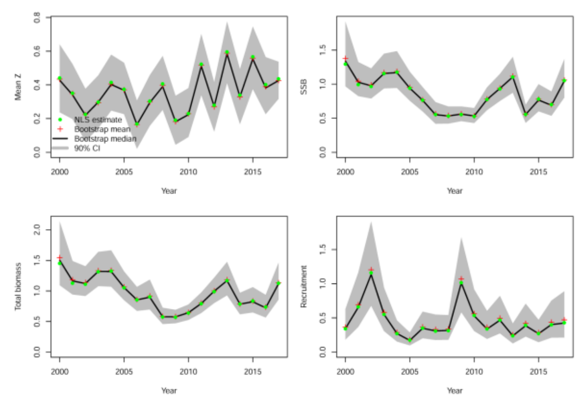
$$\boxed{Z_{a,y} = s_a \times f_y}$$

  - Enables uncertainty estimates



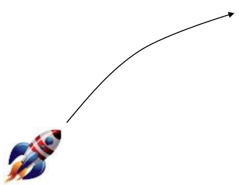
Models: Separable model

- Example: SURBAR applied to NS lemon sole



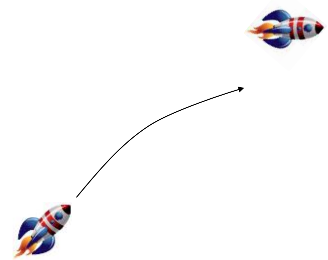
Concepts: The Kalman filter

- Rudolf Kálmán (1960): modelling rocket trajectories



Concepts: The Kalman filter

- Rudolf Kálmán (1960): modelling rocket trajectories



Concepts: The Kalman filter

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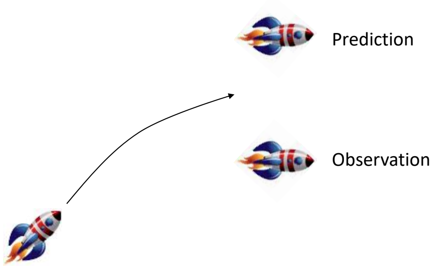

Concepts: The Kalman filter

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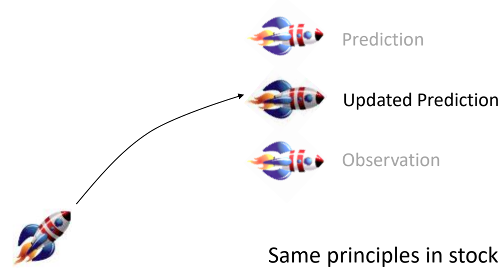
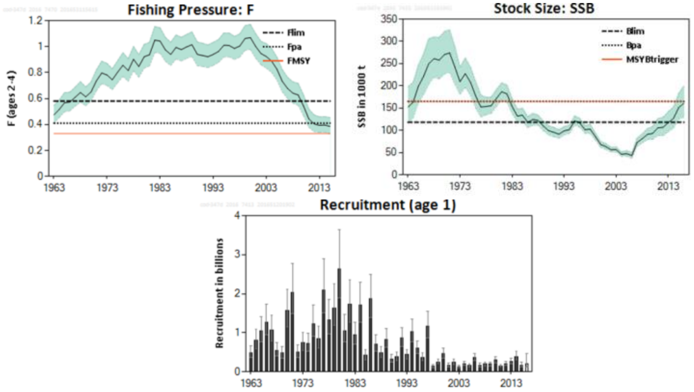


Same principles in stock assessment

- Modelling population numbers instead of rocket position

Models: Time series models

- Example: SAM applied to North Sea cod

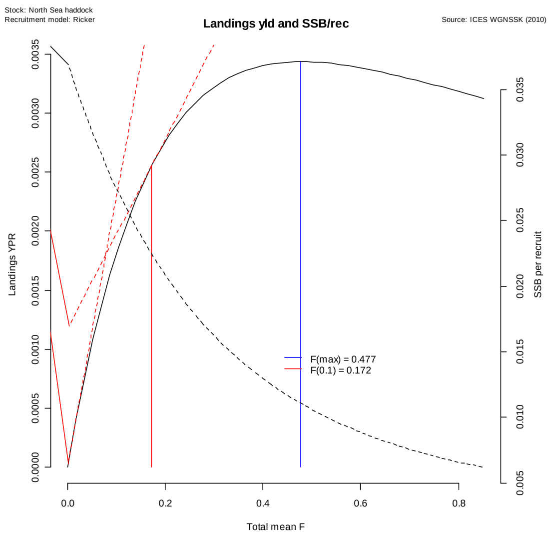


Concepts: MSY

- Maximum sustainable yield (MSY)
  - Assumes **equilibrium** (fishing mortality, growth etc. all unchanging)
  - Can be very uncertain
  - Can be difficult to fish all stocks at F(msy)
  - Different from maximum economic yield (MEY)

