Stock Assessment and Modelling Overview

Dr Neil Campbell
Marine Scotland Science

The Scottish Government

Fishing Into The Future: The Business Of Fishing
Thainstone House Hotel, Inverurie
May 2019

marine scotland science

Overview

marinescotland science

- Why assess stocks?
- Why use models?
- Defining some terms (SSB, F, recruitment, etc.)
- What is a stock?
- What are the different types of assessment in use?
- How do we use assessment results to guide management?

Concepts: Why assess stocks?

marinescotland science

UN Fish Stocks Agreement, Article 5

- Ensure long-term sustainability of shared fish stocks
- Ensure measures based on best scientific evidence available
- Apply the precautionary approach
- Assess the impacts of fishing and other human activities on target stocks and other species in the same ecosystem

Concepts: Why assess stocks?

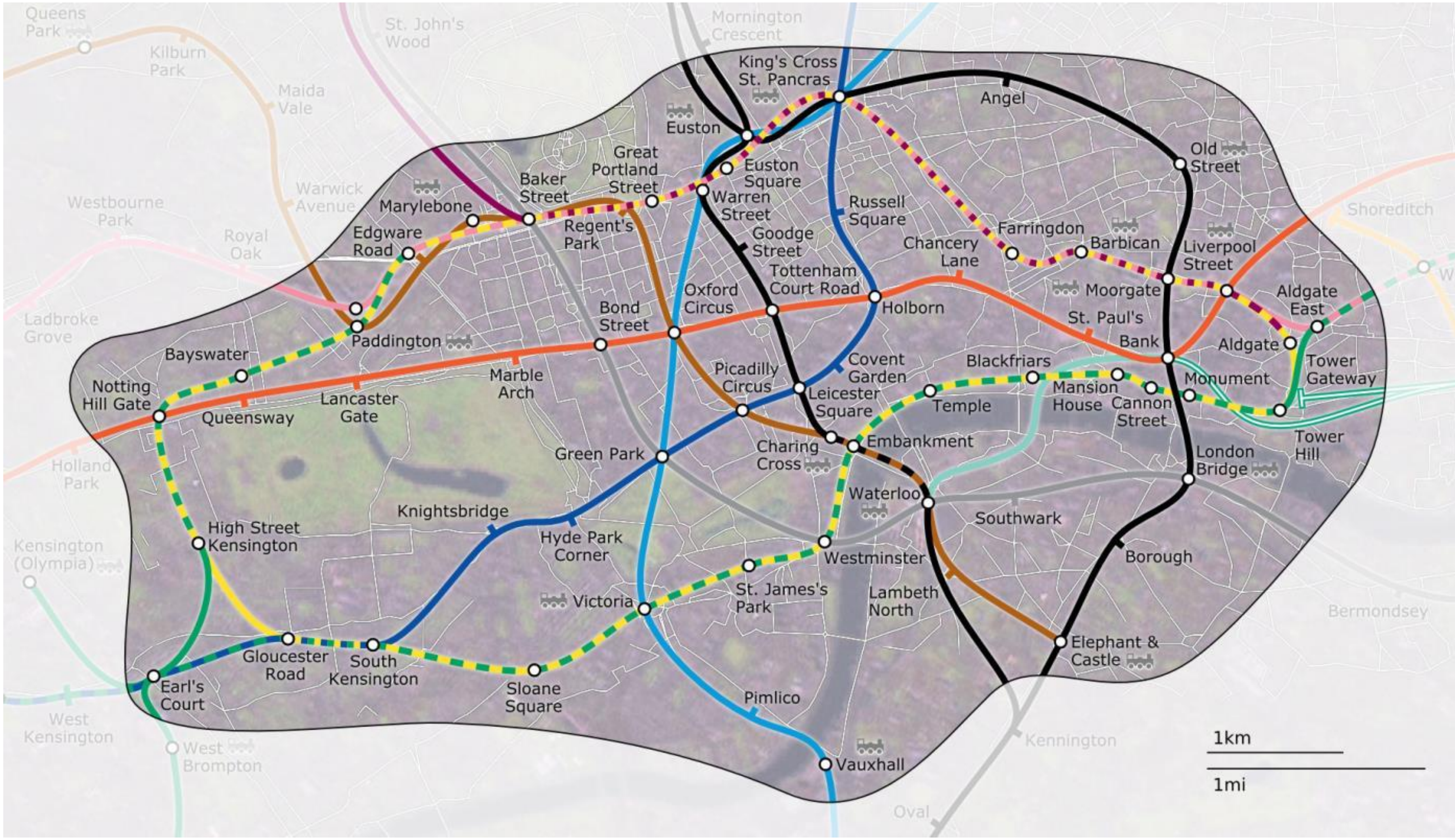
Inform discussion:

- Catch options
- Policy objectives.

Informal meeting of ministers for agriculture and fisheries (iAGRIFISH). Round table. Estonian Presidency, 2017.

Concepts: Why models?

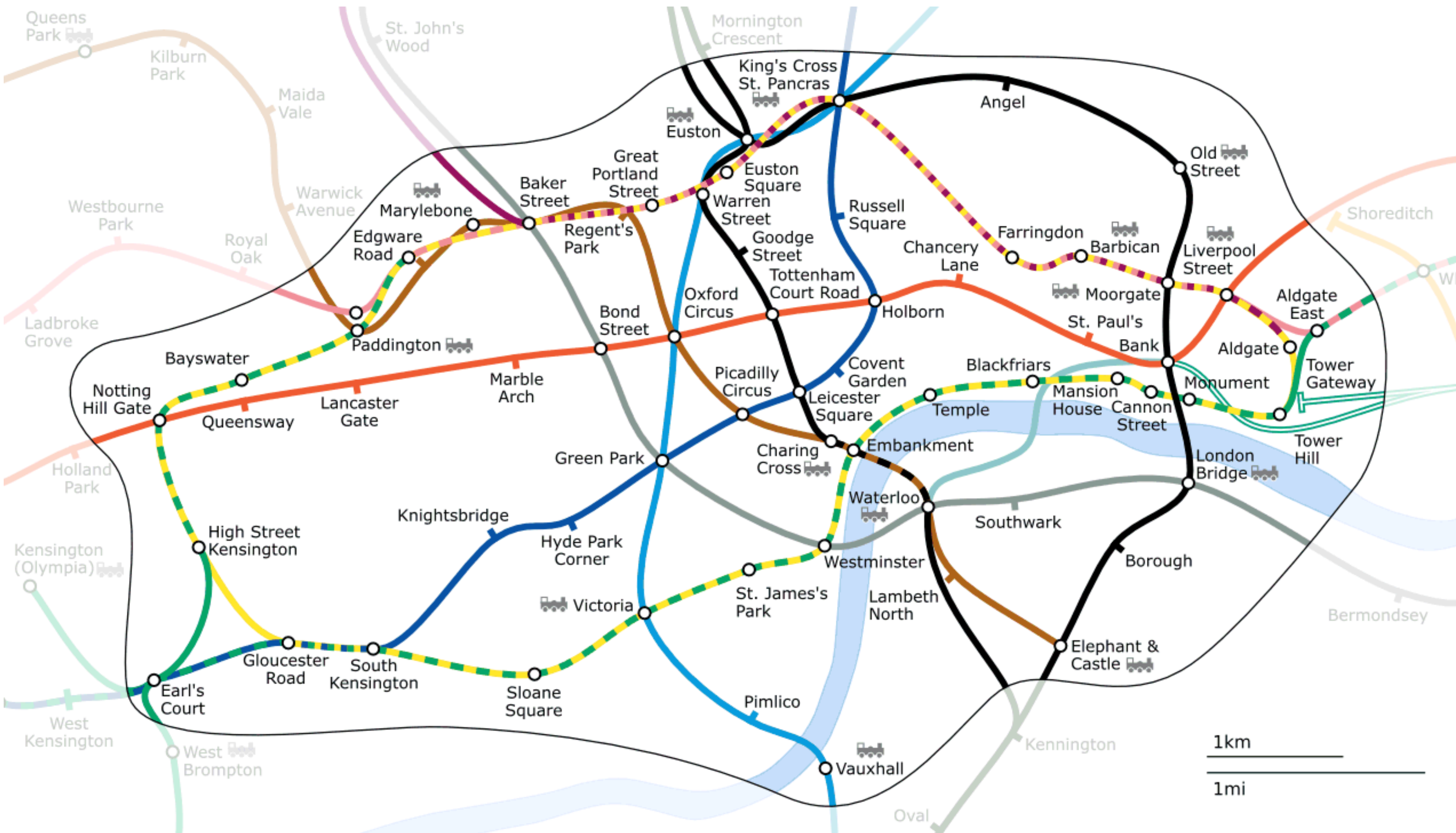
marinescotland science



Source: CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=243043

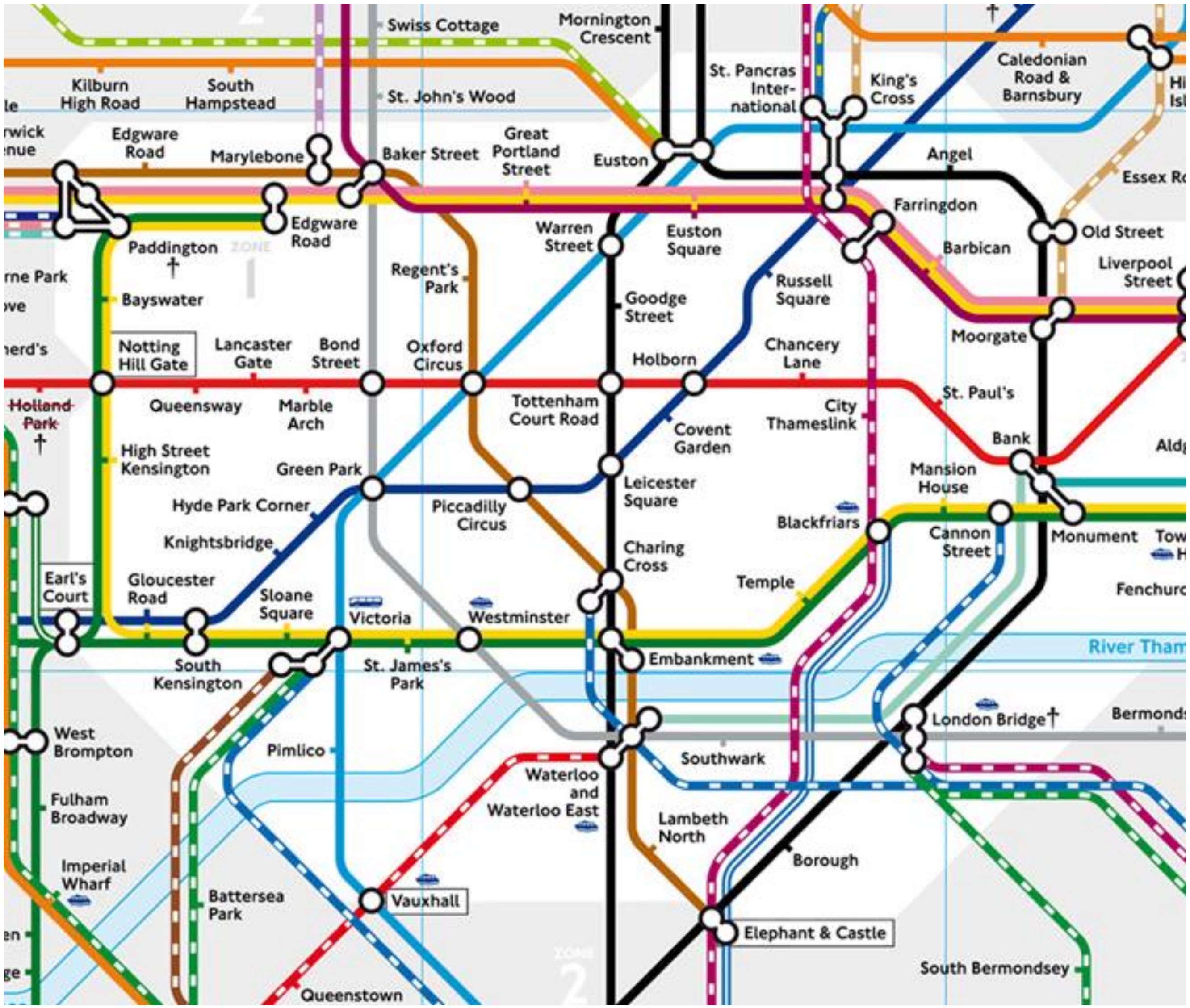
Concepts: Why models?

marinescotland
science



Concepts: Why models?

marinescotland science



Concepts: Why models?

marinescotland science

- 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: Definitions

marine scotland science

Spawning stock biomass (SSB) *B*

Recruitment *R*

Abundance *N*

Fishing mortality *F*

Natural mortality *M*

Concepts: Definitions

marinescotland science

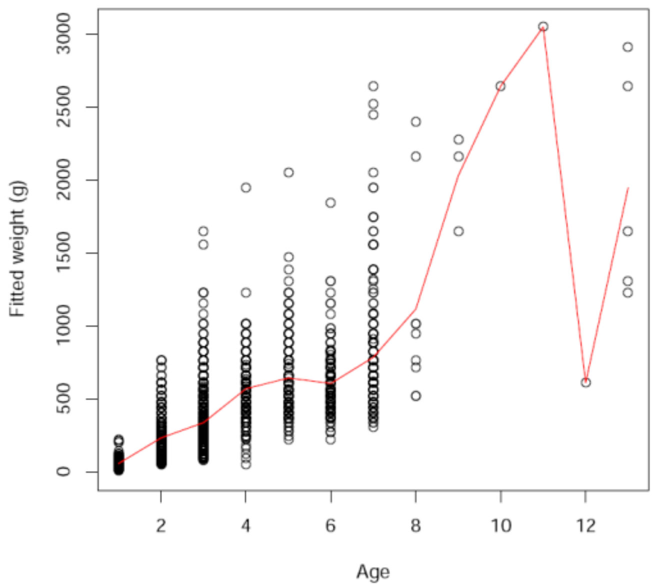
Spawning stock biomass (SSB) *B*

- The total weight of mature fish in the stock

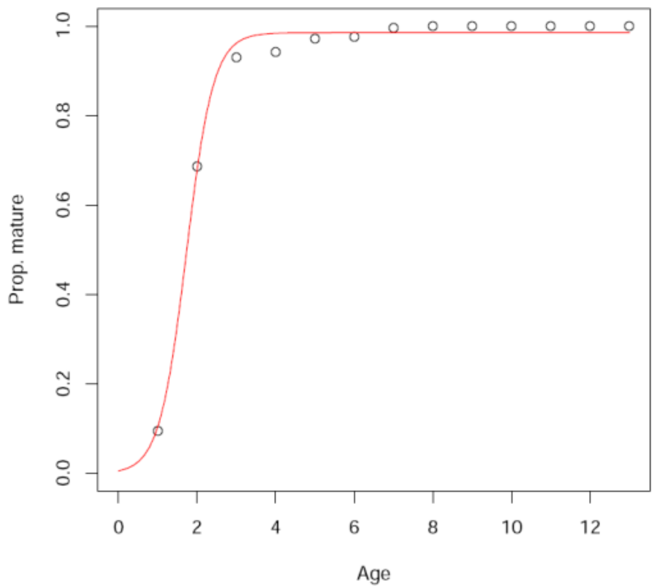
Abundance *N* x Weight *Wt* (kg) x Maturity *Mat*

