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FISHING INTO THE FUTURE

CHARTING A COURSE TO SUSTAINABLE UK FISHERIES

Fish Biology and Sustainability

Tara Marshall

c.t.marshall@abdn.ac.uk

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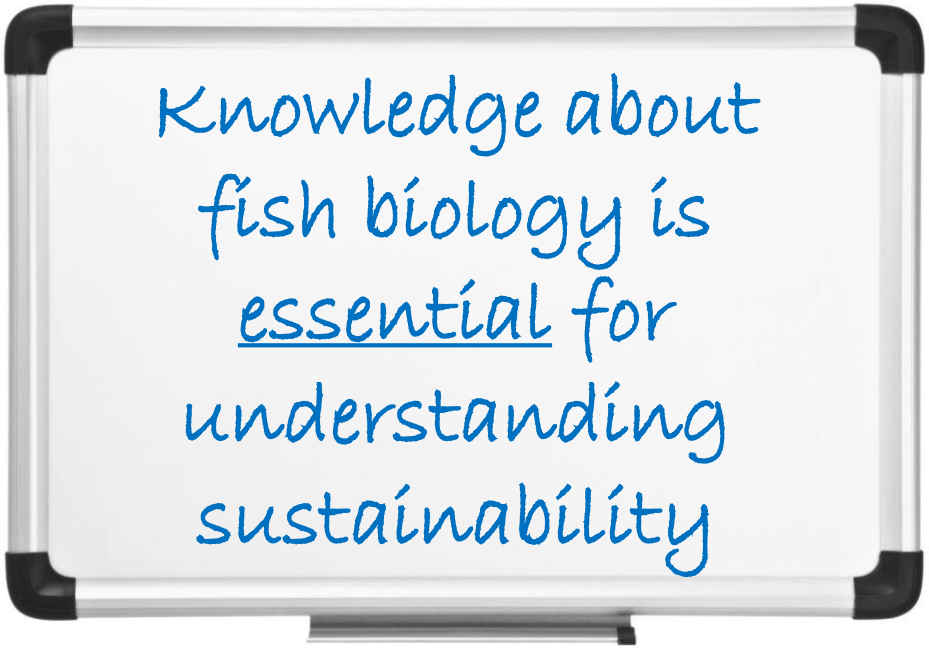
What do *you* think sustainability means?



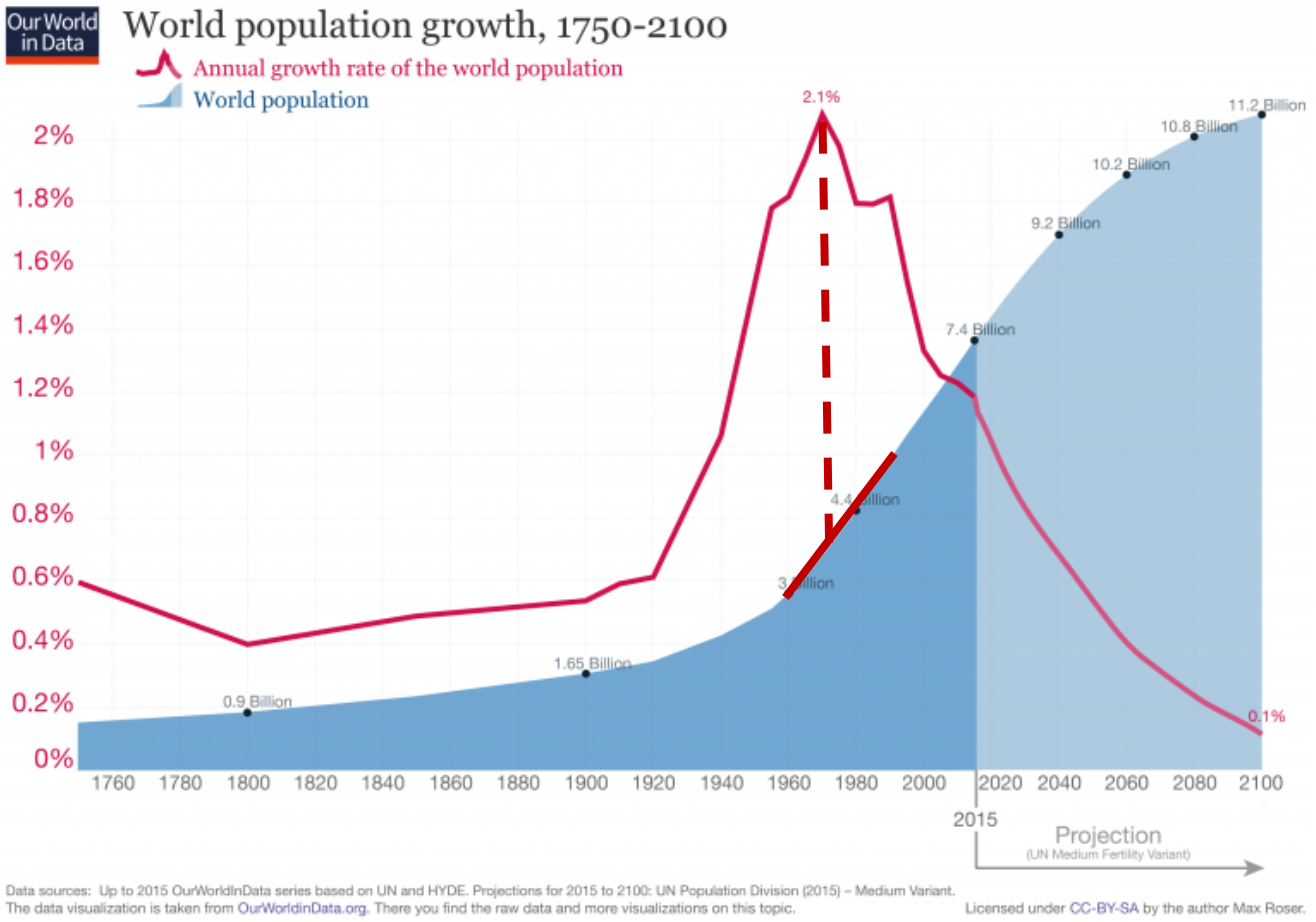
Graham's Theory of Sustainable Fishing (1935)

$$\text{MSY} = \frac{\text{population growth rate} \times \text{carrying capacity}}{4}$$

MSY will be higher when population growth rates are high AND *positive*

Michael Graham was Britain's chief fisheries scientist after World War II

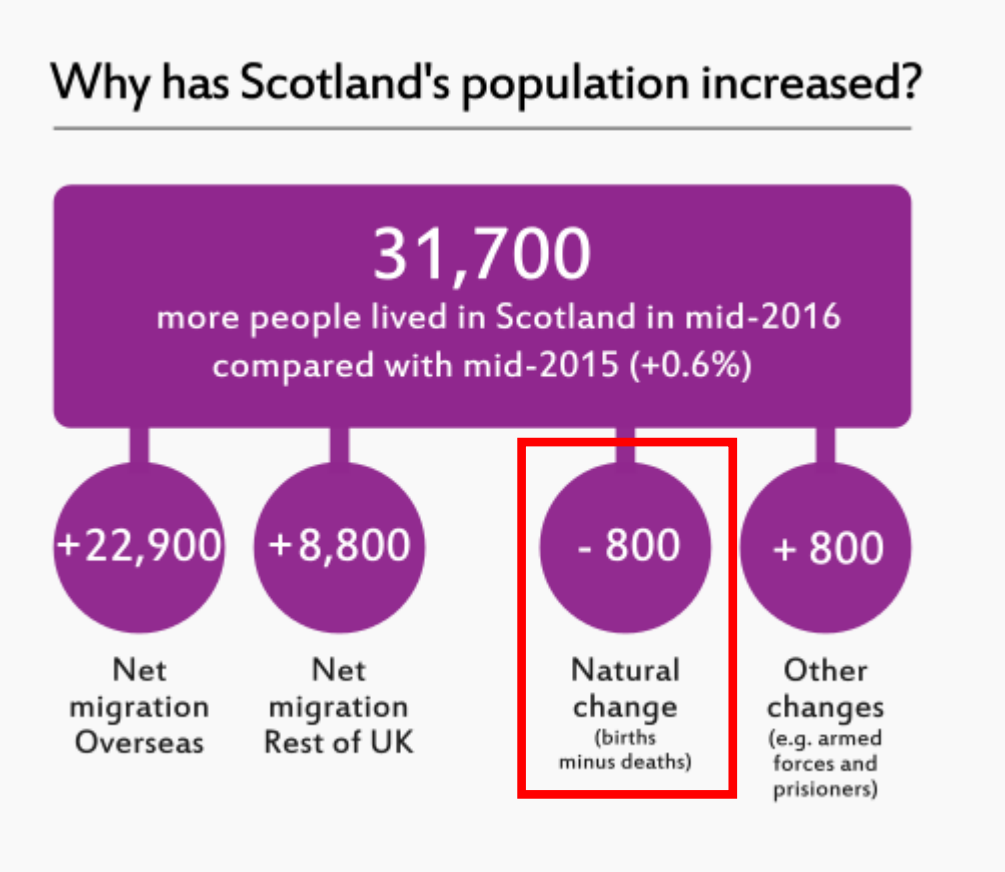
Population growth rates are familiar when applied to human populations