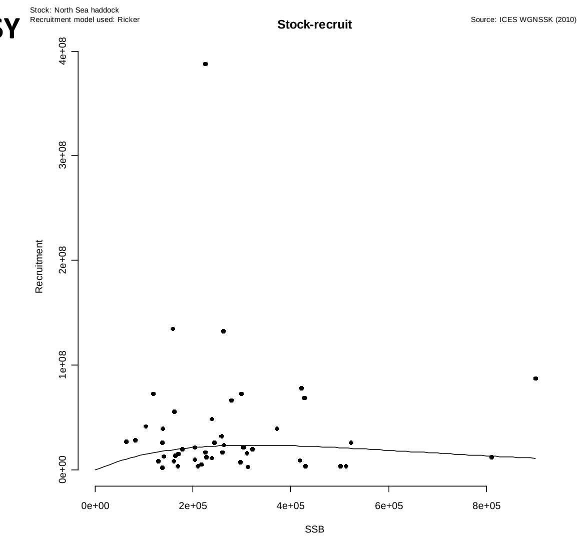
Concepts: MSY

- Yield-per-recruit (YPR) curve:



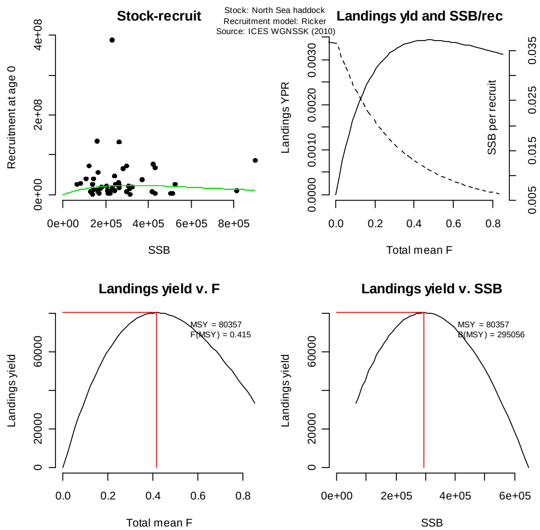
Concepts: MSY

- Stock-recruit SSB curve:



Concepts: MSY

- Summary:



Concepts: MSY

- Maximum sustainable yield (MSY)
  - Used as the basis of ICES advice in the absence of management plans
  - Fishing at F(msy) can lead to stock reductions, so:
  - Calculation modified by **risk** considerations

Concepts: Ecosystem considerations

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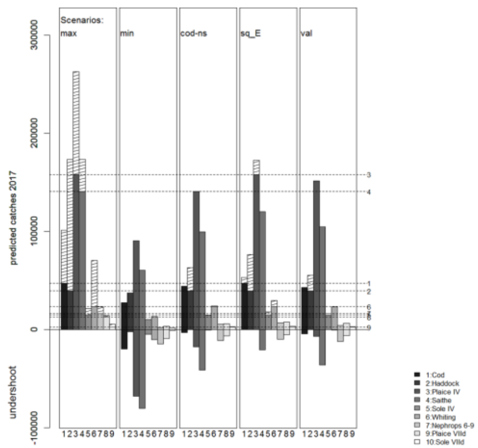
- Ecosystem notes in ICES WG reports
- WGMIXFISH summaries:
- Otherwise not much account taken yet of ecosystems effects or impacts in stock assessment



The last stage: the catch-option table

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Rationale	Total catch 2017	Wanted catch 2017	Unwanted catch 2017	IBC 2017	Basis	Total F 2017	F(land) 2017	F(disc) 2017	F(IBC) 2017	SSB 2018	% SSB change	% TAC change
MSY	65.442	57.996	7.446	0.000	New F(msy) estimate	0.260	0.214	0.046	0.000	282	-23%	-10%
Mngmnt plan	74.372	65.895	8.477	0.000	MP target F	0.300	0.246	0.054	0.000	273	-25%	3%
IBC only	0.000	0.000	0.000	0.000	No HC fishery	0.000	0.000	0.000	0.000	343	-6%	-100%
Other options	56.150	49.771	6.379	0.000	0.75 * F(sq)	0.220	0.181	0.039	0.000	290	-20%	-22%
	72.785	64.491	8.294	0.000	Fsq	0.293	0.241	0.052	0.000	275	-24%	1%
	88.494	78.379	10.115	0.000	1.25 * F(sq)	0.366	0.301	0.065	0.000	260	-28%	22%
	64.311	56.995	7.316	0.000	15% TAC decrease (full)	0.255	0.209	0.046	0.000	283	-22%	-15%
	75.253	66.674	8.579	0.000	Rollover TAC (full)	0.304	0.250	0.054	0.000	273	-25%	0%
	85.739	75.945	9.795	0.000	15% TAC increase (full)	0.353	0.290	0.063	0.000	263	-28%	15%
	78.723	69.743	8.980	0.000	F(pa)	0.320	0.263	0.057	0.000	269	-26%	9%

Example: Northern Shelf haddock, October 2016

Summary

- Models make complex systems understandable
- Trade-off between simplicity and realism
- Many approaches to stock assessment exist
  - Often driven by data availability (but not always)
- The key end result (in ICES) is the catch-option table
  - Which is where managers take over!

Thanks…