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*

Age	Abundance ('000)	Average Weight (Kg)	Maturity	Total (T)
1	10000	0.120	0.10	120
2	3000	0.250	0.50	375
3	1000	0.310	0.95	295
4	500	0.350	1.00	175
			SSB =	**965**

Concepts: Definitions

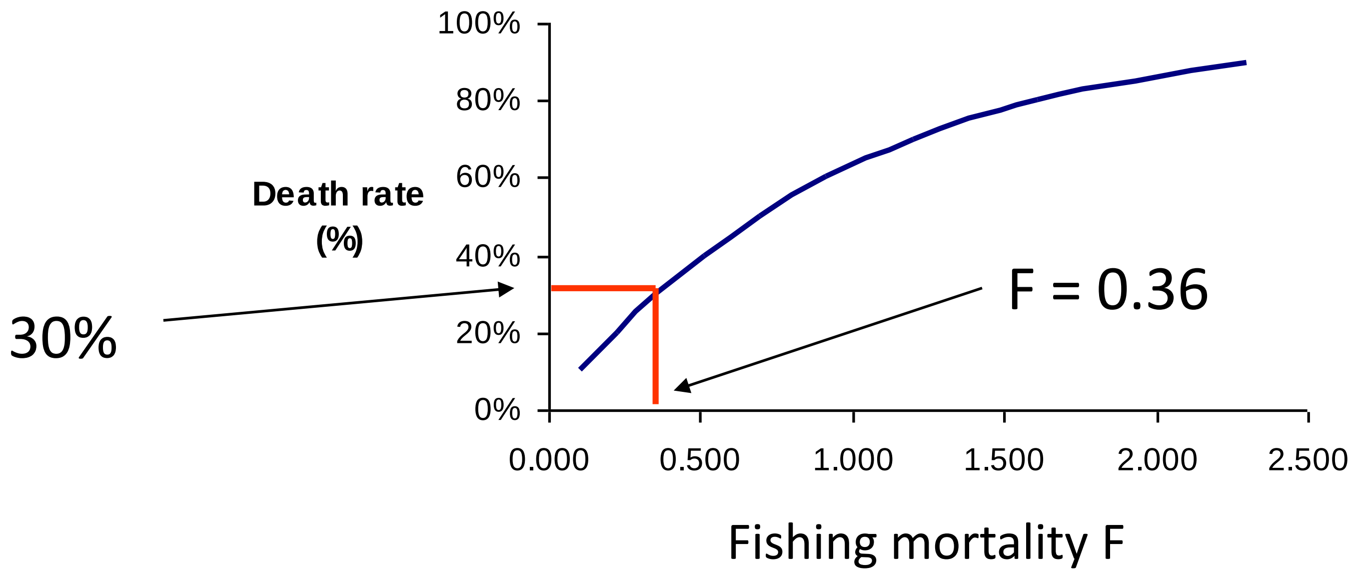
marinescotland science

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

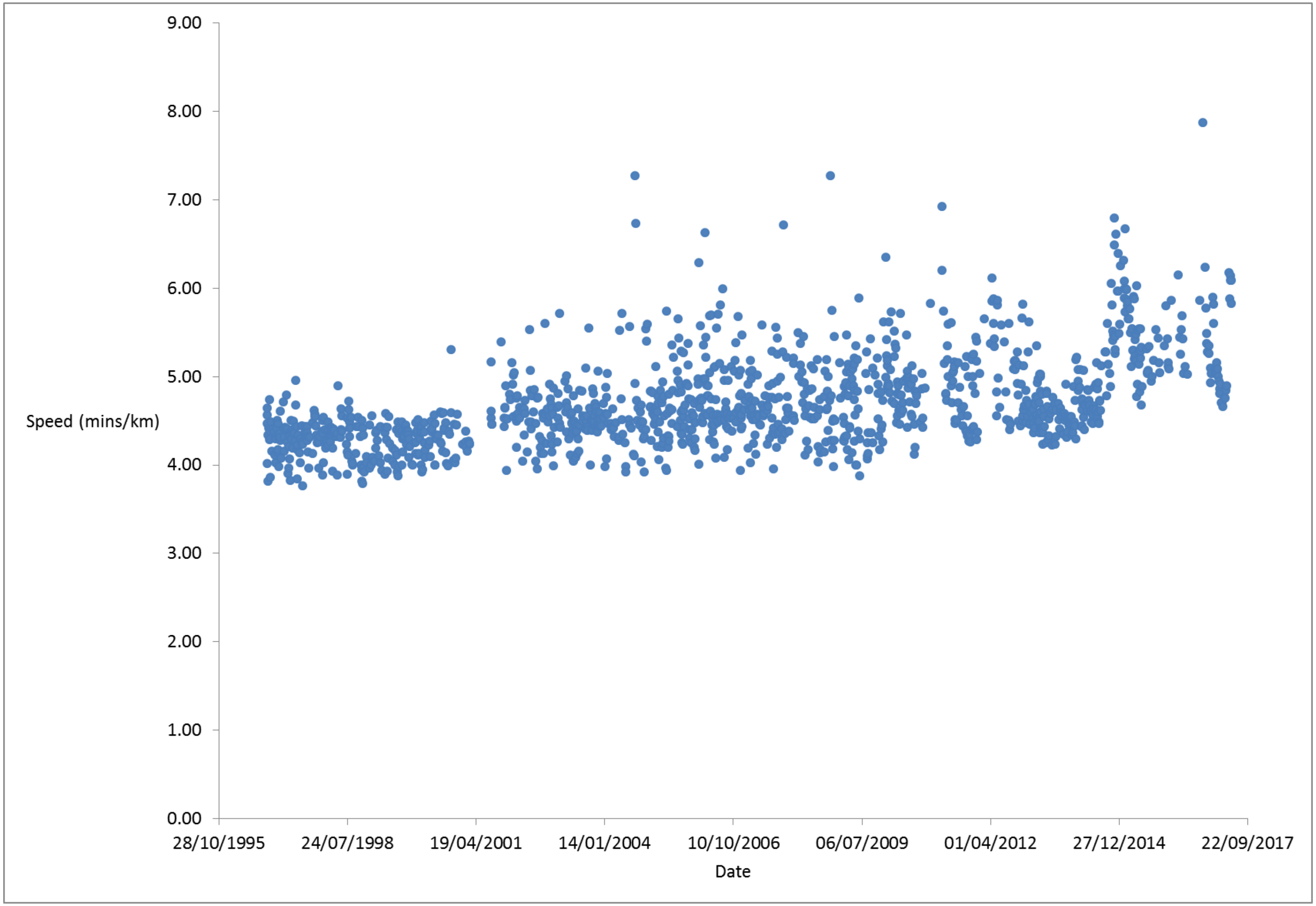
Concepts: Definitions

Fishing mortality *F*



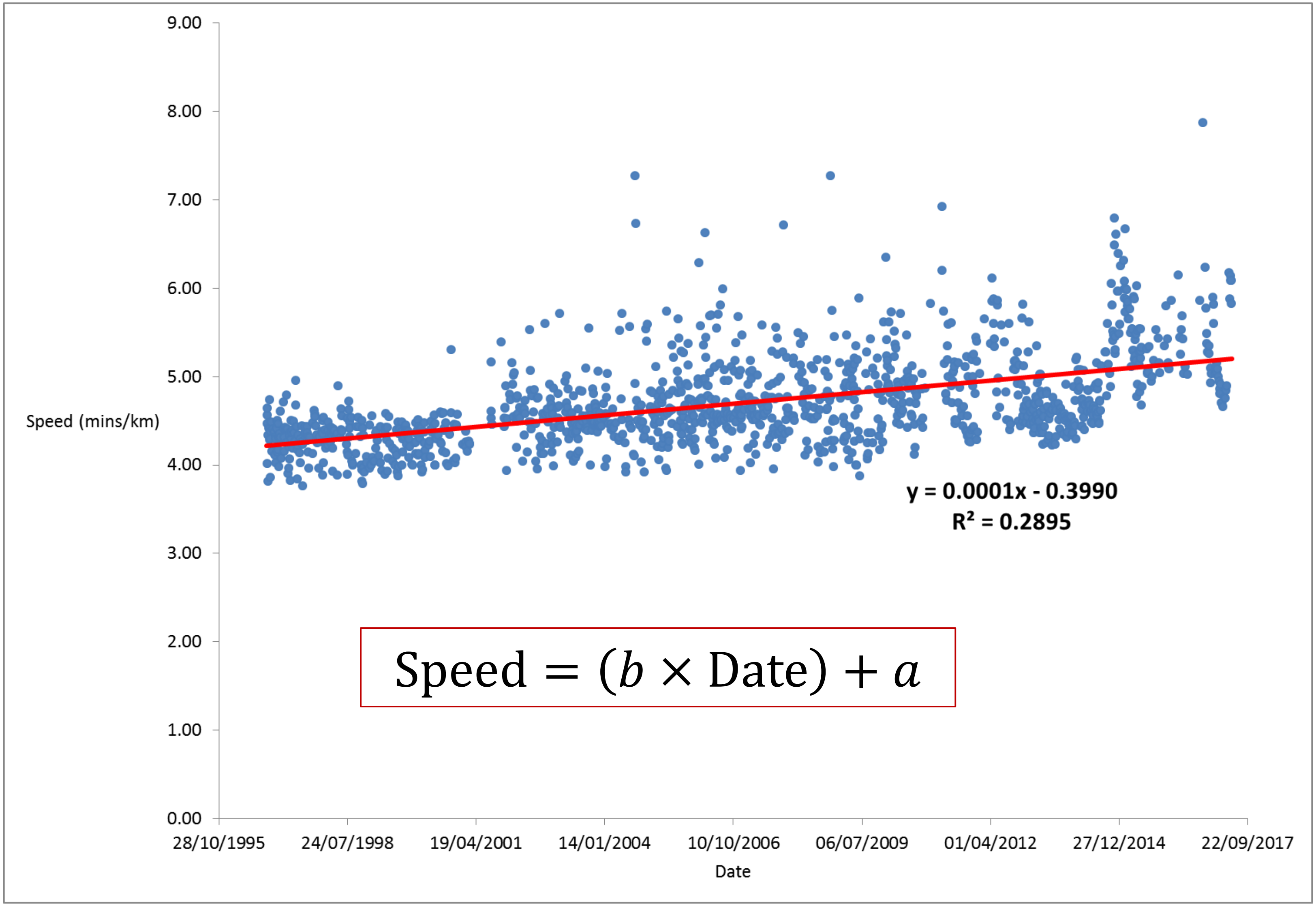
Concepts: Statistical model fitting

marine scotland science



- Regression analysis

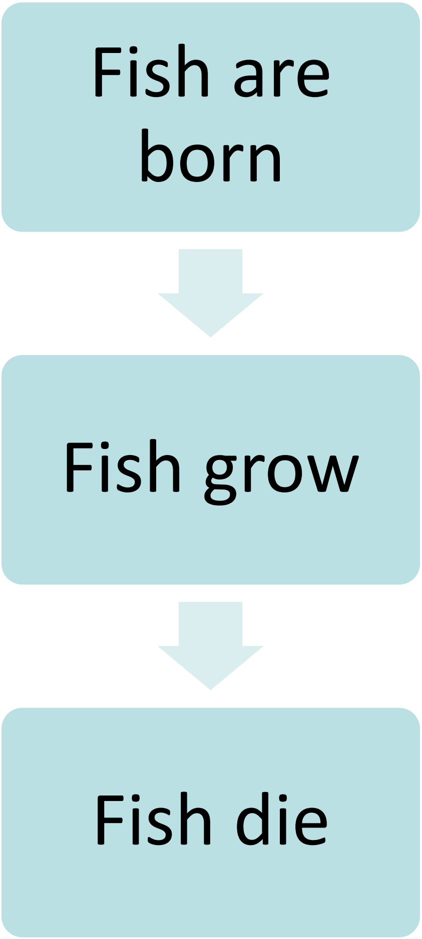
Concepts: Statistical model fitting



- 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

marine scotland science



Concepts: The simplest fisheries model

$$\boxed{\text{Biomass this year}} = \boxed{\text{Biomass last year}} - \boxed{\text{Deaths}} + \boxed{\text{Births}} + \boxed{\text{Growth of survivors}}$$