https://ourworldindata.org/world-population-growth

Population **increase** happens when population growth rate is **+'ve**

Population **decline** happens when population growth rate is **–'ve**



Projecting **population growth rate** is essential to planning for the future

Schools
Health care
Transportation

Harvesting rates

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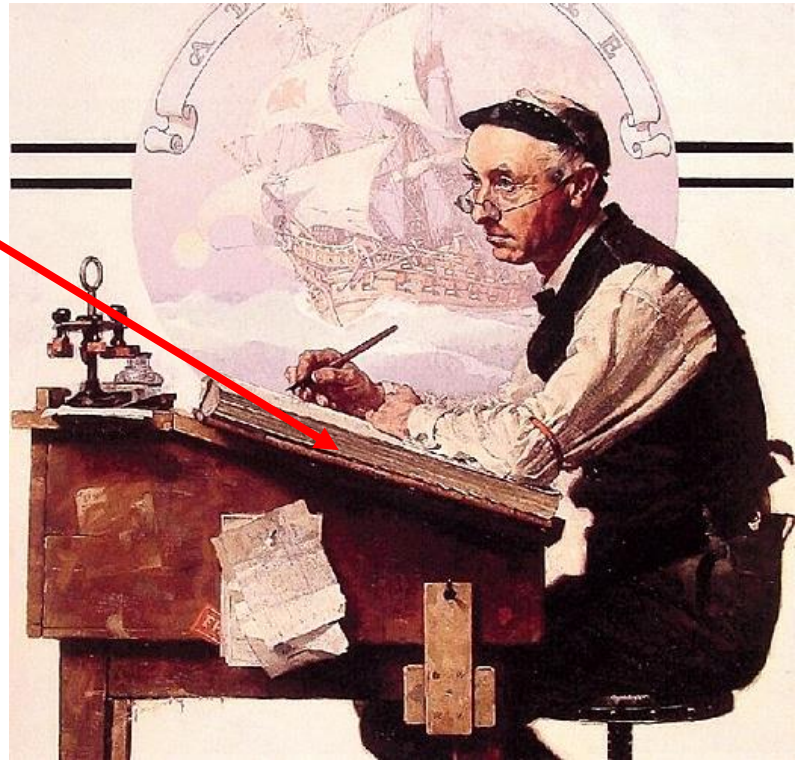
For fishing, **biomass** is a more intuitive measure than population growth rate

1. estimate total biomass of the fish stock
2. estimate fraction of total stock biomass that can reproduce
3. determine fraction of mature stock that can be sustainably removed
   - *that fraction needs to ensure that population growth is positive after accounting for removal*

Stock assessment

Stock assessment is the bookkeeping for estimating **population growth** and therefore **yields**

biology is what's in the books



On Wednesday:

Stock Assessment & Modelling

Demystifying ICES Stock Assessment Sheets

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Population growth rate depends on 5 “vital” rates

Natural mortality rate

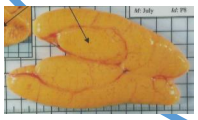
Recruitment rate

Biomass

Fishing mortality rate

Individual growth rate

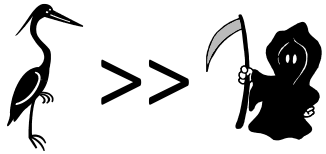
Maturation rate



Individual growth rate
Maturation rate
Recruitment rate
Natural mortality rate

Fishing mortality rate

We need to know all these **vital rates**
so we can determine



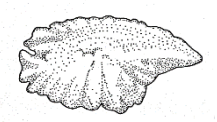
Estimating **rates** requires knowing age

just like in human populations!

Is this a small, old cod
or a big, young cod?

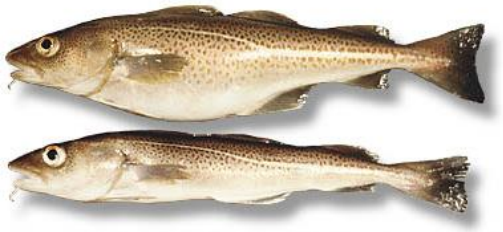
Vital Rate 1: Individual growth rate

Growth is the rate of production of new tissue (per year)



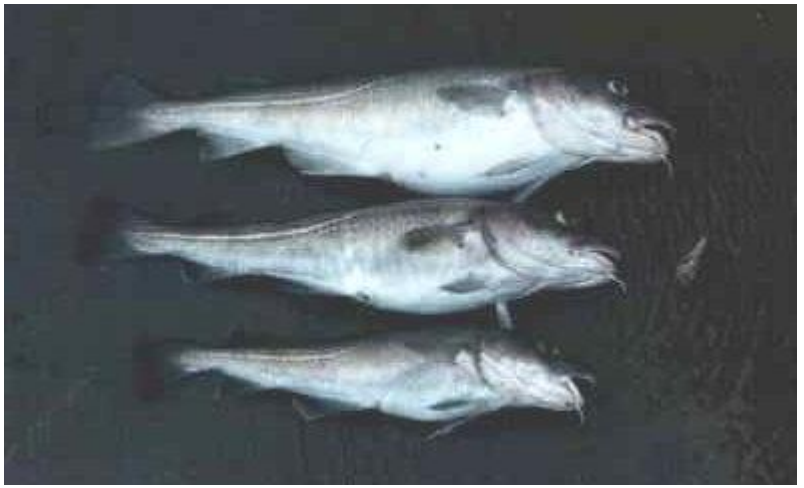
Increase in length	fixed tissues: skeleton, circulatory and nervous tissue
Condition	storage tissues: fat, muscle
Reproduction	gonads

Individual fish gain and lose these in response to activities and environment

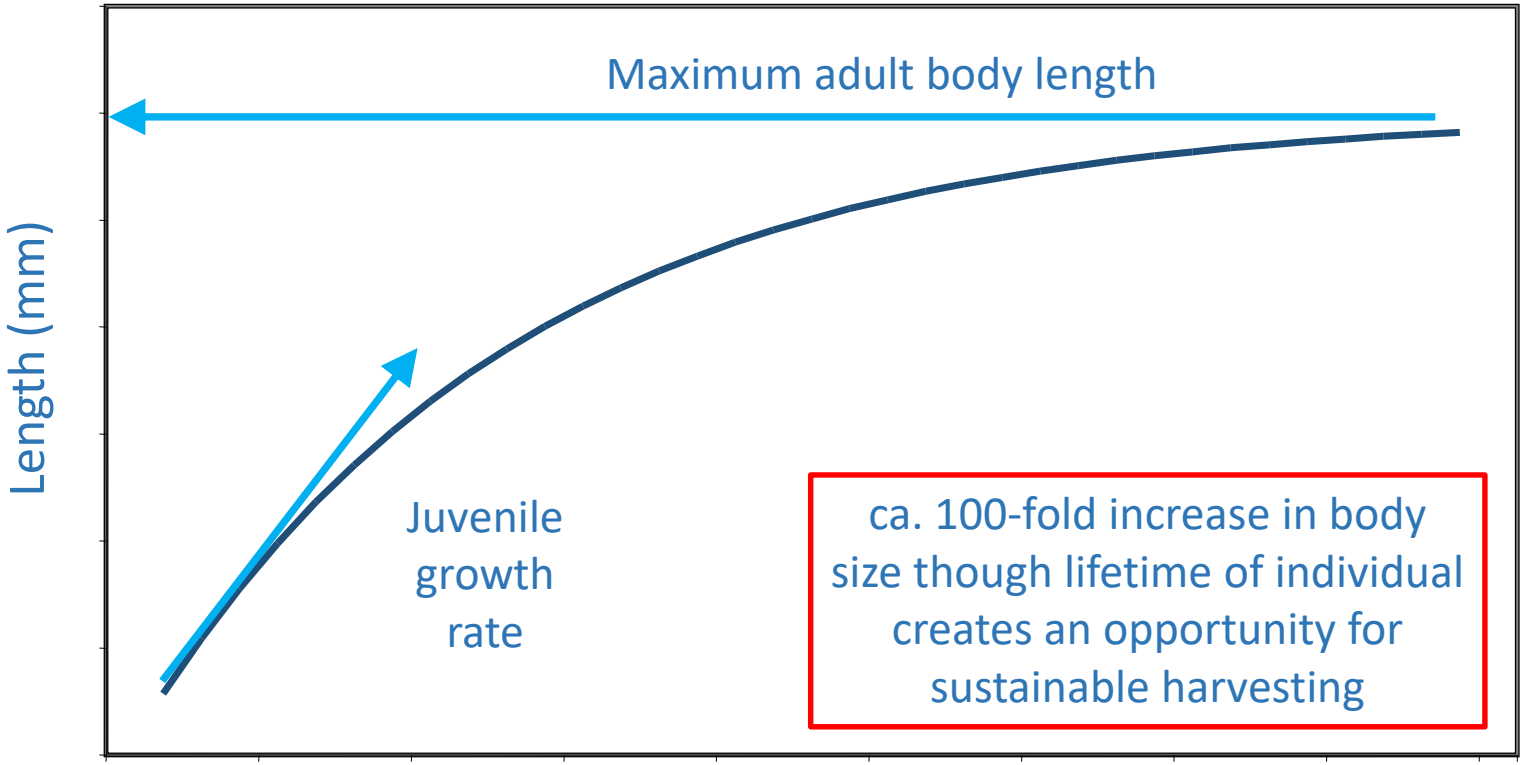


Factors impacting individual growth rates

- genetics
- environment
  - food quality & quantity
  - temperature
- behaviour and biology
  - differences between ♂ and ♀
  - activity pattern
  - hierarchical behaviour
  - competition



Individual growth rates



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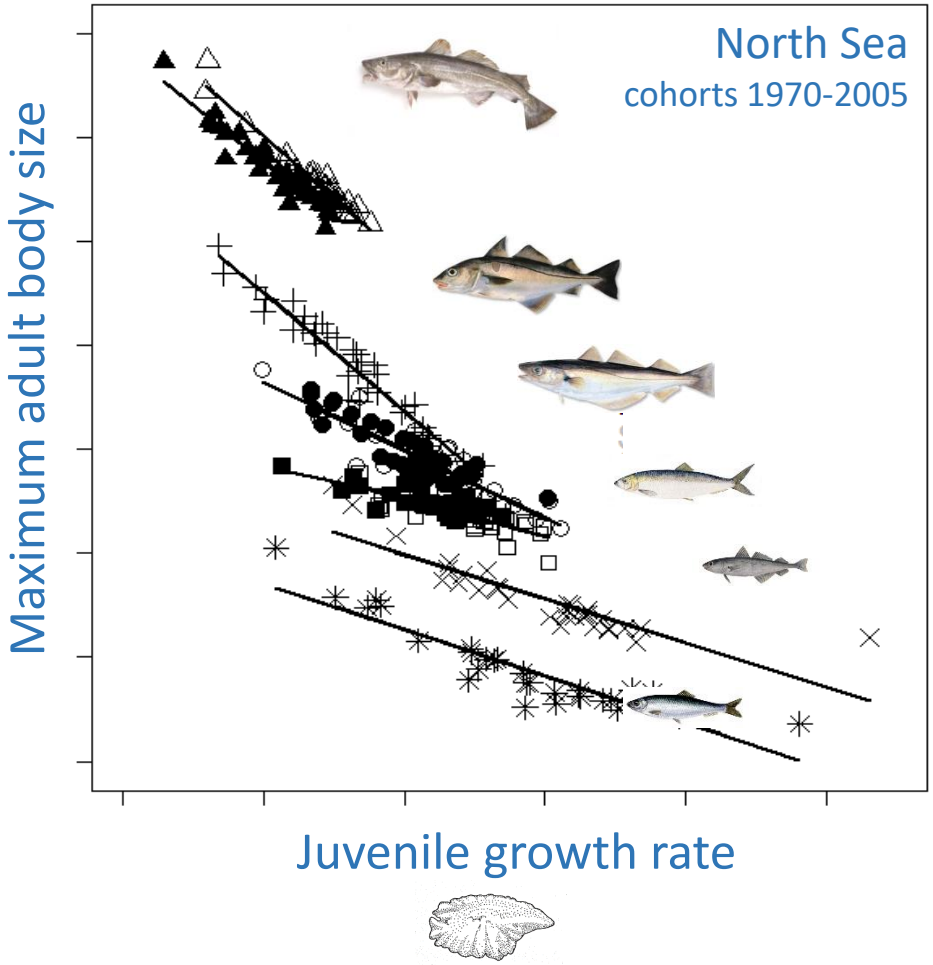
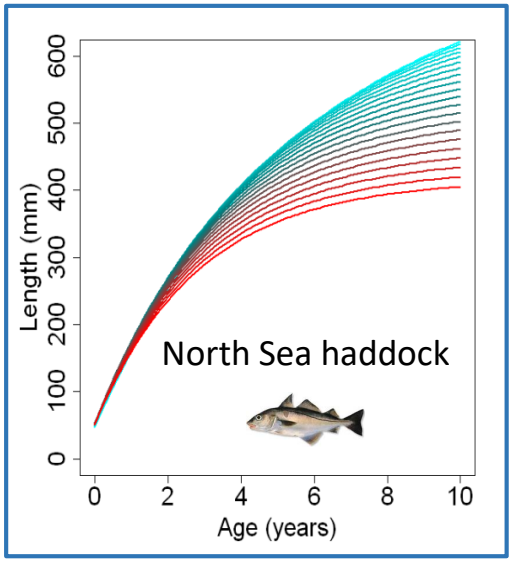
Warming temperatures in the North Sea impact growth rates



cohorts that are faster growing as juveniles have smaller adult body sizes



25% decrease in *per capita* yield has <u>already</u> occurred

For fish the secret of growing big is growing ***slowly*** at colder temperatures

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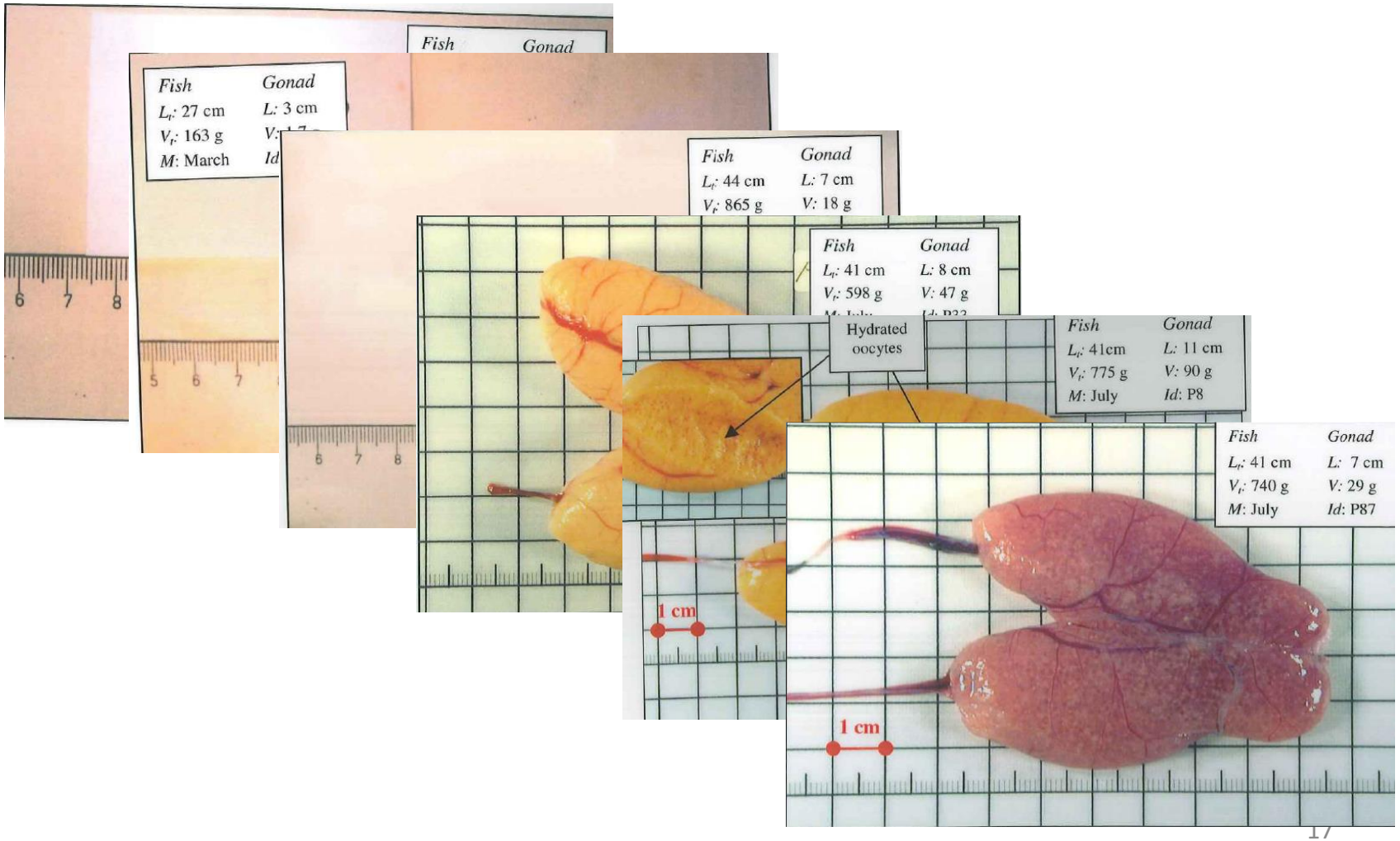
Vital Rate 2: Maturation rate