Concepts: The simplest fisheries model

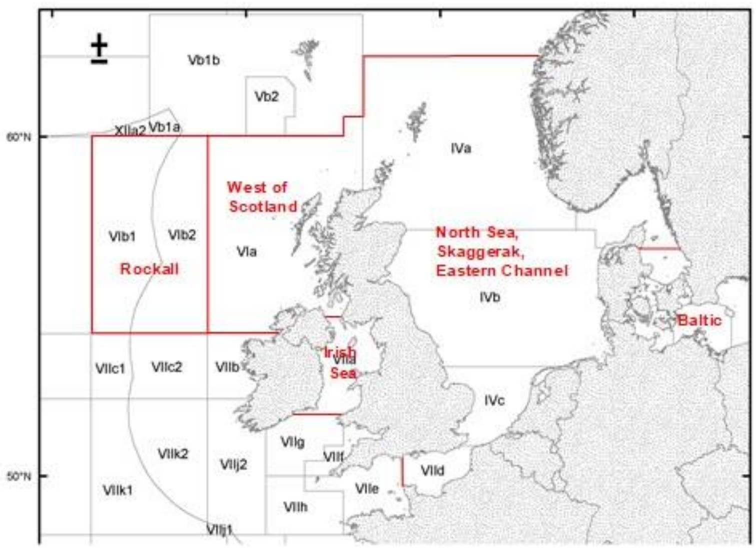
marinescotland science

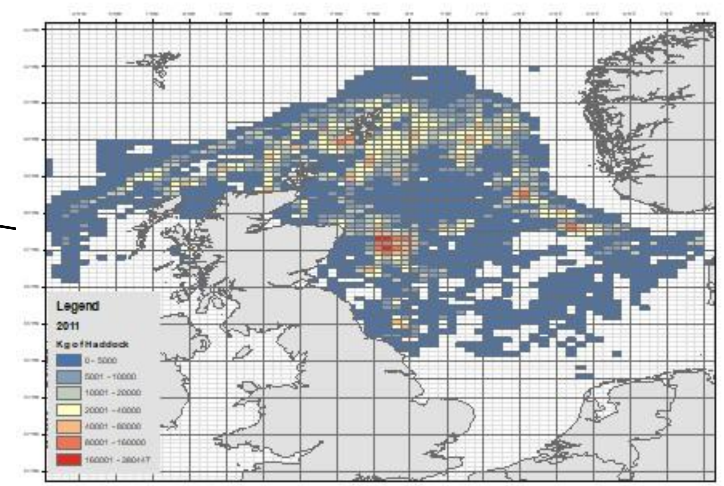
Biomass this year = Biomass last year - Deaths + Births + Growth of survivors

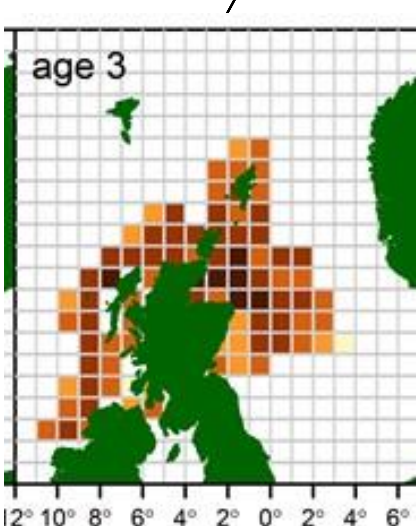
- Emigration + Immigration ?

Concepts: What is a fish stock?