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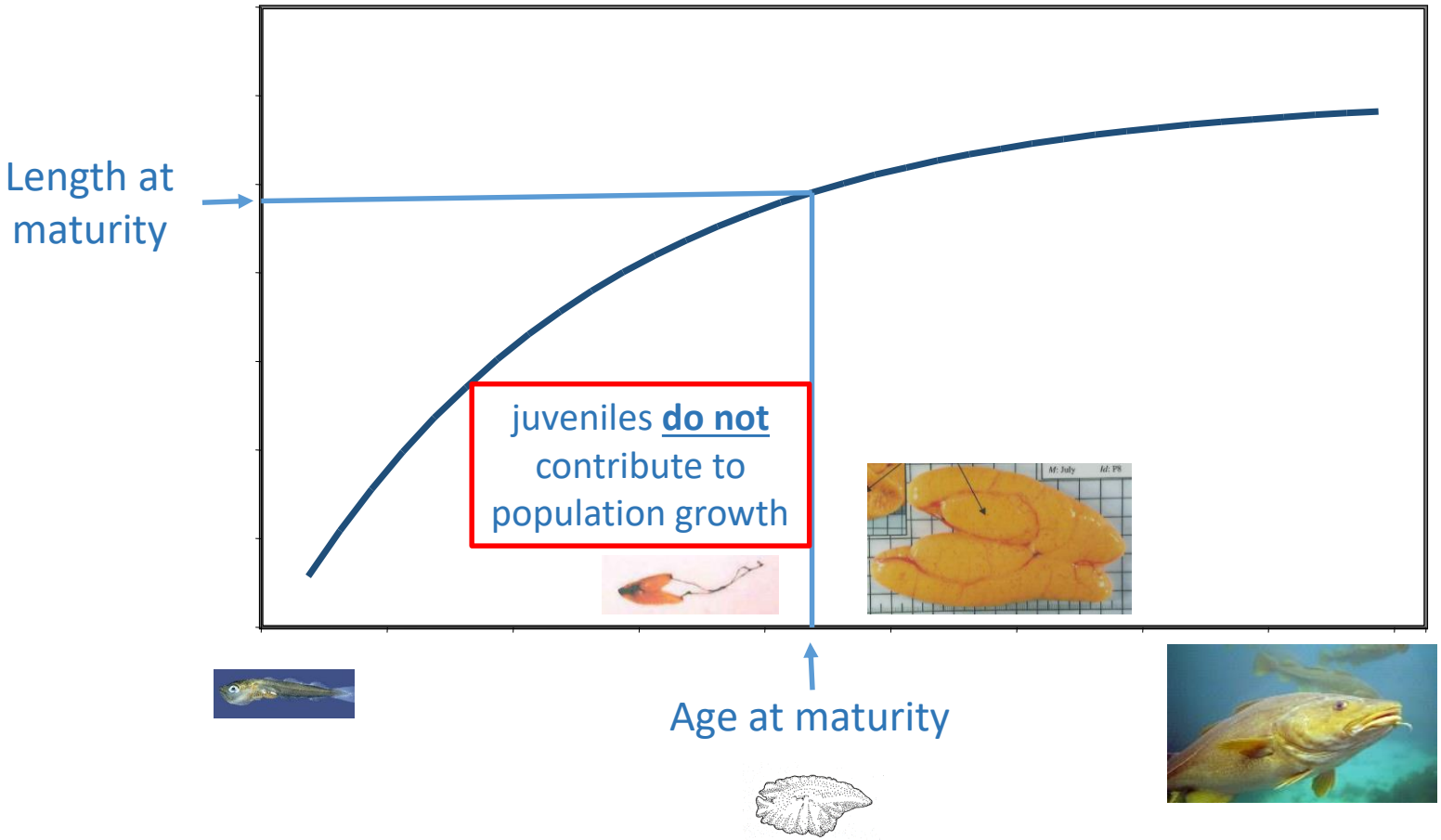
Maturation rate is how quickly the individual moves from juvenile to adult stage



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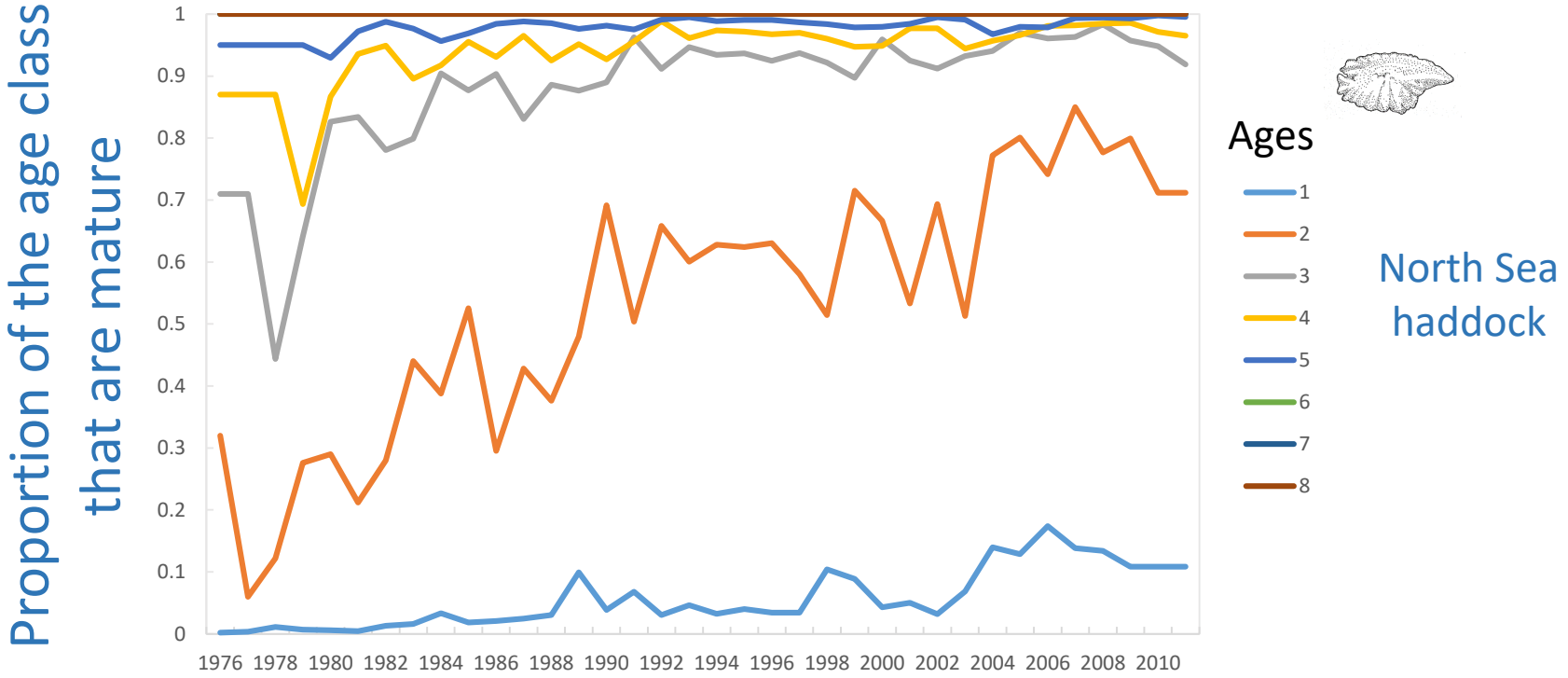
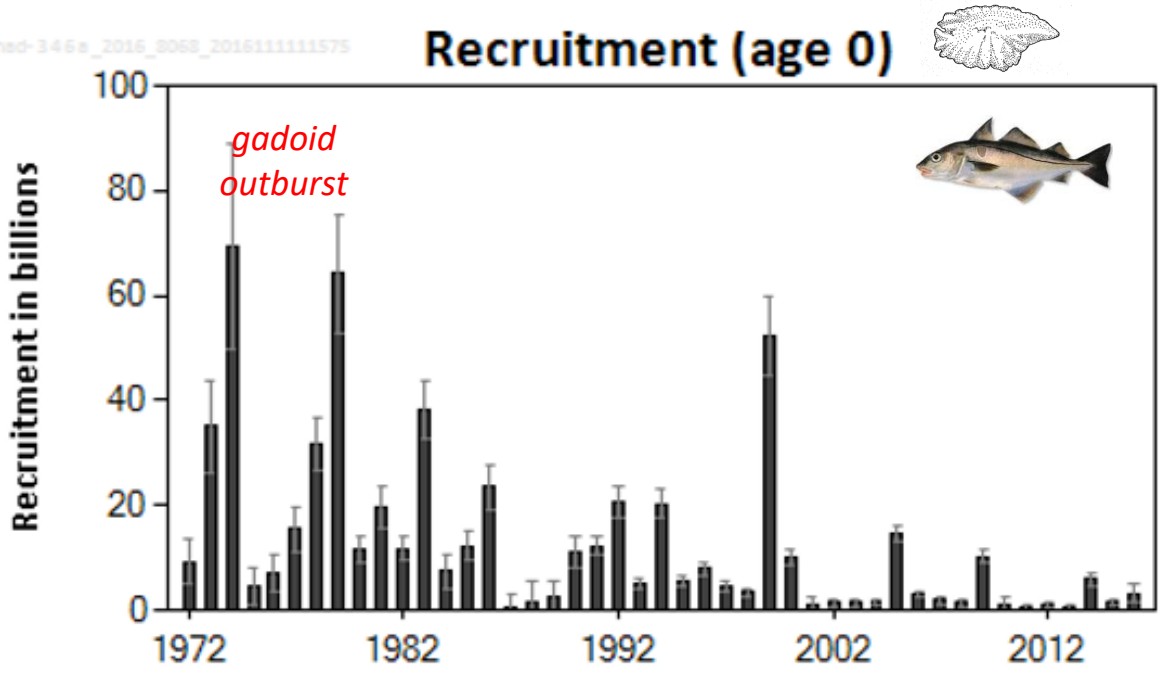
Many fish stocks are maturing at younger ages & smaller sizes (*faster* maturation rate)



Data courtesy P. Wright MSS

Vital Rate 3: Recruitment rate



"Recruitment since 2000 has been characterized by a low average level with occasional larger year classes."

Data for North Sea haddock from ICES WGNSSK 2016

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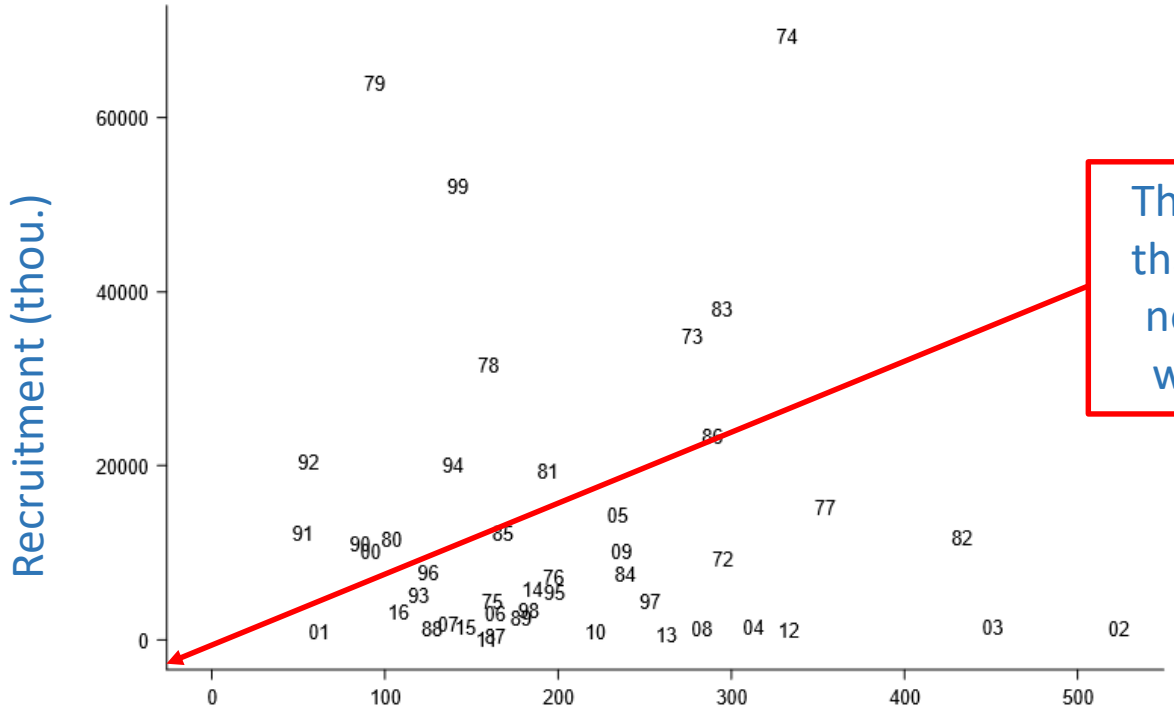
Stock recruit relationship