marine scotland science



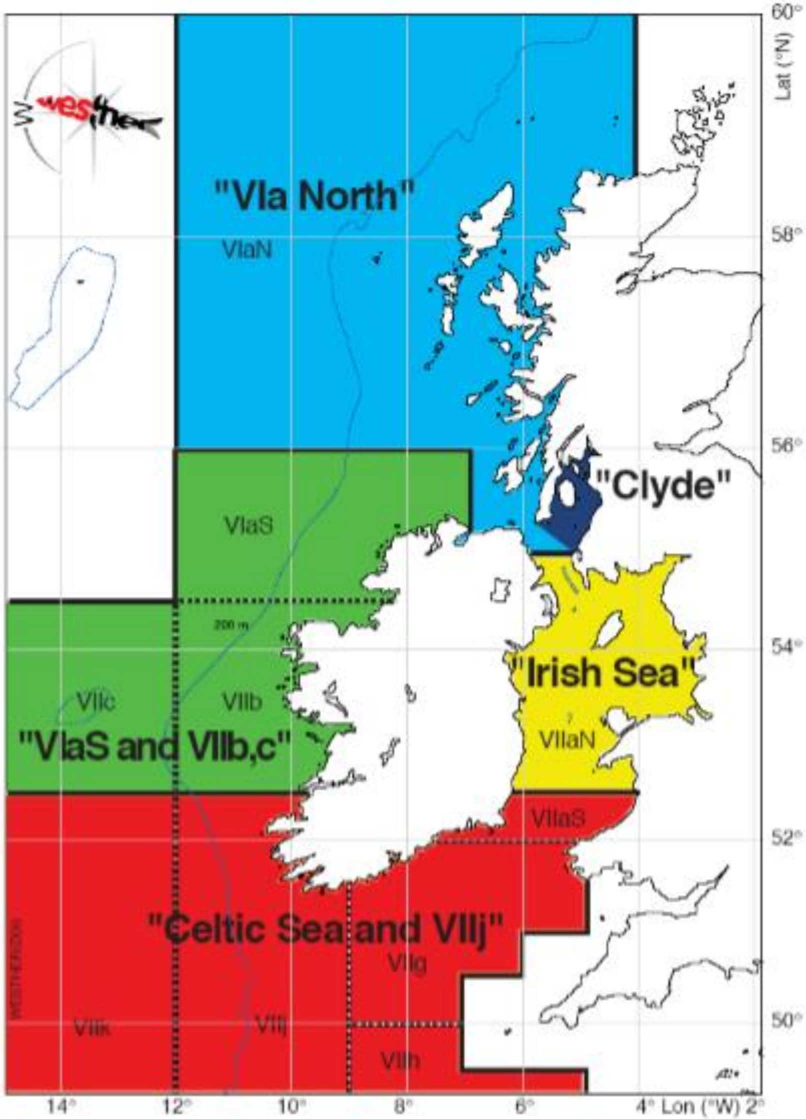




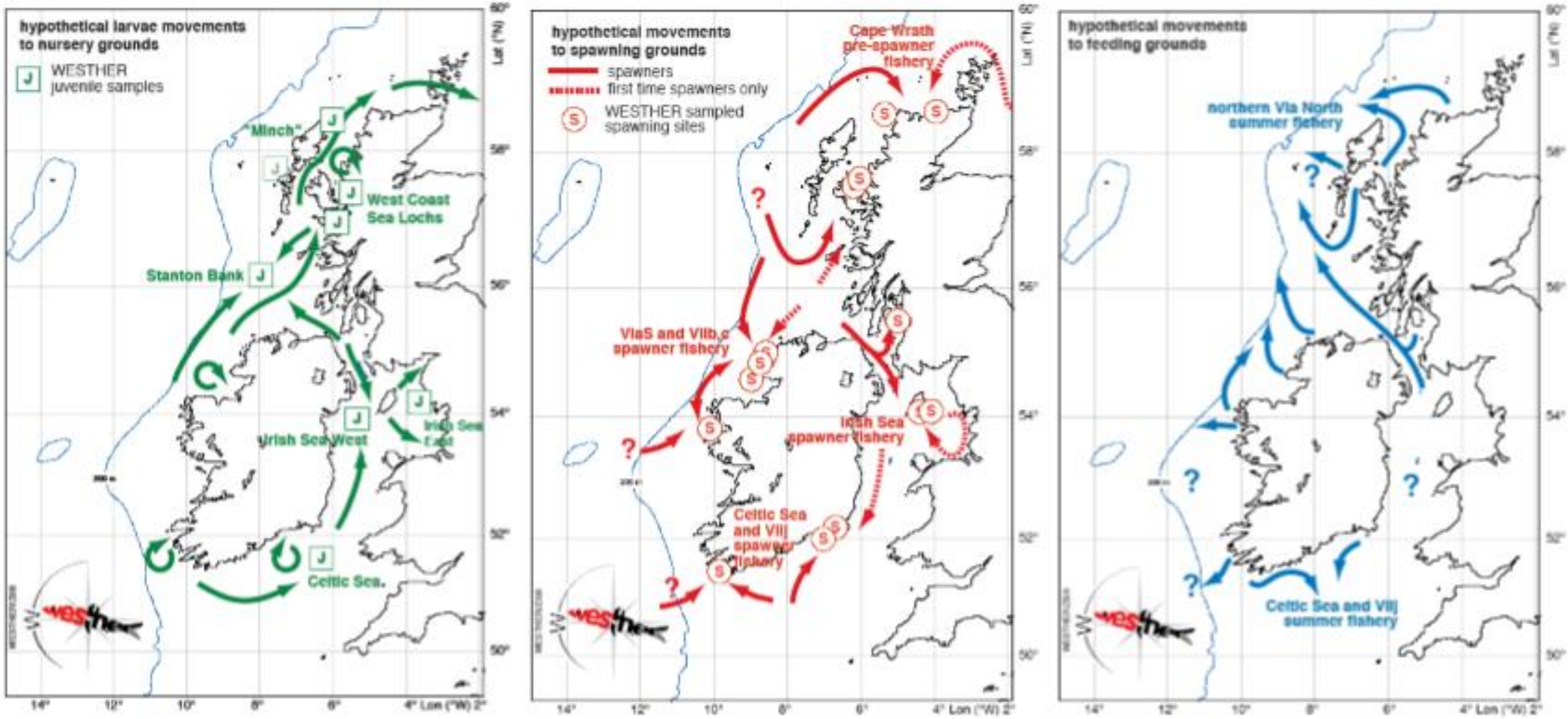
Stock Identification

- Fisheries Data
- Genetics
- Parasites
- Shape
- Composition
- Tagging

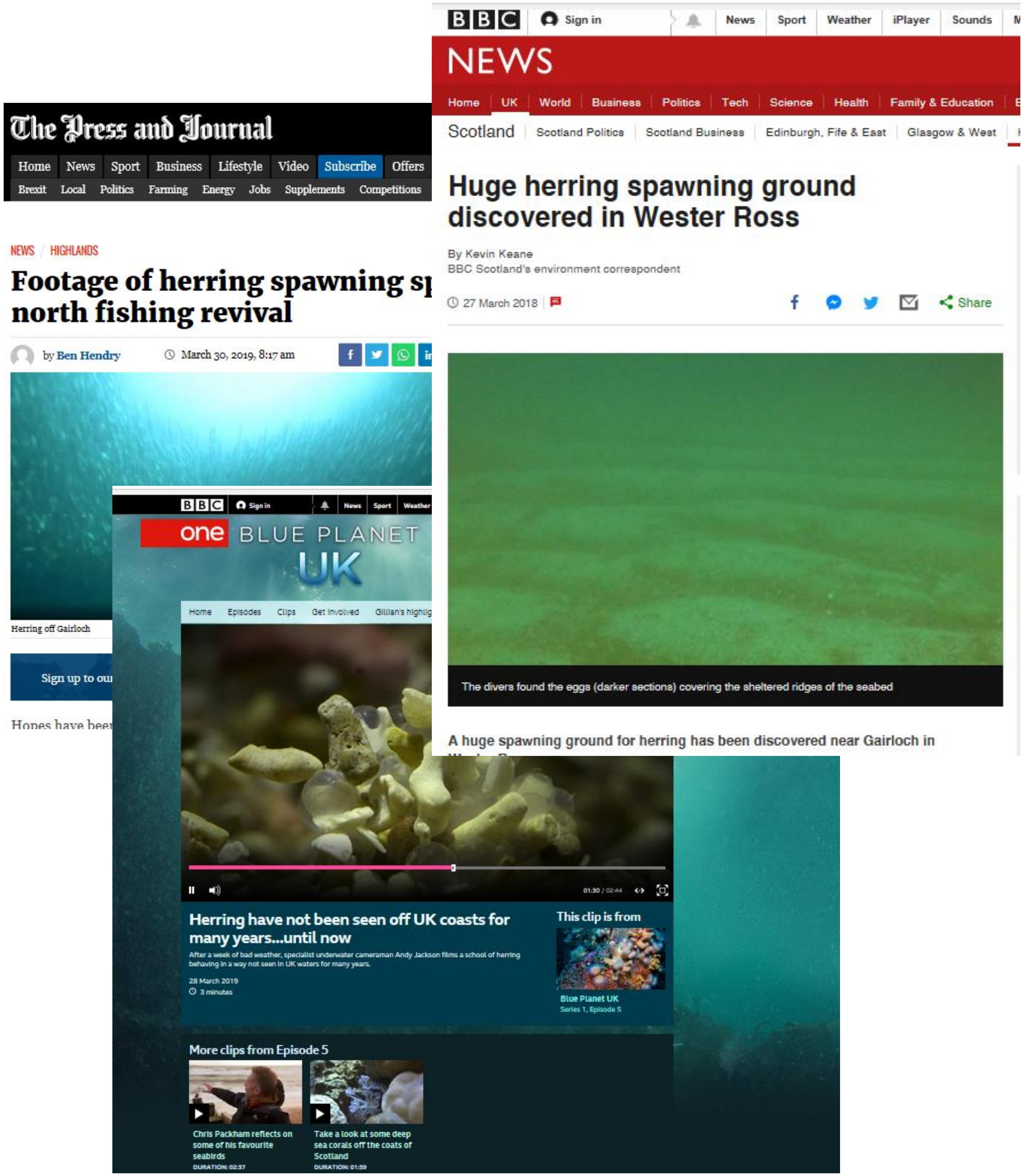
Example: Herring west of UK and Ireland

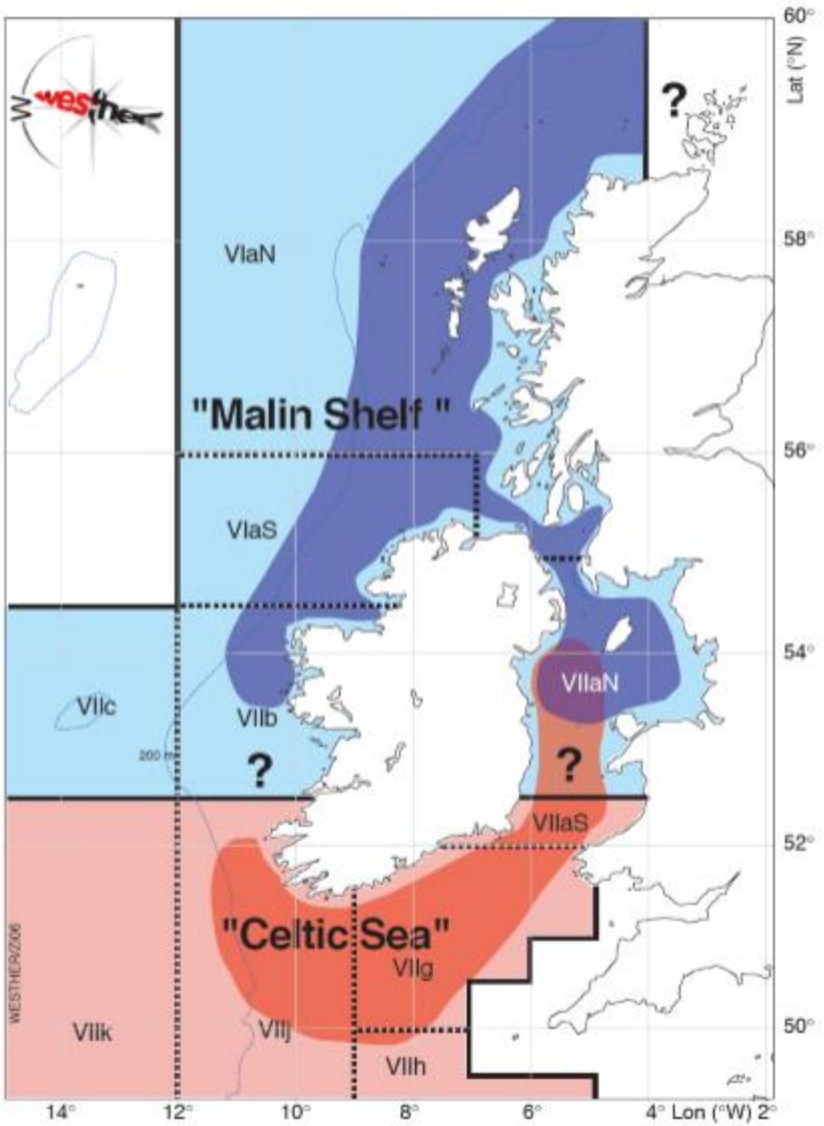


Example: Herring west of UK and Ireland



Example: Herring west of UK and Ireland





Type of assessment

- Catch trends
- Survey trends
- Survey-based assessment
- Analytical assessment

Catch trends

- Assessment is based on patterns in landings
- CPUE where effort data available

- Pros
  - Simple, cheap, easy to understand
  - Can flag up where things are going wrong

- Cons
  - Not useful as a predictive tool

Catch trends – an example

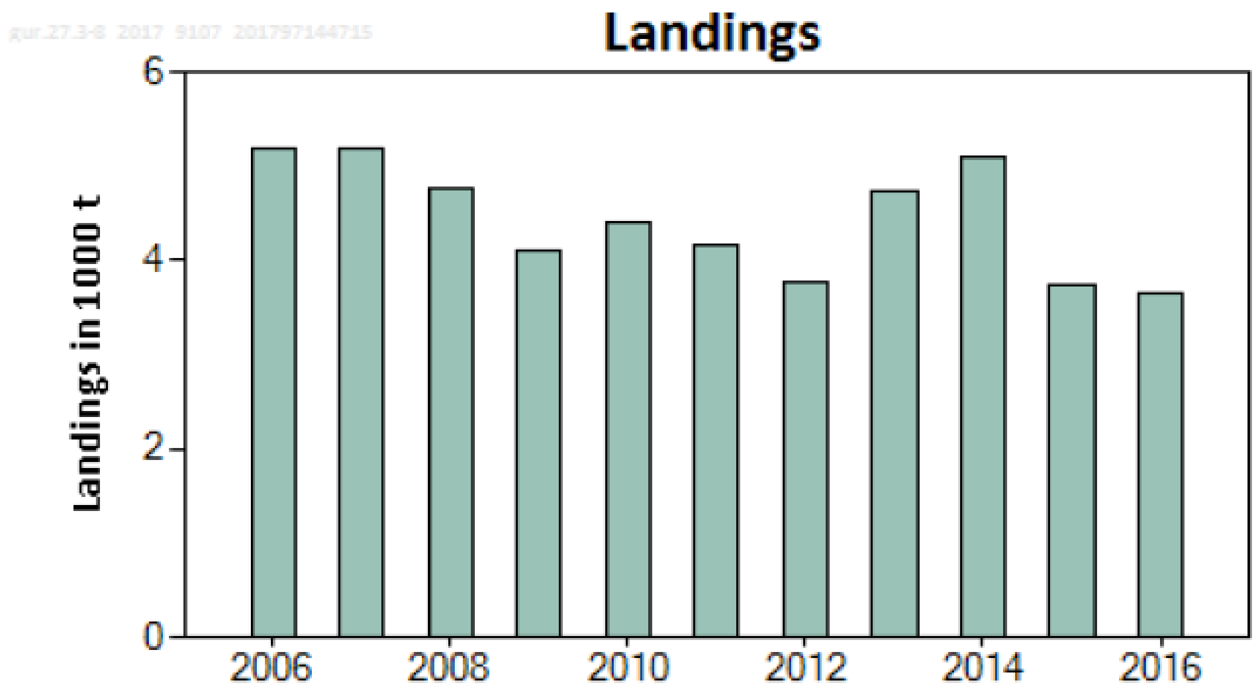
marine scotland science

- Red Gurnard in the Northeast Atlantic (ICES Divs. 3 – 8)

Catch trends – an example

marinescotland science

- Red Gurnard in the Northeast Atlantic (ICES Divs. 3 – 8)



ICES stock advice

ICES advises that when the precautionary approach is applied, landings should be no more than 3618 tonnes in each of the years 2018 and 2019. ICES cannot quantify the corresponding catches.

Survey trends

- Assessment is based on patterns in surveys
- Pros
  - Simple, still quite cheap, easy to understand
  - Can flag up where things are going wrong
- Cons
  - May not reflect what stakeholders are seeing
  - Changes in survey design can disrupt time series

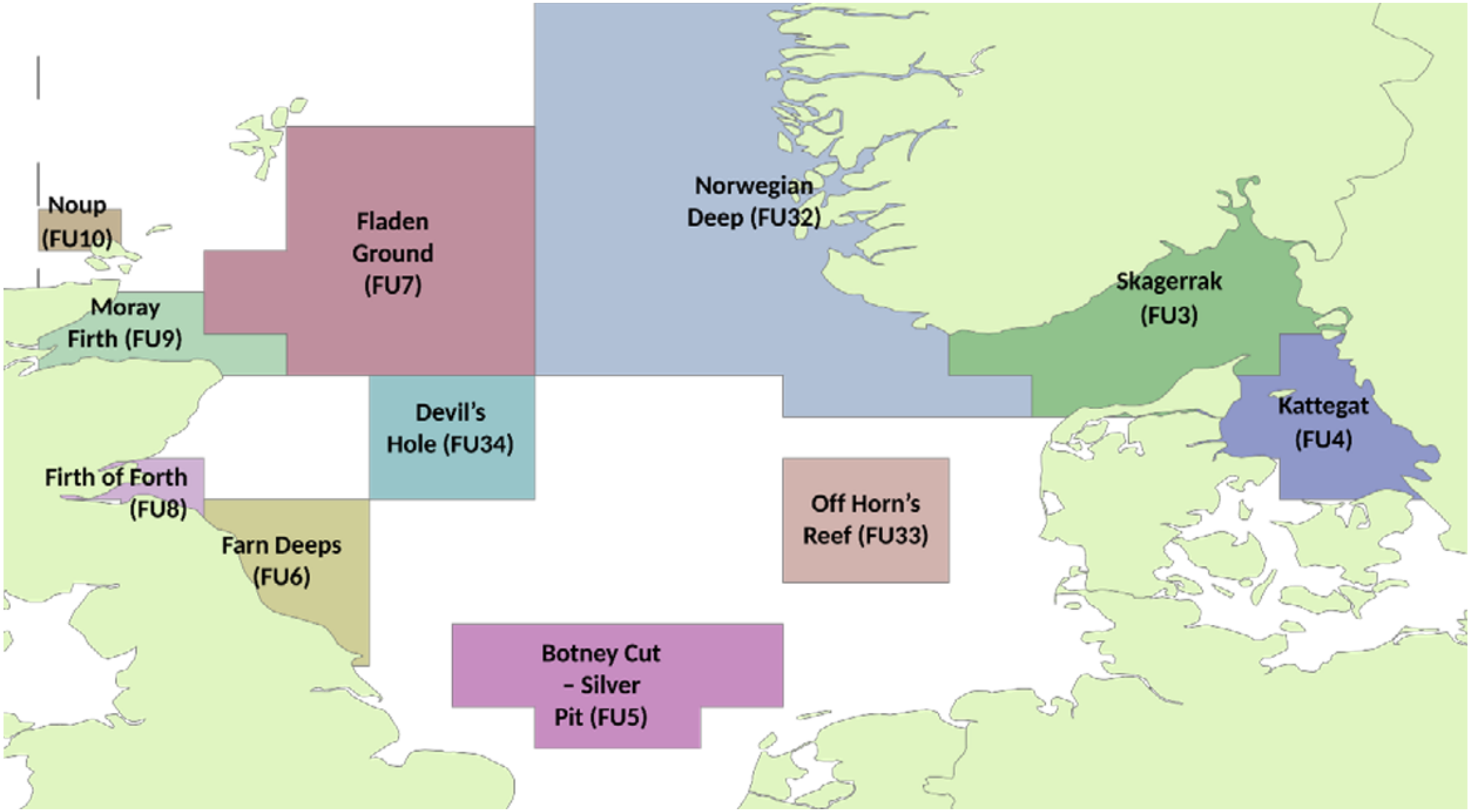
Survey trends – an example

marinescotland science

- *Nephrops* in Div 4, Functional Unit 7 (Fladen, North Sea)

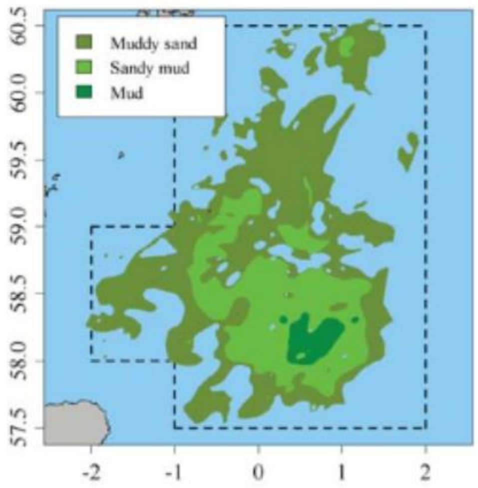
Survey trends – an example

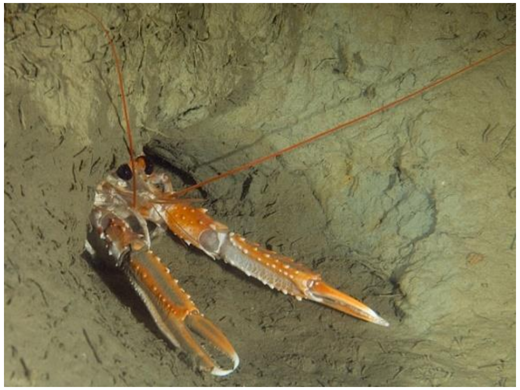
- *Nephrops* in Div 4, Functional Unit 7 (Fladen, North Sea)



Survey trends – an example

- *Nephrops* in Div 4, Functional Unit 7 (Fladen, North Sea)





Survey trends – an example

marinescotland science

- *Nephrops* in Div 4, Functional Unit 7 (Fladen, North Sea)

Area of mud X Density of burrows

28 153 km^2

0.16m^{-2}

= 4.45 billion

Survey trends – an example

- *Nephrops* in Div 4, Functional Unit 7 (Fladen, North Sea)

Population X Target Harvest Rate X Average Weight

4.45 billion

7.5%

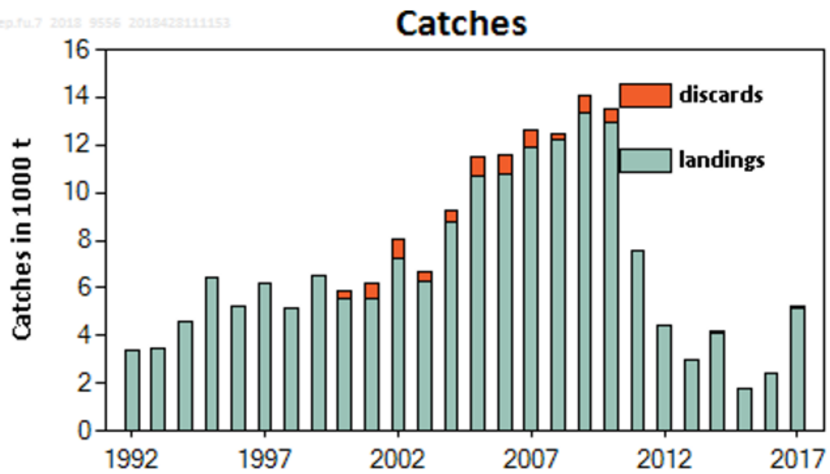
39.75g

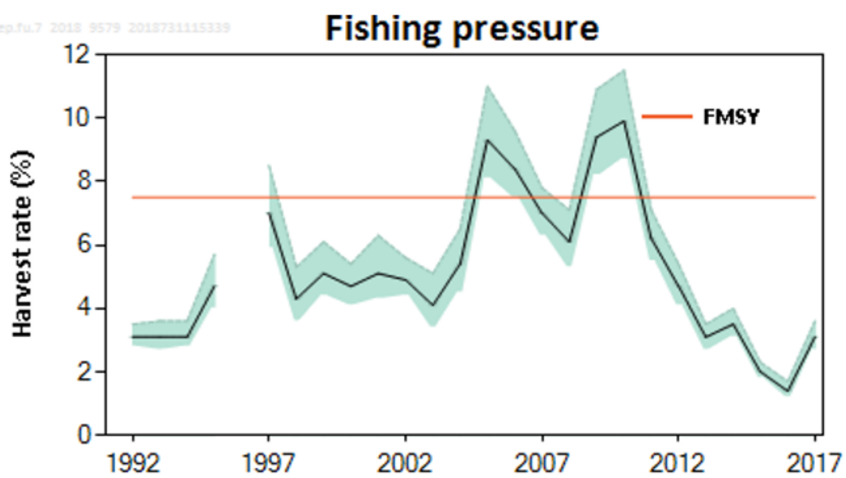
= **13 350 t**

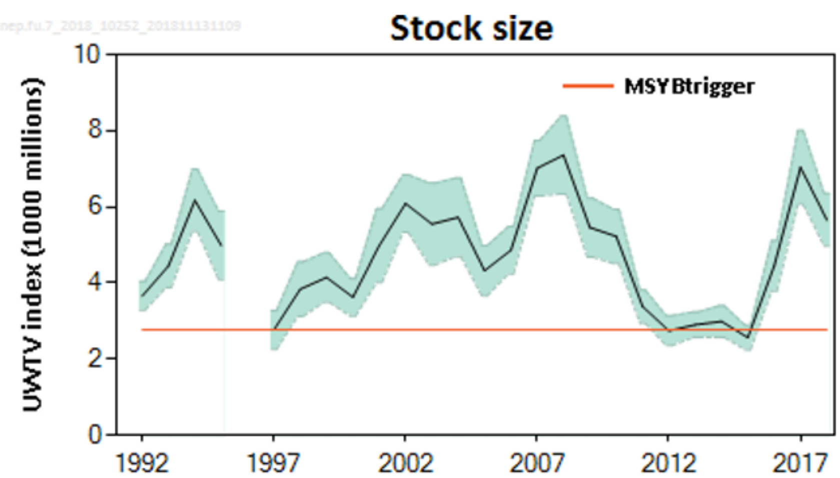
Survey trends – an example

marine scotland science

- *Nephrops* in Div 4, Functional Unit 7 (Fladen, North Sea)