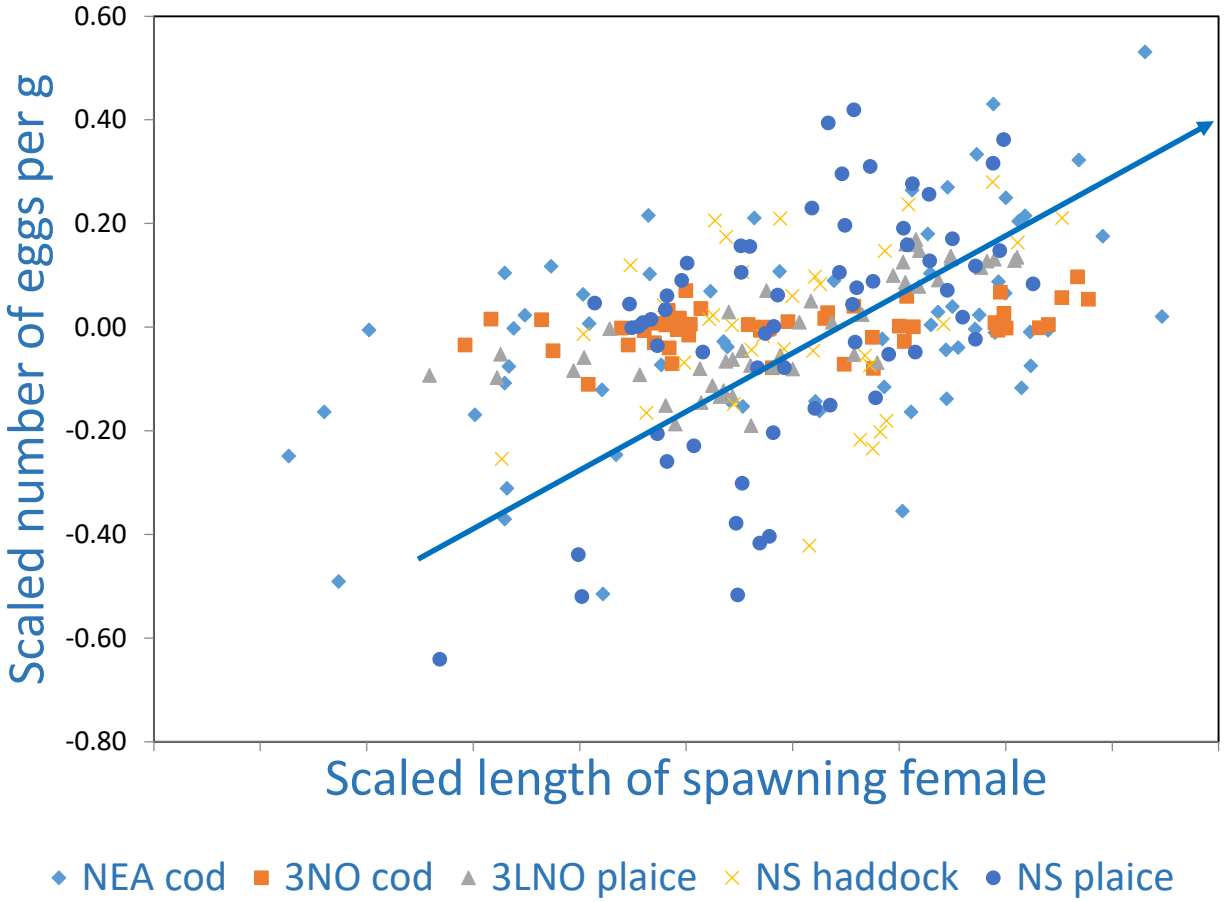


The *only* certainty is that when there are no spawners there will be no recruits

Data for N. Sea haddock from ICES WGNSSK

The lack of a clear relationship between spawning stock biomass and recruitment is the **rock** against which *SS Fisheries Science* founders

Bigger females produce proportionally more eggs



per gram body weight large females produce about **2X** the number of eggs that the small females do

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Protecting BOFFFs

- produce more eggs per g body weight
- produce more batches of eggs over a longer period of time ("*bet hedging*")
- produce eggs that are better quality

Sustainable fishing should ensure that BOFFFs are well represented in the population

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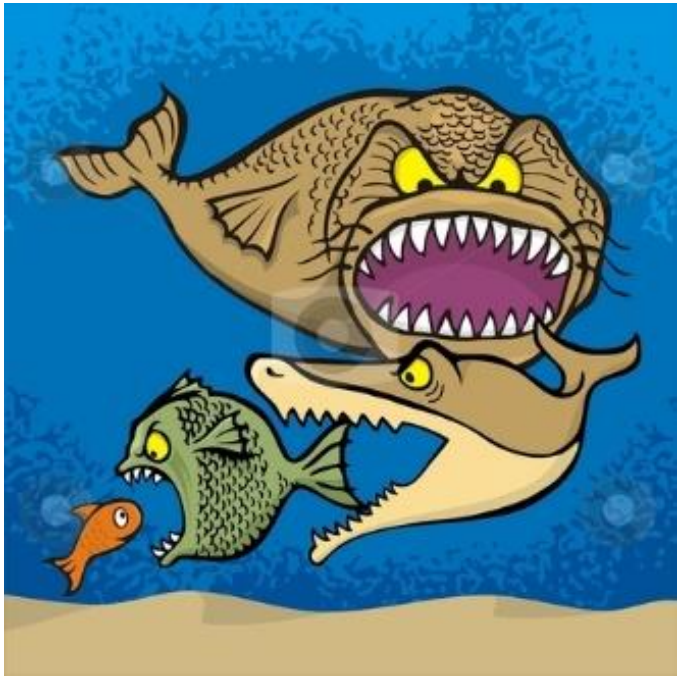
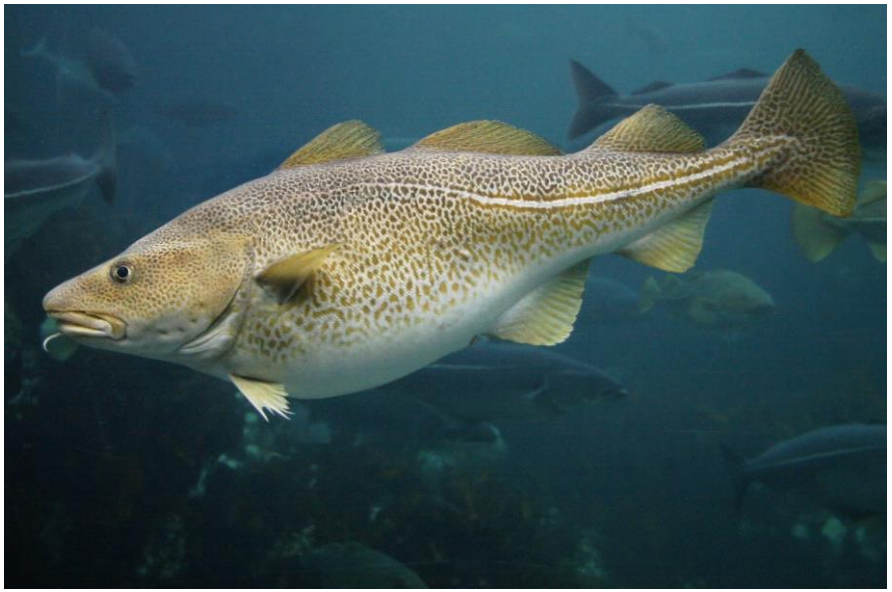
Vital Rate 4: Natural mortality rate



many causes of natural mortality (predation, starvation, disease, cannibalism)

difficult to estimate natural mortality rates for stocks that are being fished

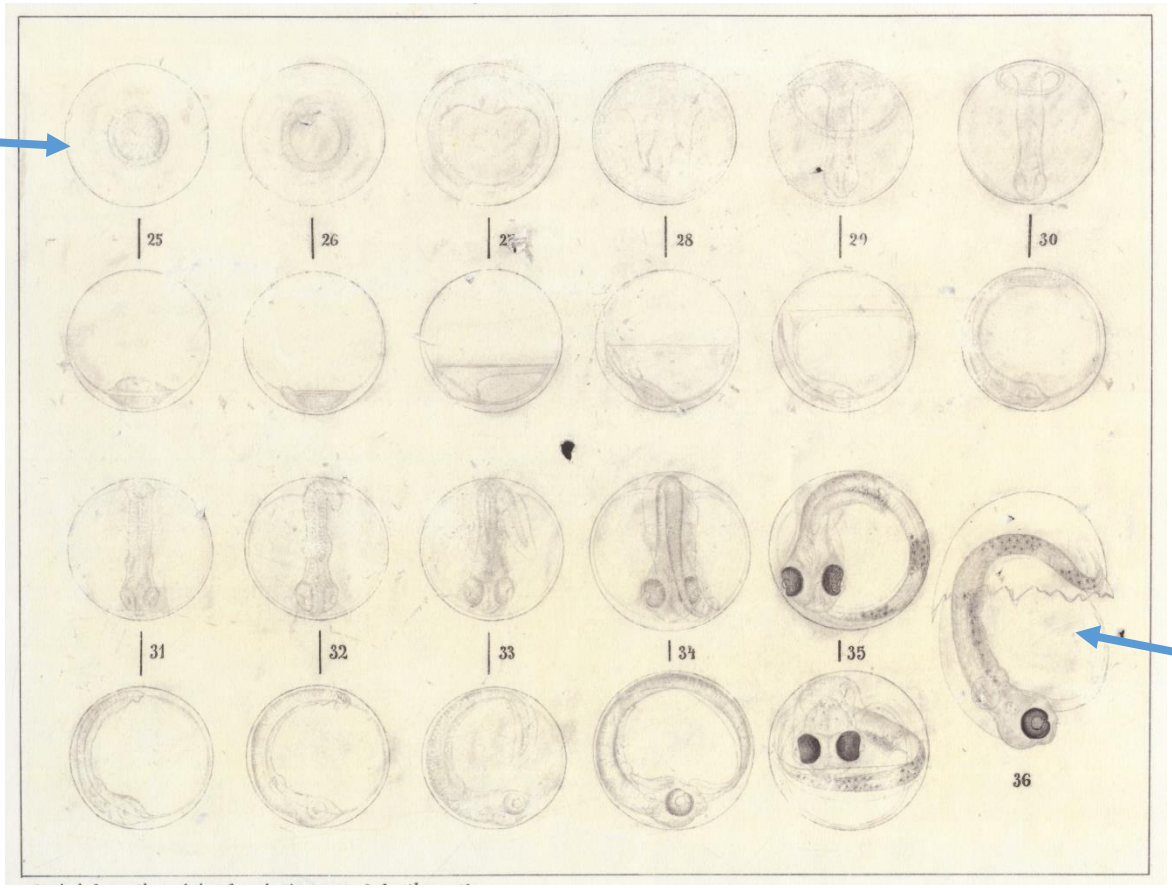
The odds on cod



Life cycle of cod – the first weeks

day-old egg

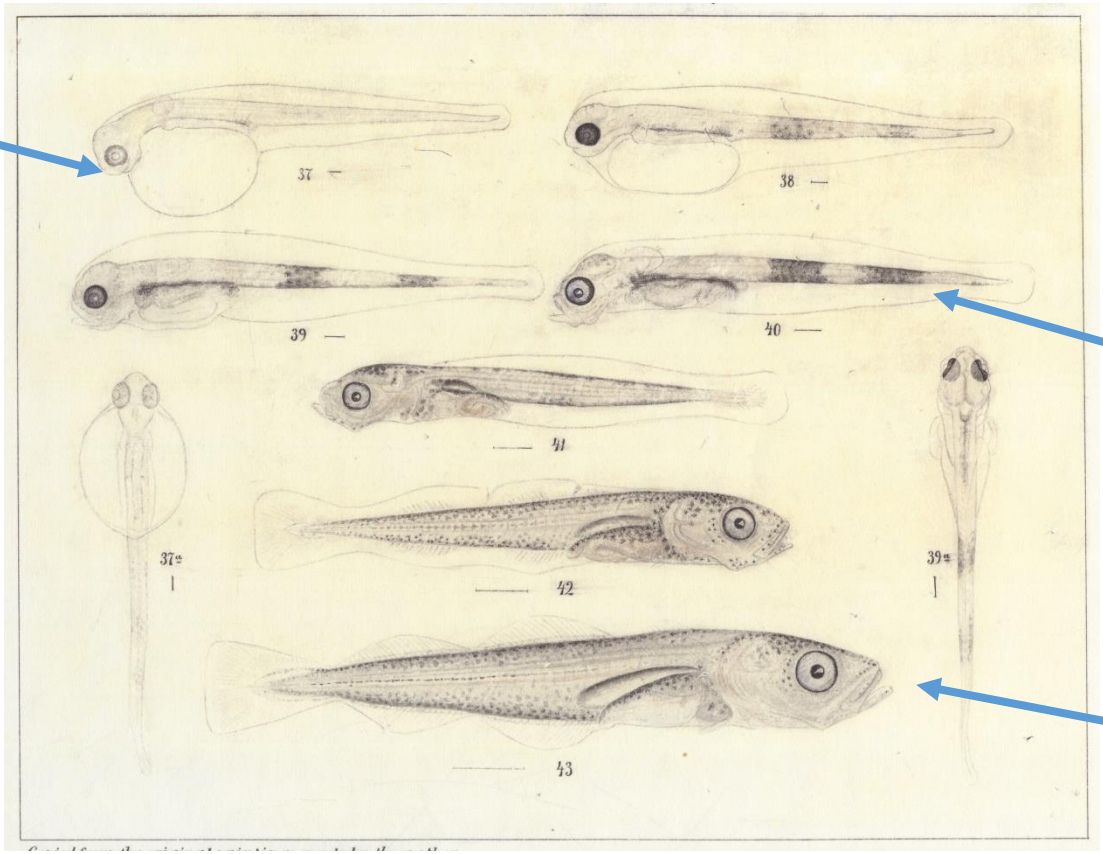
G. O. Sars
father of ichthyoplankton
1837 - 1927



hatched larva

Life cycle of cod – the first year

yolk sac larva

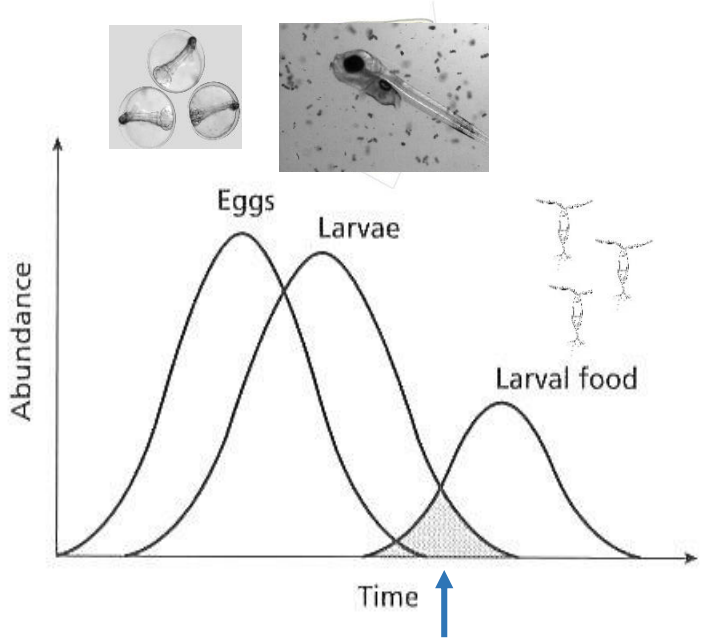


Critical stage

first-feeding larvae

juvenile

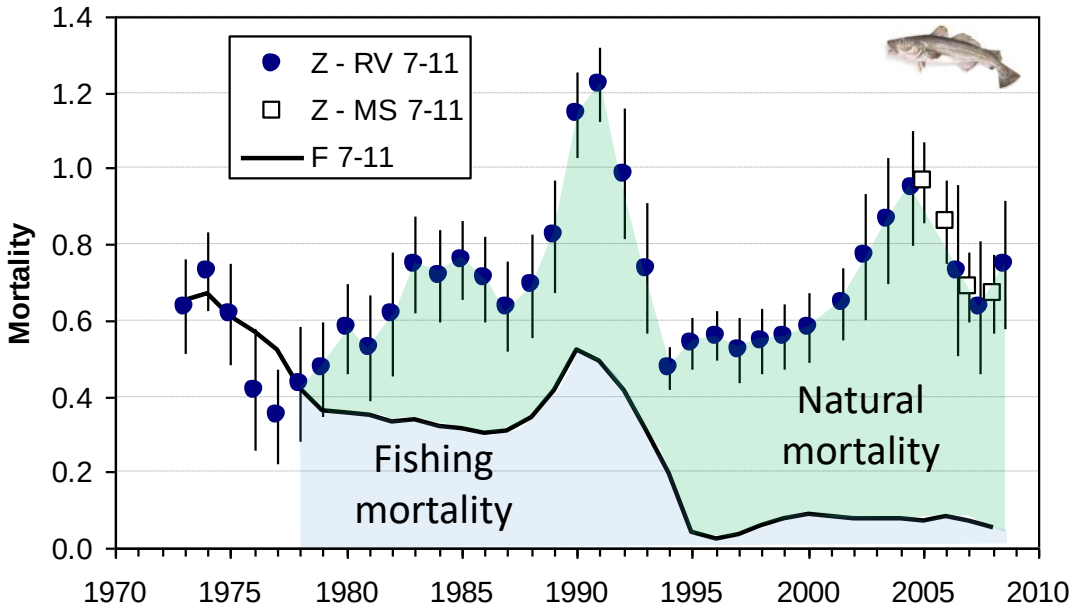
Larval survival depends on feeding success



Shaded area shows overlap in time ("*match*") between first-feeding larvae and their food during the "*critical period*"

Closed fisheries give scientists a unique opportunity to estimate natural mortality (*Why?*)

S. Gulf of St. Lawrence



Are seals on the East coast the reason?