Survey trends – an example

marine scotland science

- *Nephrops* in Div 4, Functional Unit 7 (Fladen, North Sea)

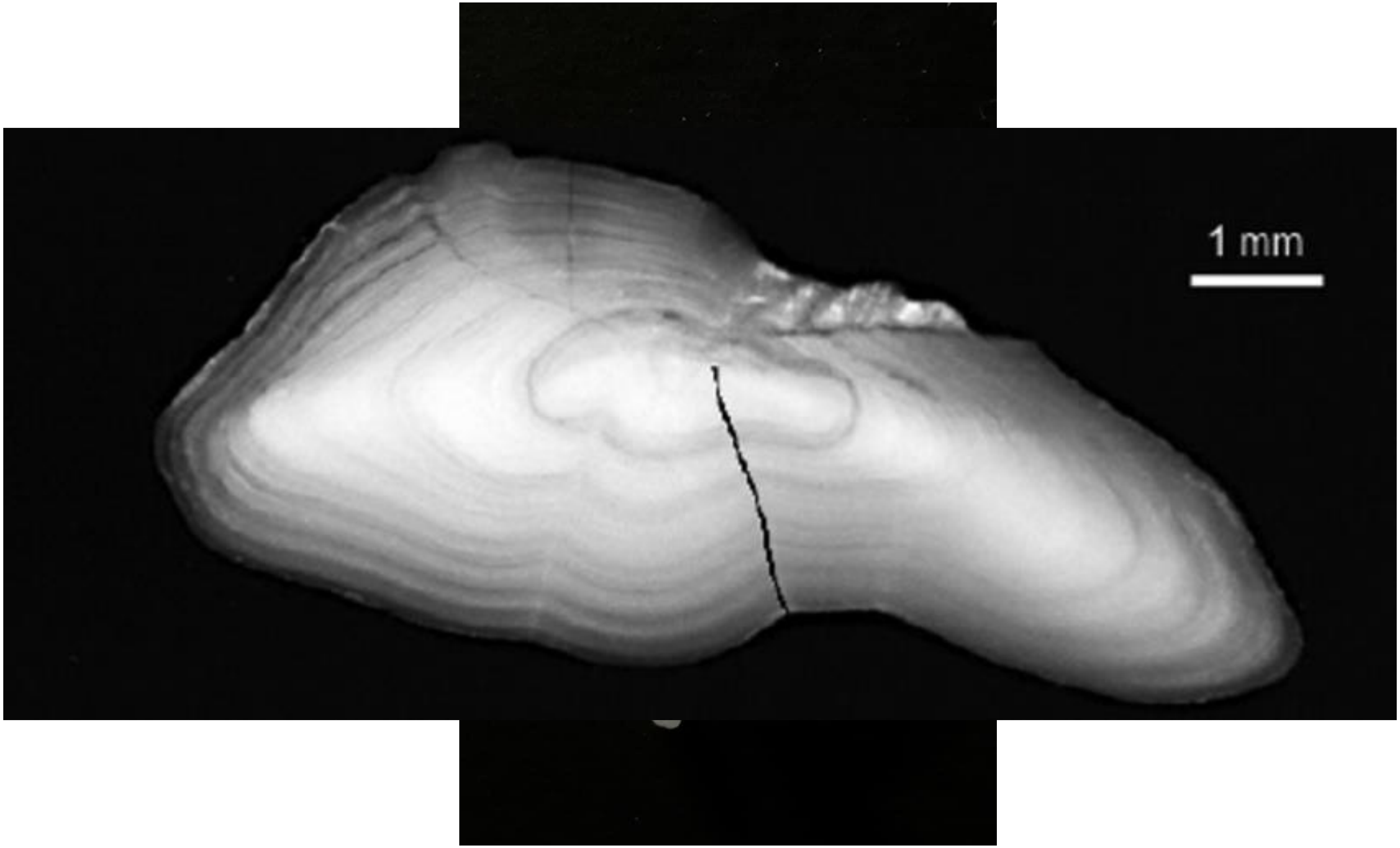
Norway lobster (*Nephrops norvegicus*) in Division 4.a, Functional Unit 7 (northern North Sea, Fladen Ground)

ICES advice on fishing opportunities

Please note: The present advice replaces the advice given in June 2018 for catches in 2019.

ICES advises that when the proposed EU multiannual plan (MAP) for the North Sea is applied, catches in 2019 that correspond to the F ranges in the MAP are between 11 596 tonnes and 13 178 tonnes. The entire range is considered precautionary when applying the ICES advice rule.

Age-based Assessments



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

- Then the number that die due to fishing is:

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

×

Concepts: The catch equation

- Which we just call the catch *C*:

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

Concepts: The catch equation

marinescotland science

- 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!

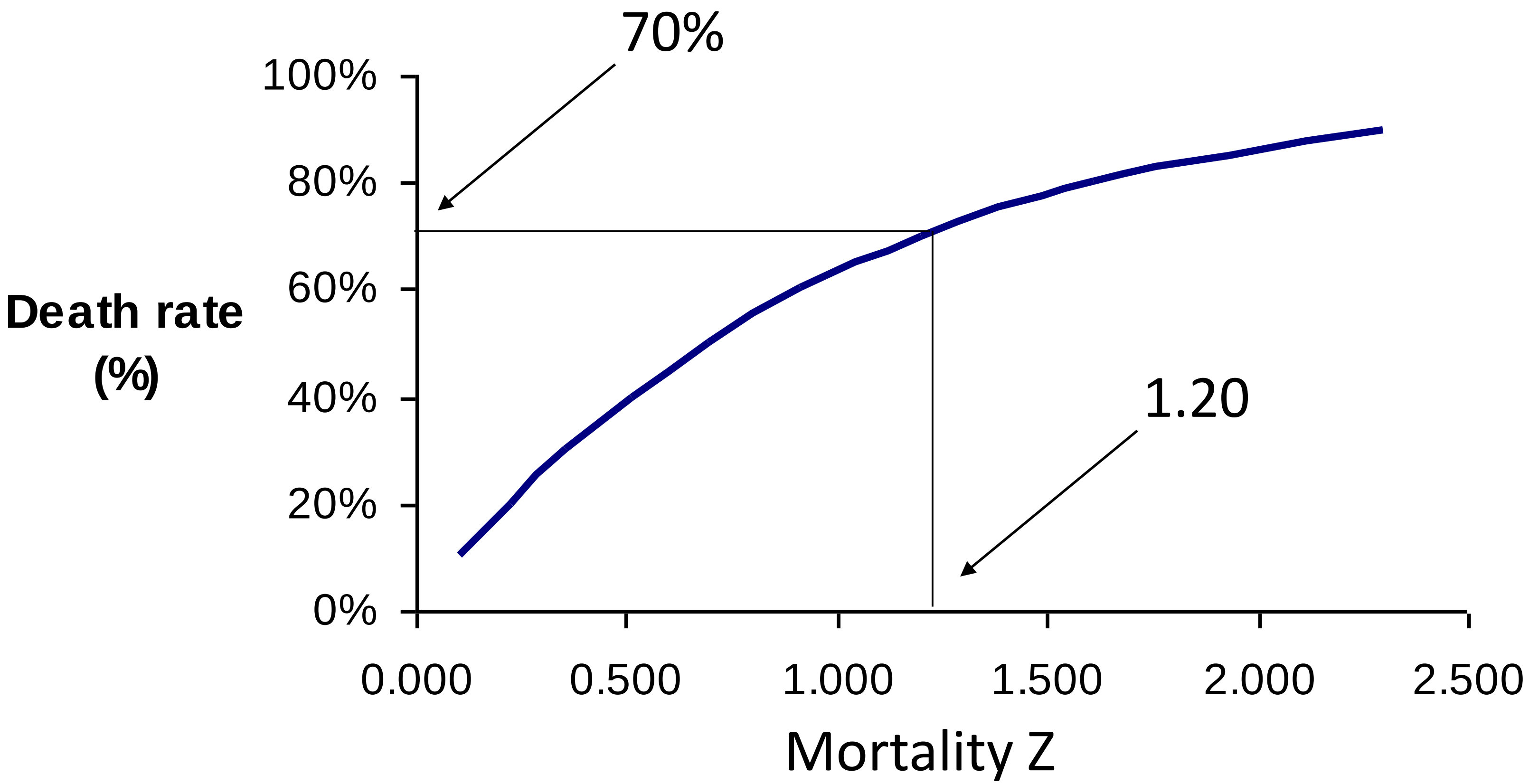
Models: Cohort analysis

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



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 = 115000 = 77%

So Z = 1.46

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 = 25000 = 71%

So Z = 1.25

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

?

Models: Cohort analysis

marinescotland science

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							$\boxed{0.69}$

Models: Cohort analysis

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

marinescotland science

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

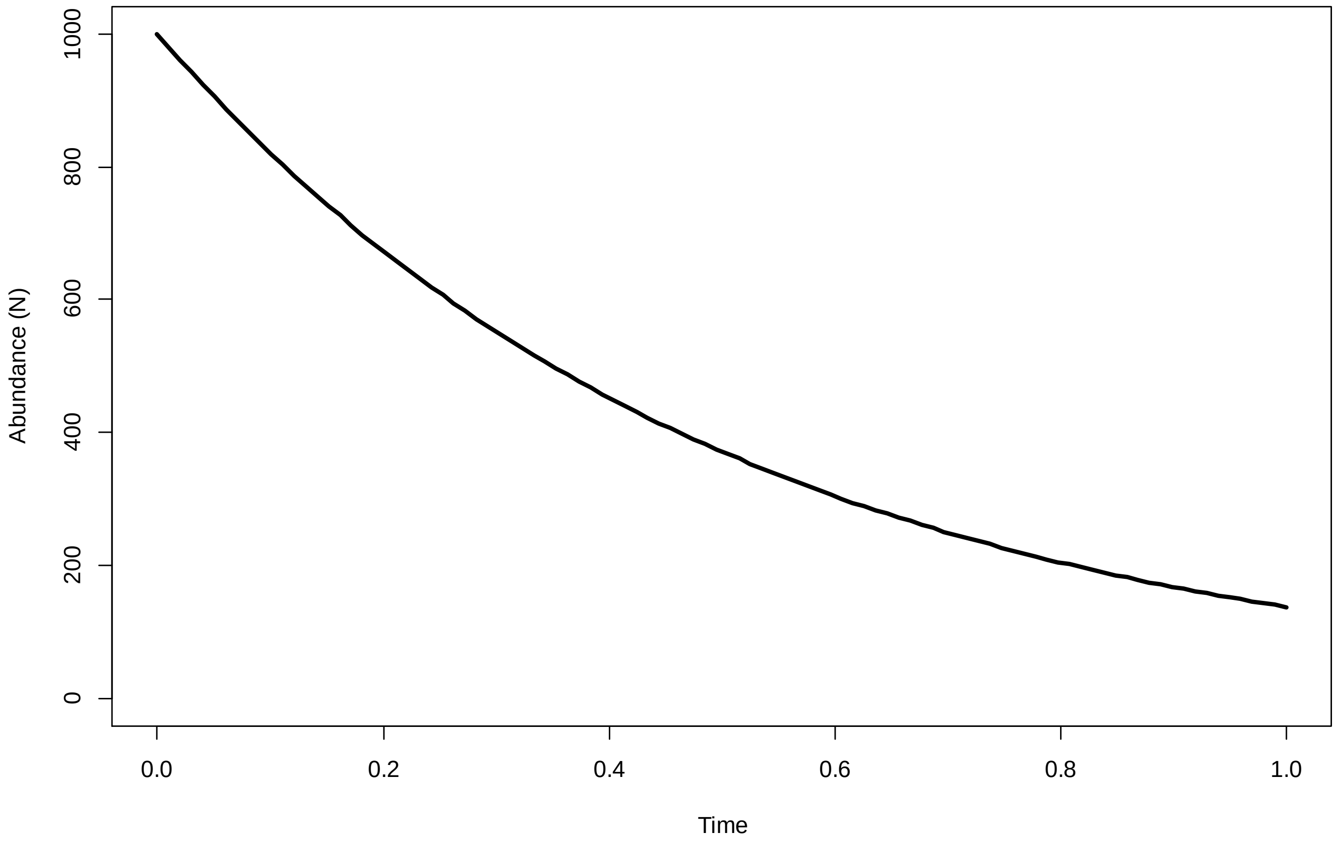
marinescotland science

- So if we know (or make some assumptions about…!)
  - Catch
  - Abundance
  - Natural mortality
- Then we can calculate fishing mortality
  - Except for the last year!
- But we **don’t** know abundance…