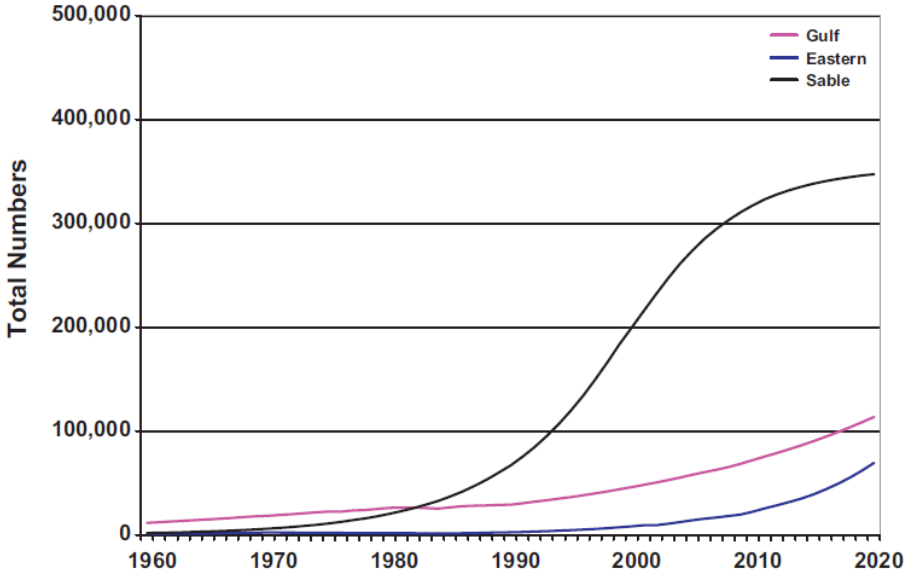


Fig. 4. Gulf, Eastern Shore and Sable grey seal herd total numbers during 1960–2020 as estimated and predicted using the population models.

Population size of seals on the East coast of Canada

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Vital Rate 5: Fishing mortality rate

STAY TUNED:

Stock Assessment & Modelling

Tomorrow!

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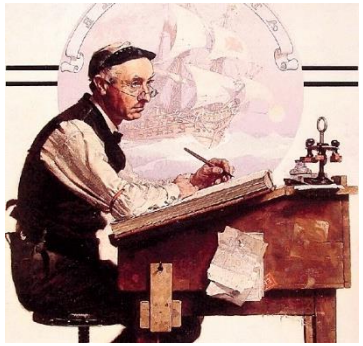
Simple rule for sustainable fisheries: ensure that fishing mortality is ***less than*** the natural mortality



Age	Natural Mortality
0	1.024
1	1.188
2	0.581
3	0.357
4	0.340
5	0.337
6	0.252
7	0.219
8	0.201
9	0.200
10	0.201
11	0.219
12	0.219
13	0.219
14	0.219
15+	0.219

Biological Reference Point for fishing at MSY

$F_{MSY} = 0.19$

2016 ICES assessment for North Sea haddock

How do these five “vital” rates enter ICES stock assessment?

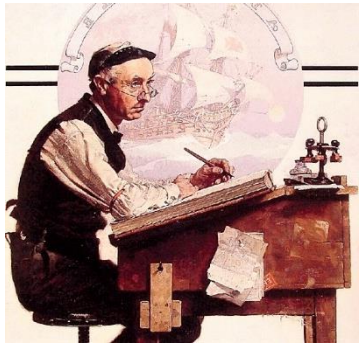
2015					
Age	Numbers	Individual Weight	Proportion Mature	Natural Mortality	Fishing Mortality
0	1488346	0.031	0	1.024	0.004
1	2108931	0.145	0	1.188	0.040
2	78915	0.417	0	0.581	0.412
3	60264	0.561	1	0.357	0.453
4	8929	0.752	1	0.340	0.355
5	16608	0.698	1	0.337	0.503
6	78677	0.631	1	0.252	0.367
7	6862	0.685	1	0.219	0.166

Recruitment rate

Natural and Fishing Mortality rates

Growth rate

Maturation rate



How does stock assessment represent the biology of population growth in 2015?

2015					
Age	Numbers	Individual Weight	Proportion Mature	Natural Mortality	Fishing Mortality
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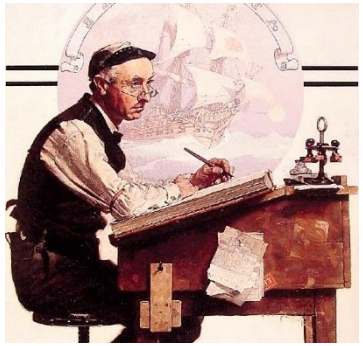
Average Fish Mortality for ages 2-4

proxy for death rate in 2015



Spawning Stock Biomass

proxy for birth rate in 2015

2016 ICES assessment for North Sea haddock

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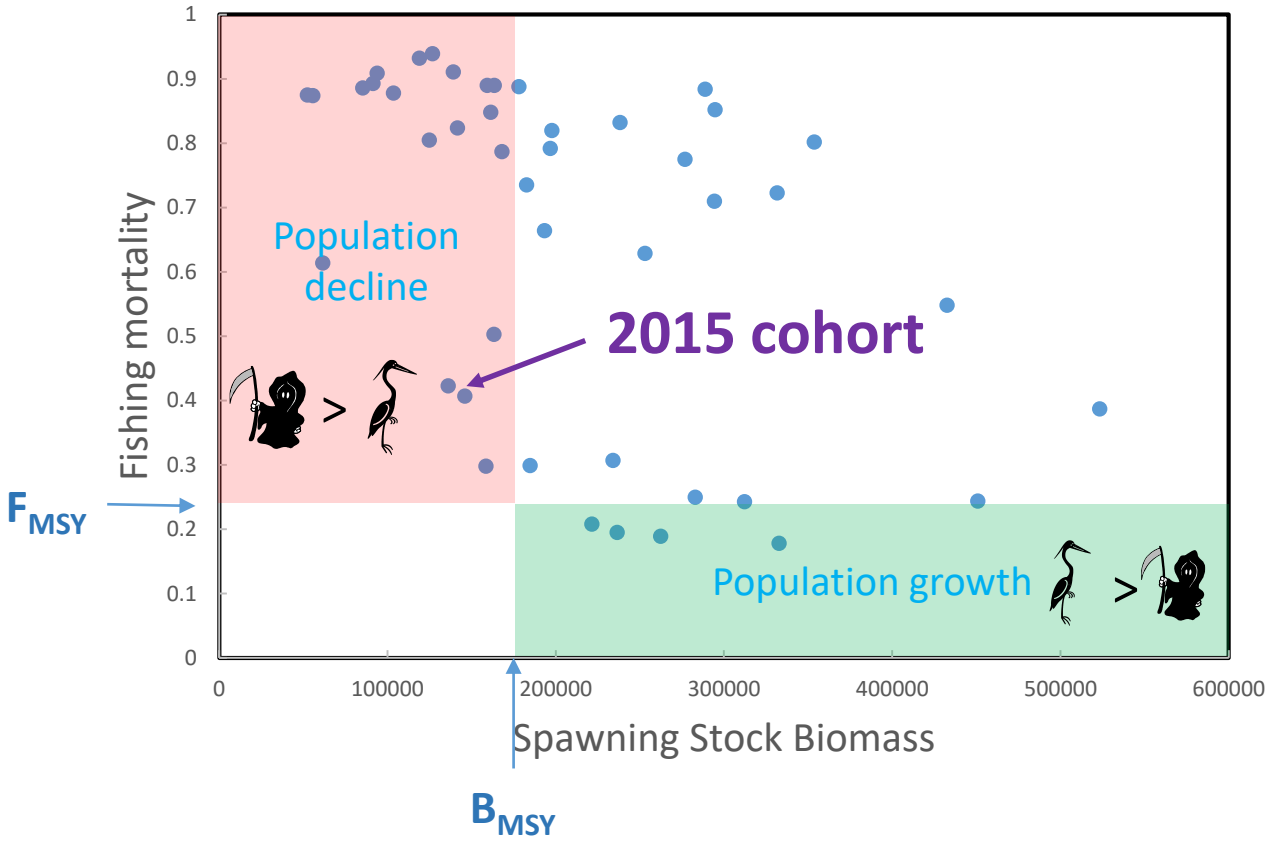


But nature is unpredictable …

Individual growth rate
Maturation rate
Recruitment rate
Natural mortality rate

because these 4 vital rates are inherently variable

Fishing mortality rate

this rate must be variable

When fish stocks are depleted the impact of predation can be severe

Natural mortality rate

Keep fishing mortality rates low and less than natural mortality rates

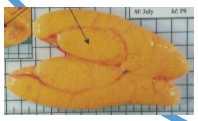
No spawners means no recruits

Recruitment rate

Biomass

Fishing mortality rate

Individual growth rate



Only mature individuals contribute to population growth
Bigger females (BOFFFS) produce proportionally more eggs

Fish body size increases by 100-fold over their life cycle
Warming temperatures mean fast juvenile growth but smaller adult size and lower *per capita* yields

sustainable fishing practices allow fish populations to achieve positive population growth under variable environmental and ecological conditions

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What do you think sustainability means *now*?

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Questions?