Concepts: Exponential decline

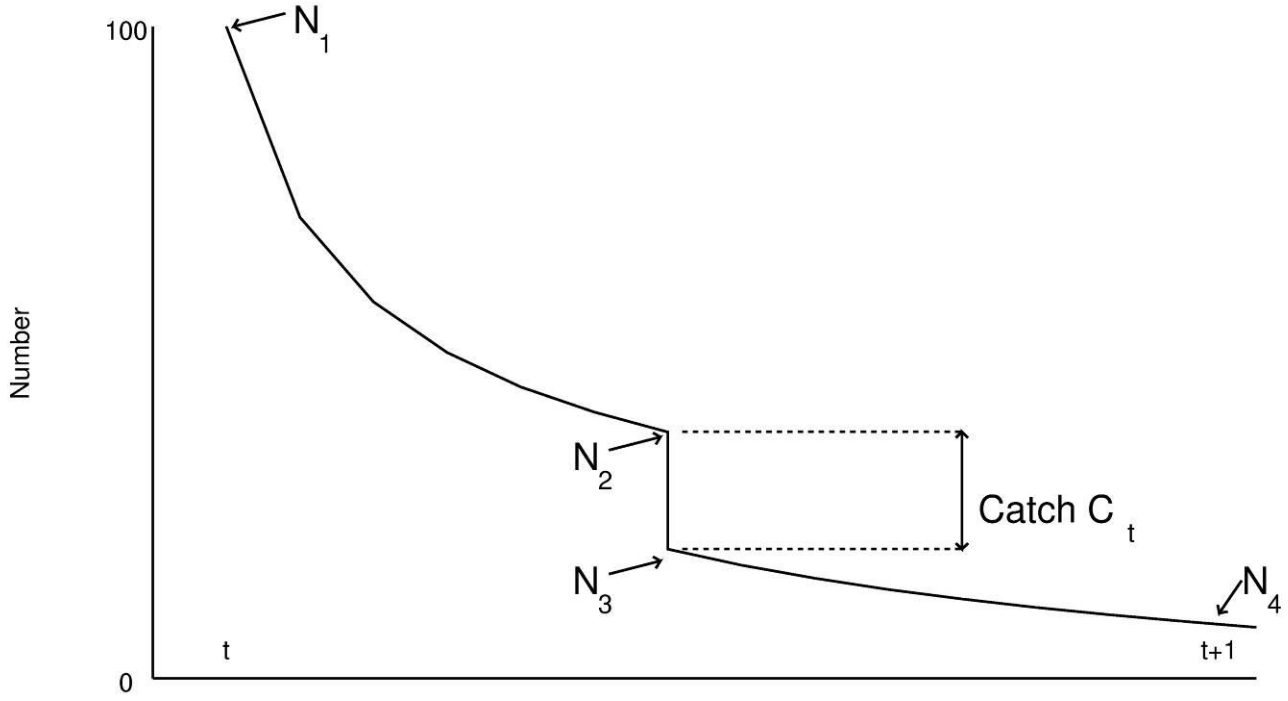
- A cohort is assumed to decline exponentially:

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



Concepts: Exponential decline

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



Models: Cohort analysis

marinescotland science

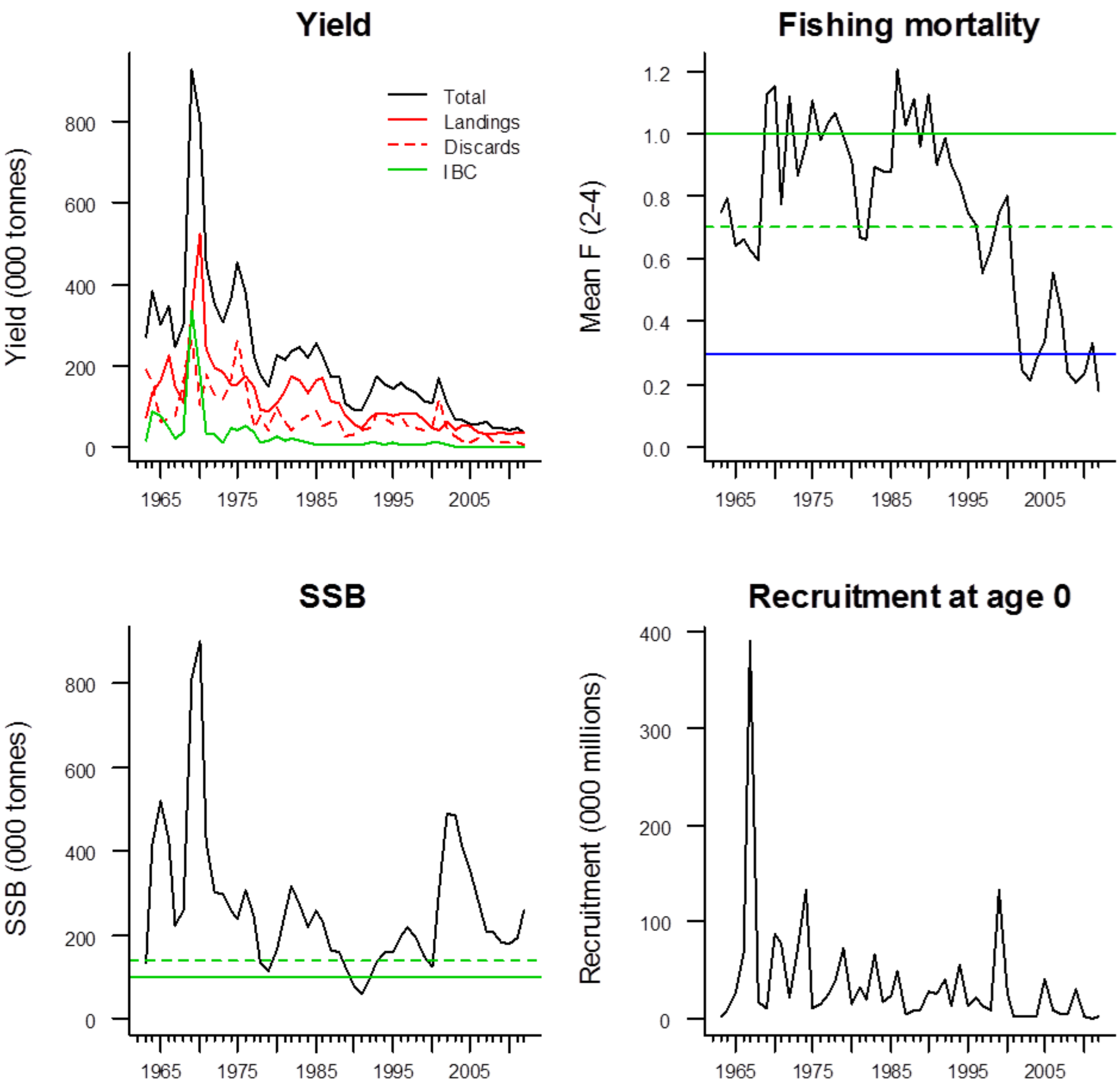
- So we **can** do an assessment with catch data only
- Pros:
  - Many samples
- Cons
  - Fishermen follow fish
  - Some catch data may be missing
  - Difficult to estimate some *F*s
- Survey data can help to address these problems

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

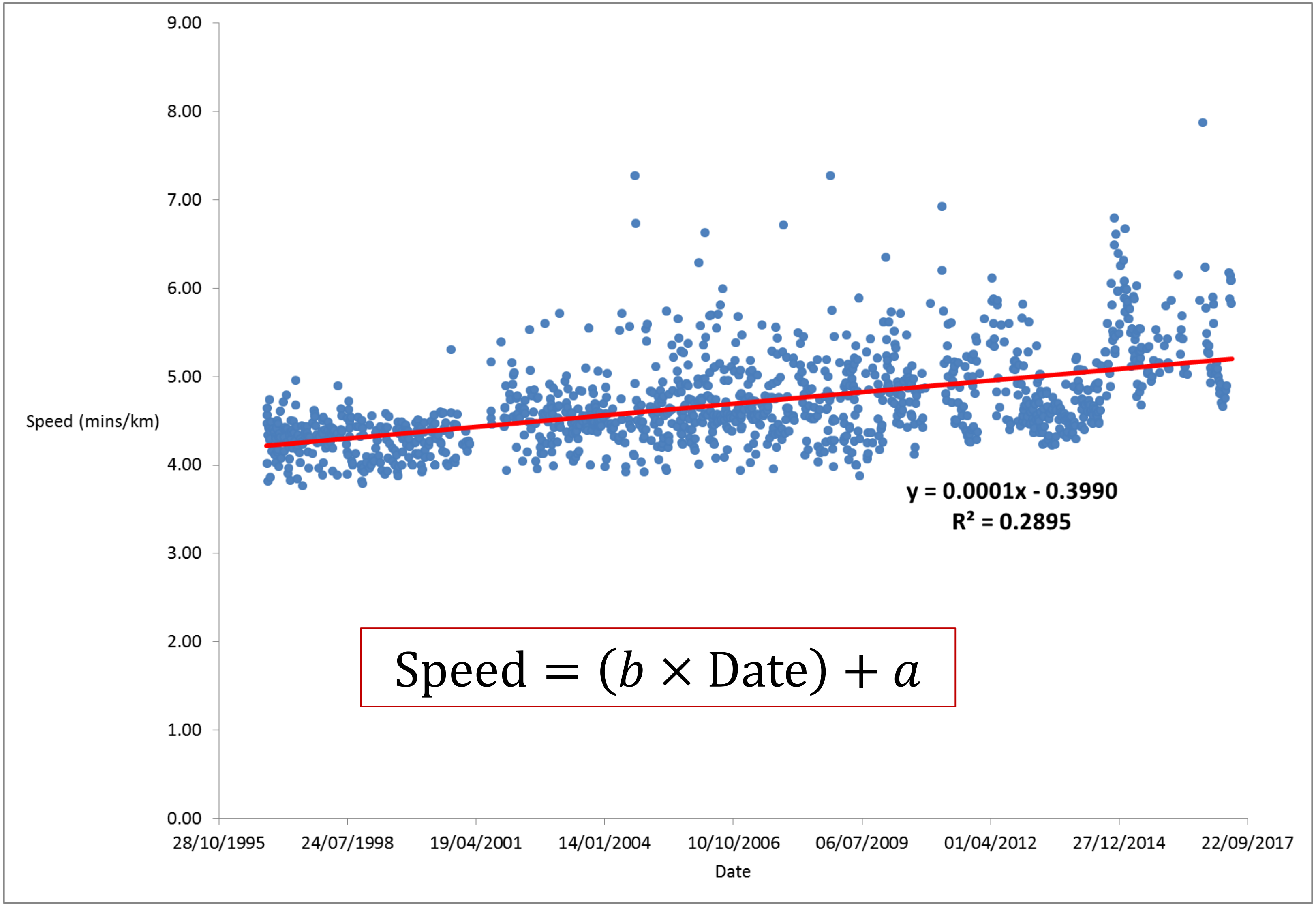
Models: Cohort analysis

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



Models: Separable model

marinescotland science

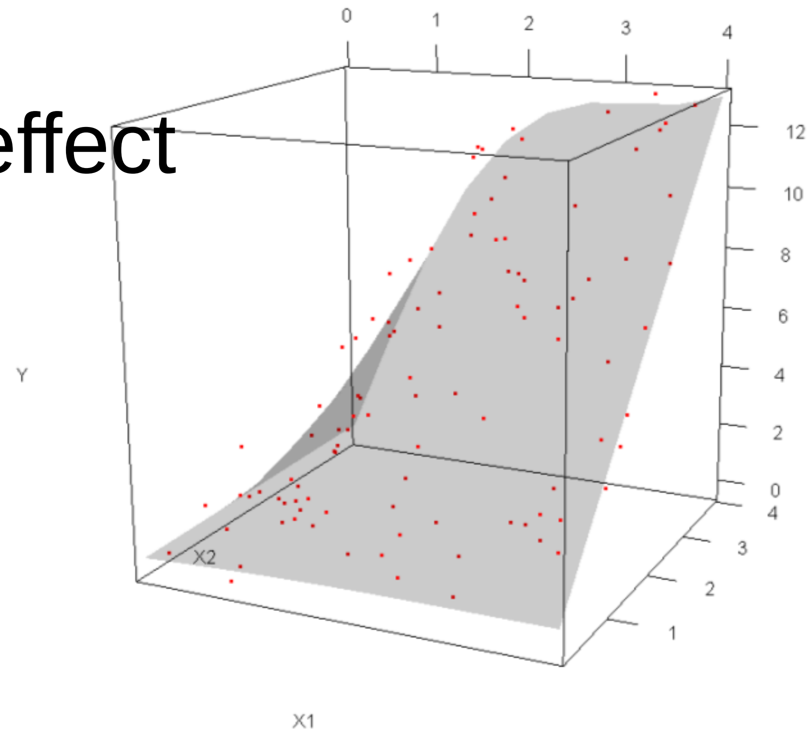


- Regression analysis
- Find a line that passes as close to as many of the points as possible
- Summarises relationship as simply as possible

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

Mortality (Z) = Age effect X Year effect

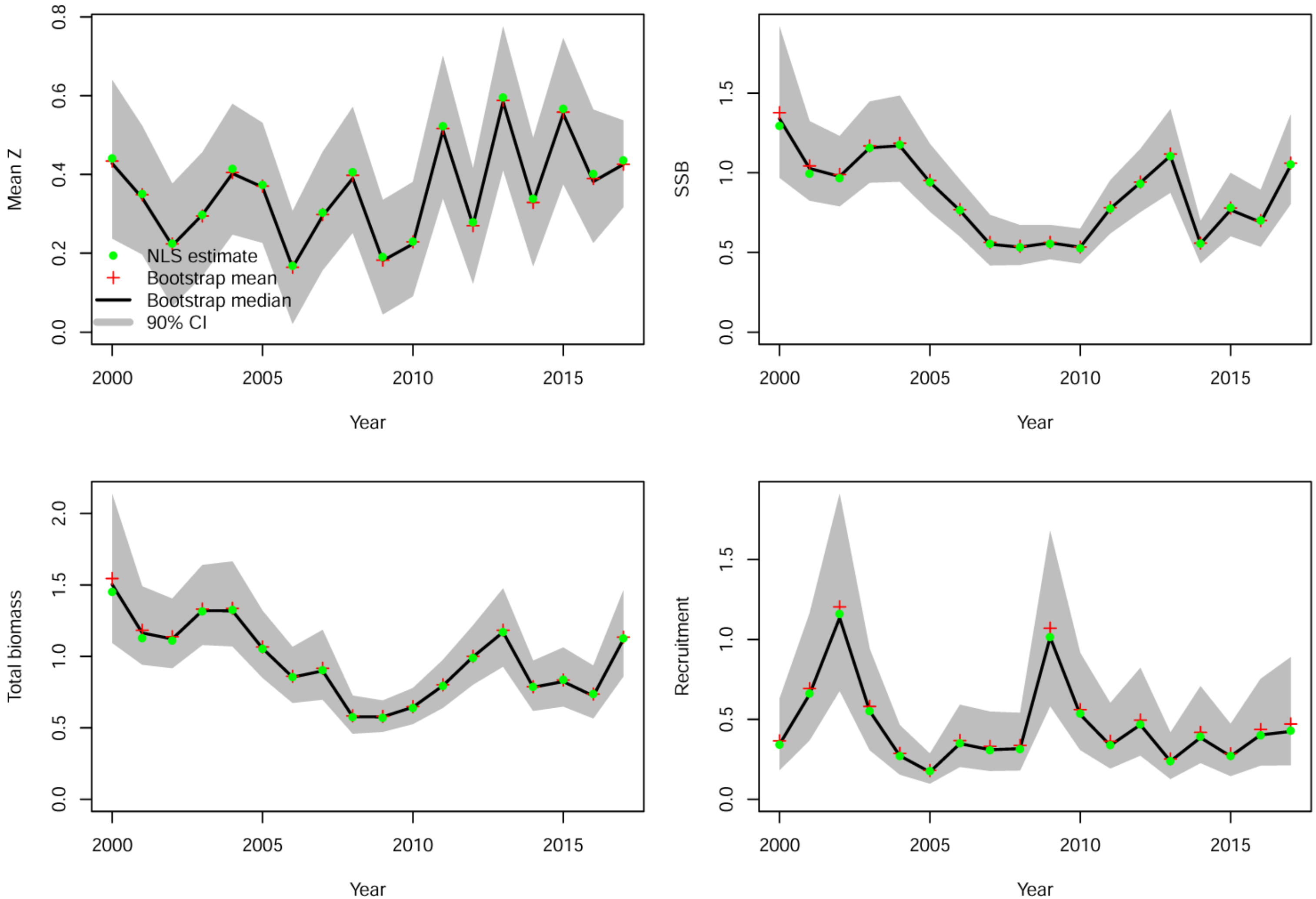


  - Enables uncertainty estimates

Models: Separable model

Models: Separable model

- Example: SURBAR applied to NS lemon sole



Reference Points

marinescotland science

Stock assessment

- State of the stock
- Fishing mortality

But what should we do with this information?!

Limit reference points – situations to be avoided

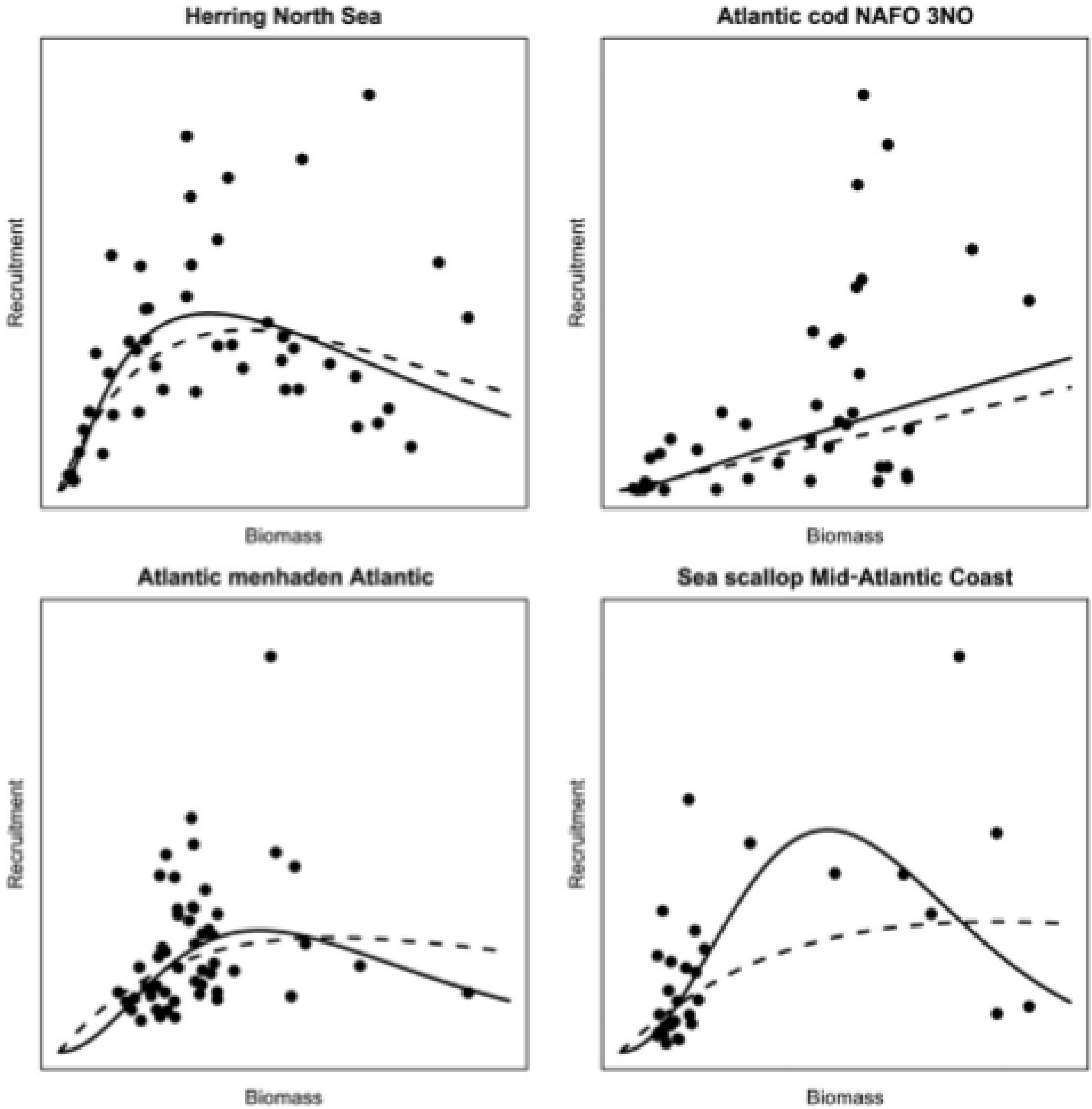
Target reference points – situations which give maximum outputs

Limit Reference Points

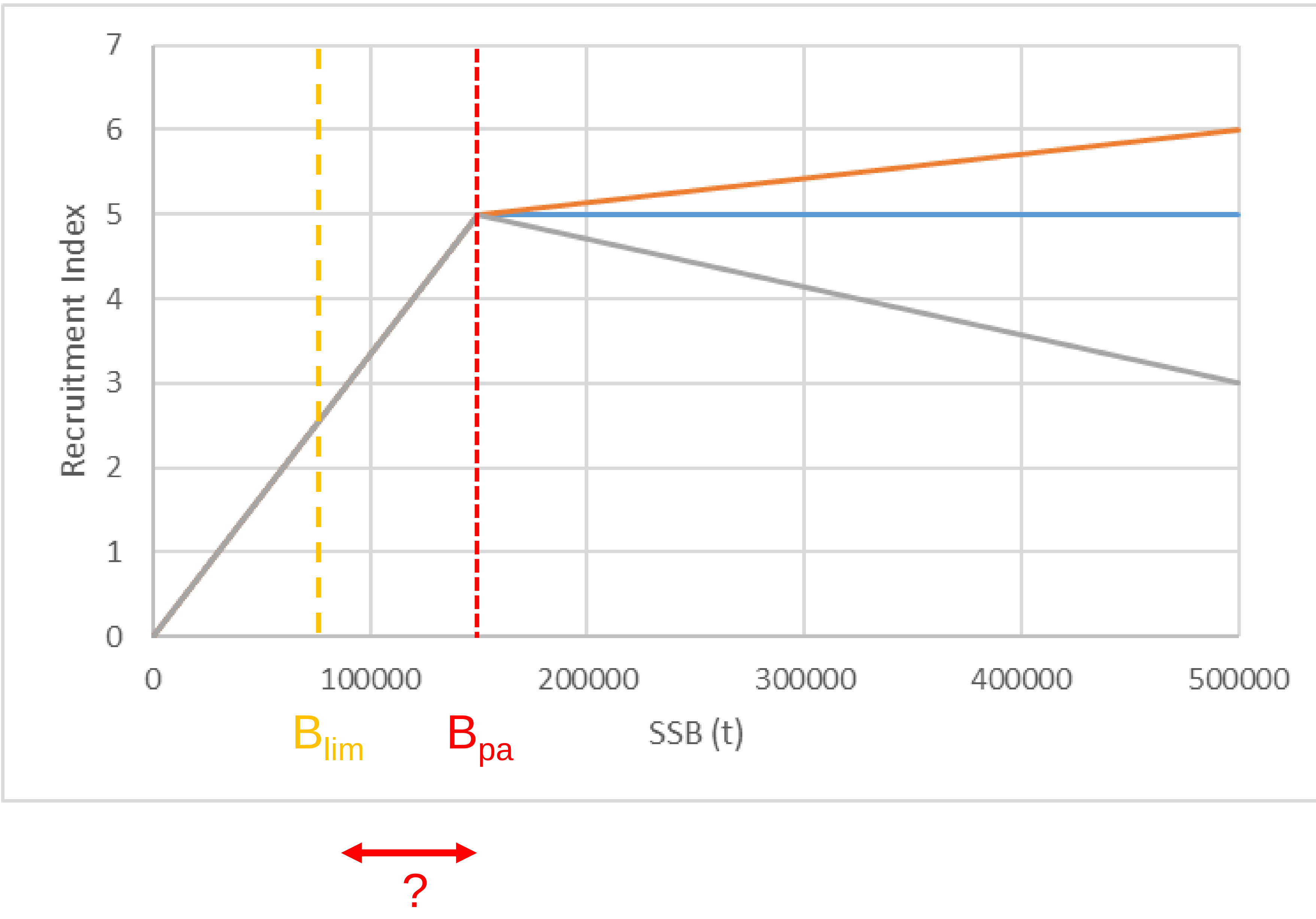
marinescotland science

	SSB below reference level	SSB above reference level
Fishing mortality above threshold	Stock is overfished and being exploited unsustainably	Stock is not overfished but is being exploited unsustainably
Fishing mortality below threshold	Stock is overfished but overfishing is not occurring	Stock is not overfished, nor is overfishing occurring

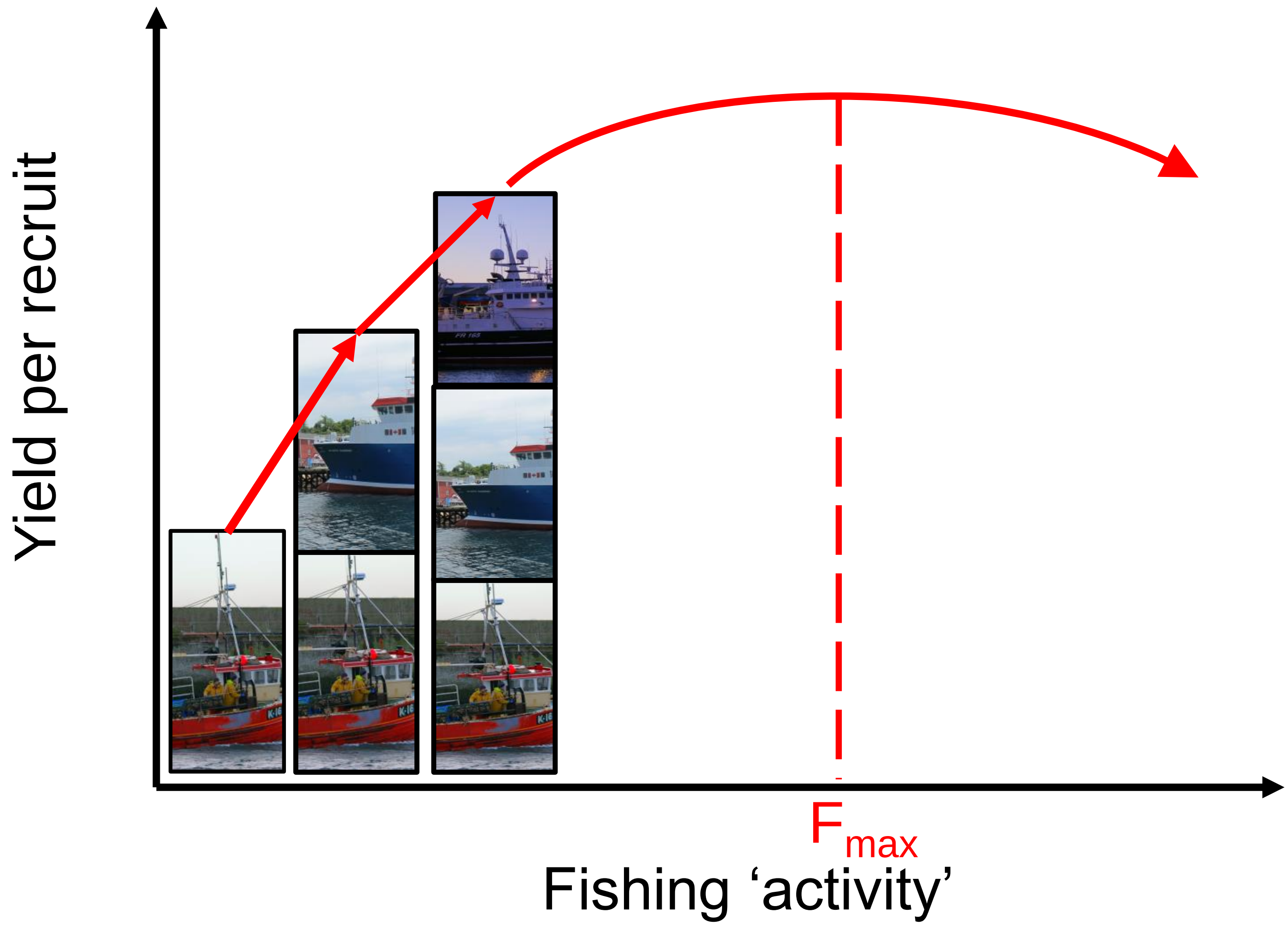
Limit Reference Points



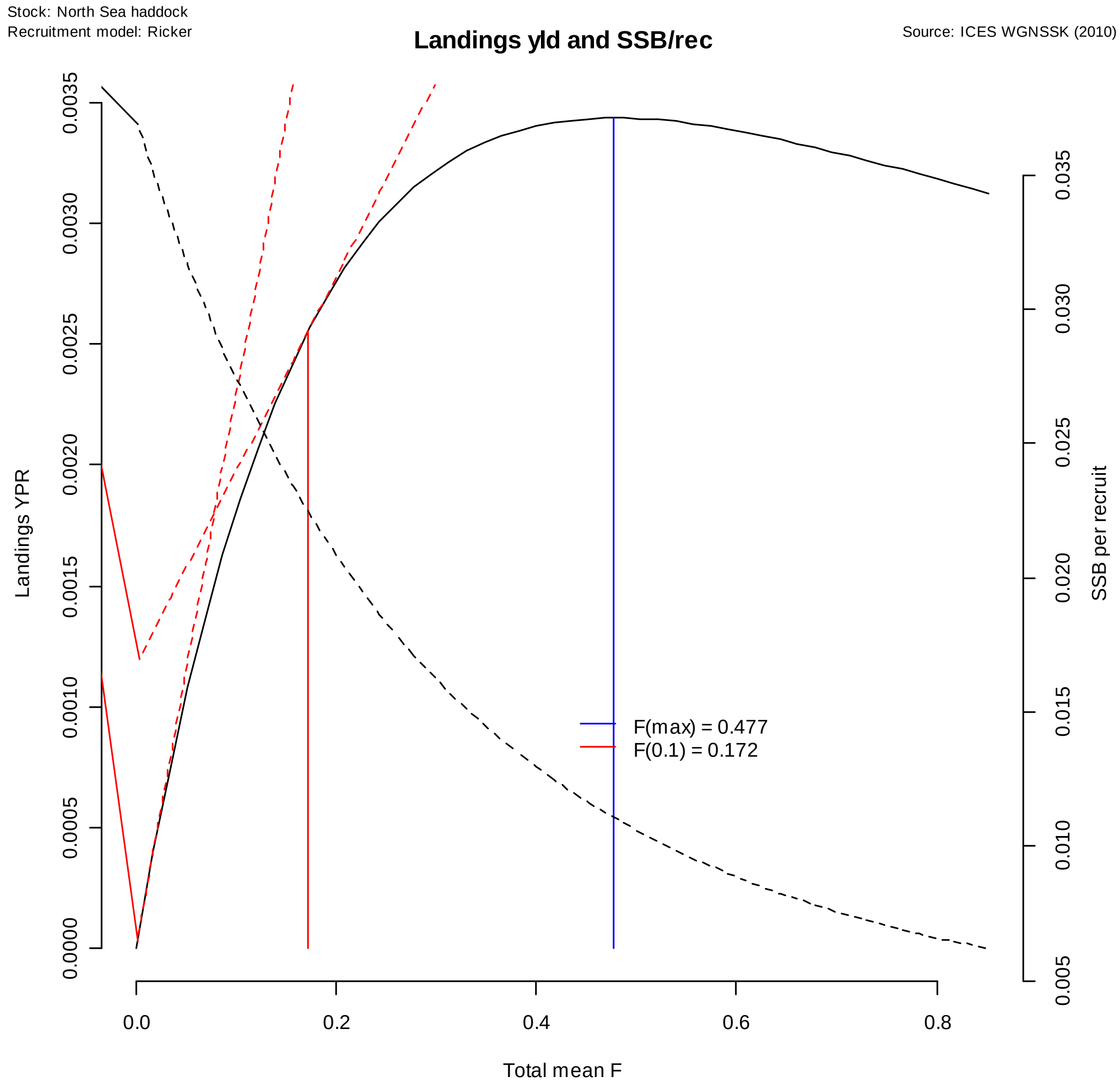
Limit Reference Points



Concepts: F_{max}

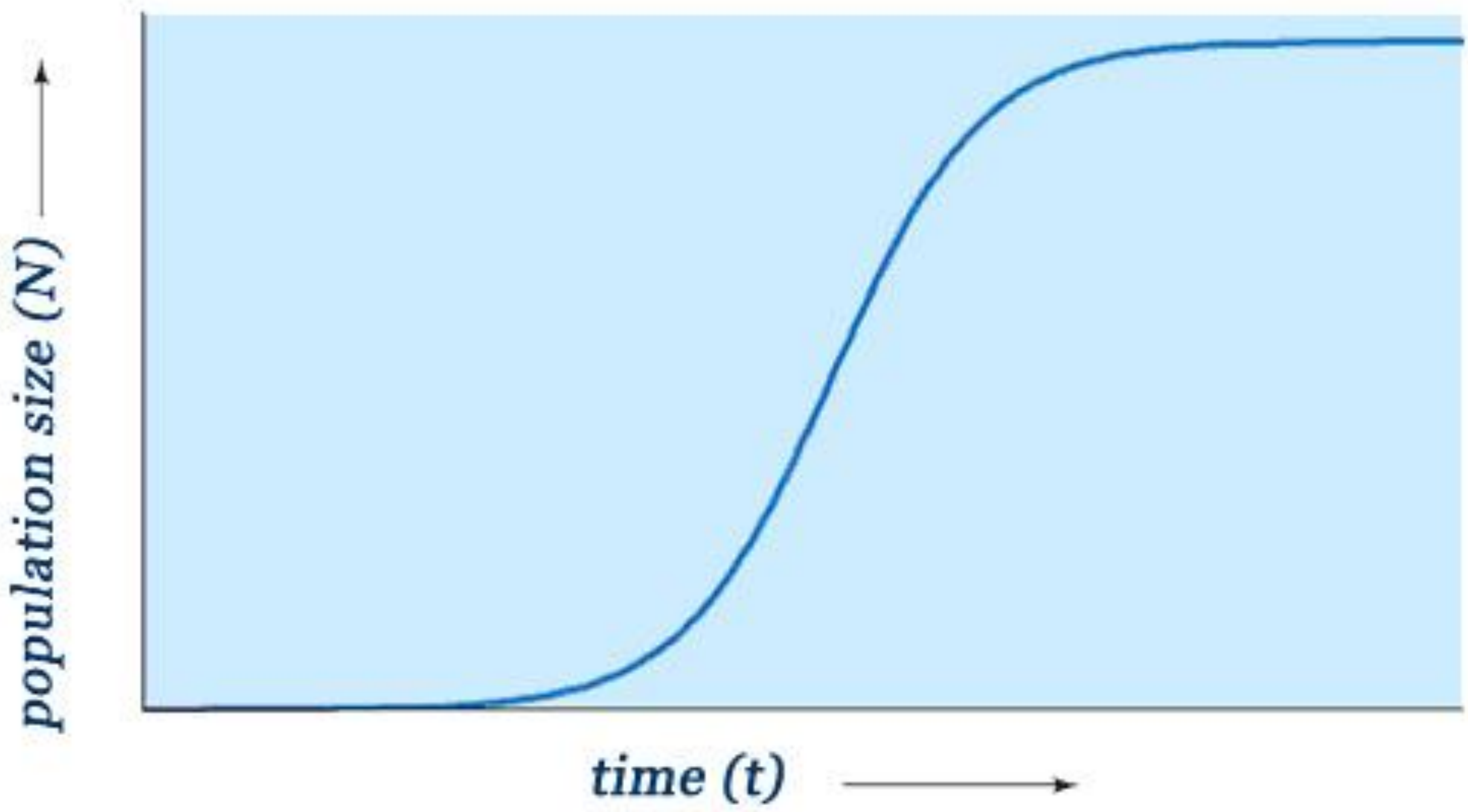


Concepts: $F_{0.1}$

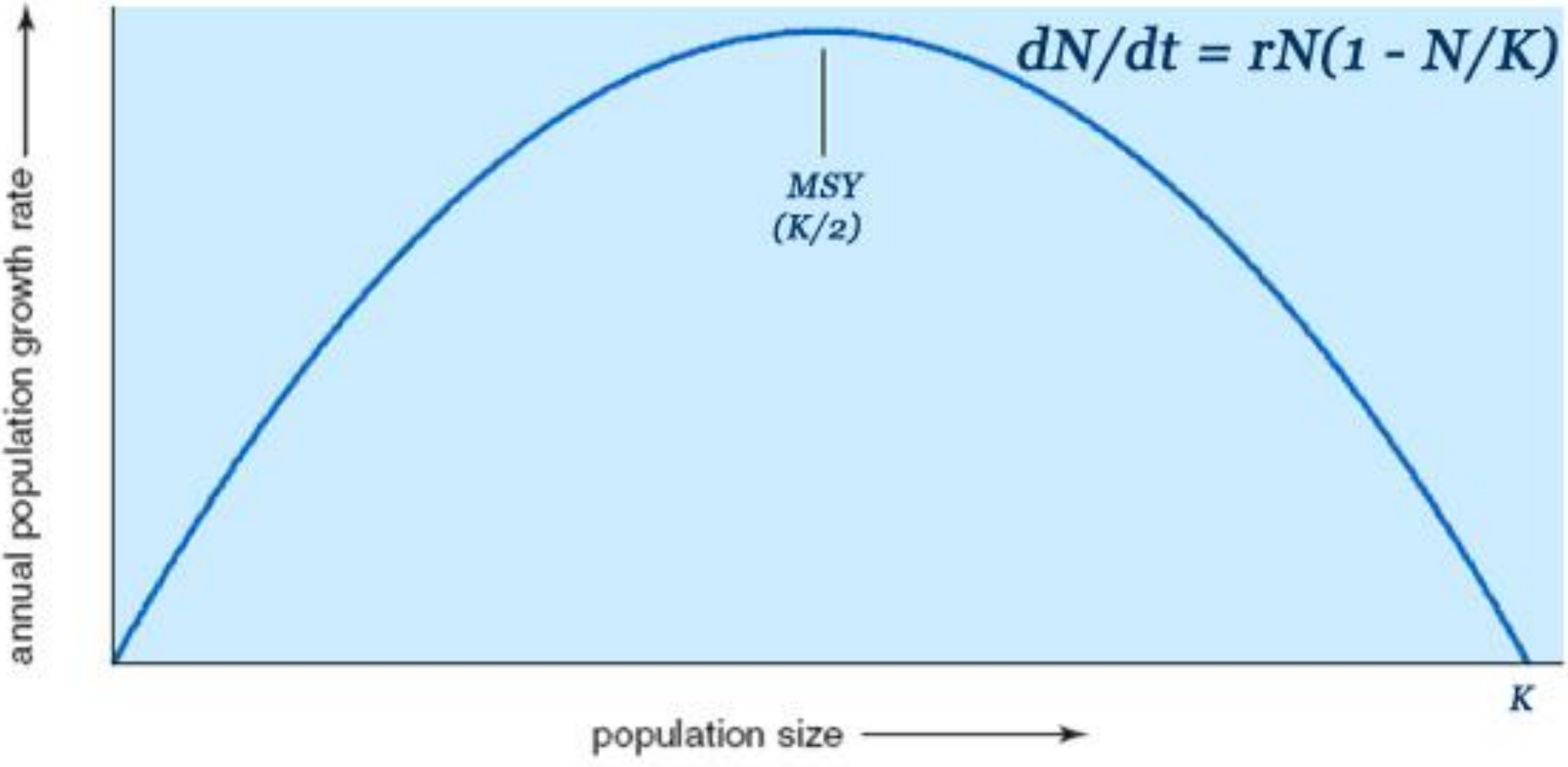


Concepts: MSY

marinescotland science



Concepts: MSY



Concepts: MSY

marinescotland science

- 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

marinescotland science

- 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

The last stage: the catch-option table

marinescotland science

Table 3 Blue whiting in subareas 1–9, 12, and 14. Annual catch scenarios. All weights are in tonnes.

Basis	Total catch (2019)	F_{total} (2019)	SSB (2020)	% SSB change *	% Catch change **	% Advice change ***
ICES advice basis						
Long-term management strategy ($F = F_{MSY}$)	1143629	0.32	3752236	-13	-33	-18
Other scenarios						
MSY approach: F_{MSY}	1143629	0.32	3752236	-13	-33	-18
F = 0	0	0	4850444	12	-100	-100
F_{pa}	1725357	0.53	3201021	-26	1	24
F_{lim}	2476742	0.88	2499796	-42	45	79
SSB (2020) = B_{lim}	3587714	1.75	1500171	-65	110	159
SSB (2020) = B_{pa}	2747920	1.04	2250714	-48	60	98
SSB (2020) = MSY $B_{trigger}$	2747920	1.04	2250714	-48	60	98
$F = F_{2018}$	1528542	0.45	3386825	-22	-11	10
SSB (2020) = SSB (2019)	544778	0.140	4325259	0	-68	-61
Catch (2019) = Catch (2018)	1712874	0.53	3212778	-26	0	23
Catch (2019) = Catch (2018) -20 %	1370342	0.40	3536701	-18	-20	-1
Catch (2019) = Advice (2018) -20 %	1109872	0.31	3784400	-13	-35	-20

* SSB 2020 relative to SSB 2019.
** Catch in 2019 relative to catch in 2018 (1 712 874t, ICES estimate).
***Advice value for 2019 relative to advice value for 2018.

The advised catch is lower than last year's advice due to the low recruitment in 2017 and 2018 and decreasing biomass in addition to a downwards revision in the estimate of SSB in recent years.

Summary

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

Thanks…