Patterns and drivers of resilience in over-fished populations

Philipp Neubauer

DRAGONFLY
Data Science

...background...

Research interest in the ecology of exploited marine populations and ecosystems

- PostDoc @ Rutgers Uni, NJ, US – Recovery of collapsed stocks
- Marsden FS – Resilience of fished ecosystems to climate change

Fisheries ecologist/data analyst @ Dragonfly

- Sustainable fisheries in NZ: Abalone, Cockle, Pipi, fisheries impacts on marine mammals

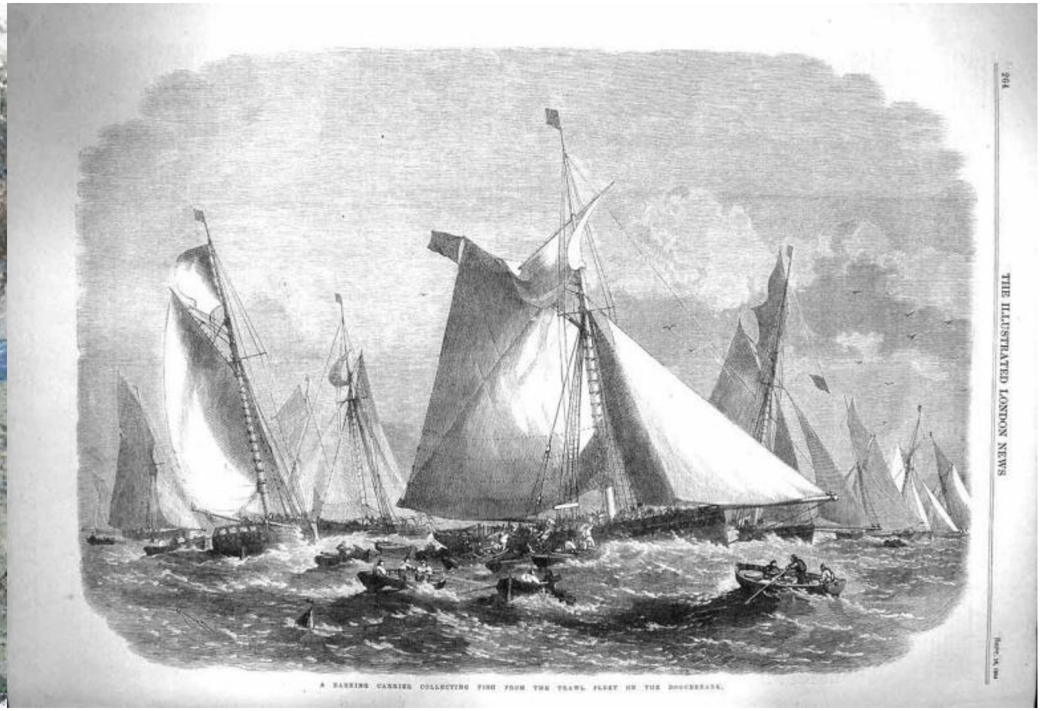
Bayesian methods in ecology and fisheries

- Estimating predator diet composition composition (PeerJ – April 23rd, , Github for R package)
- Inferring dispersal of marine organisms from geochemical markers using Dirichlet Process & Hidden Markov models (MEPS 2010, MiEE 2013 & forthcoming)

1. Introduction to fisheries
2. Global trends in fisheries
3. Recovering over-fished stocks
4. Patterns and drivers of resilience
5. (Some) Limits of resilience
6. Resilient fisheries

(A short and rather incomplete) Introduction to fisheries

THINK ABOUT FISHING

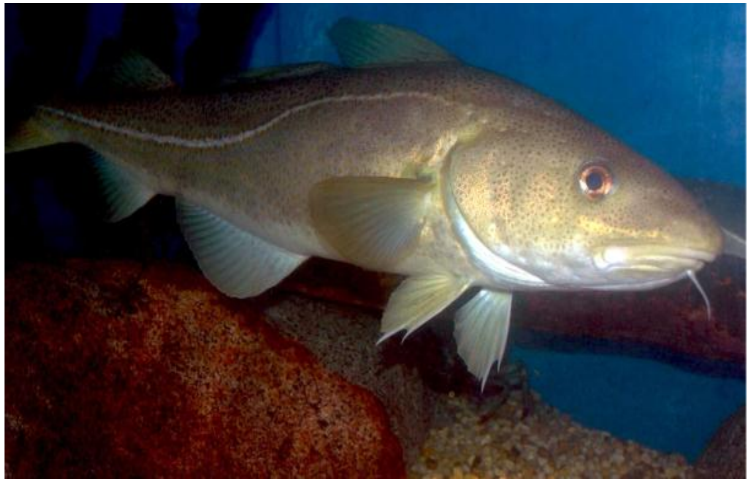


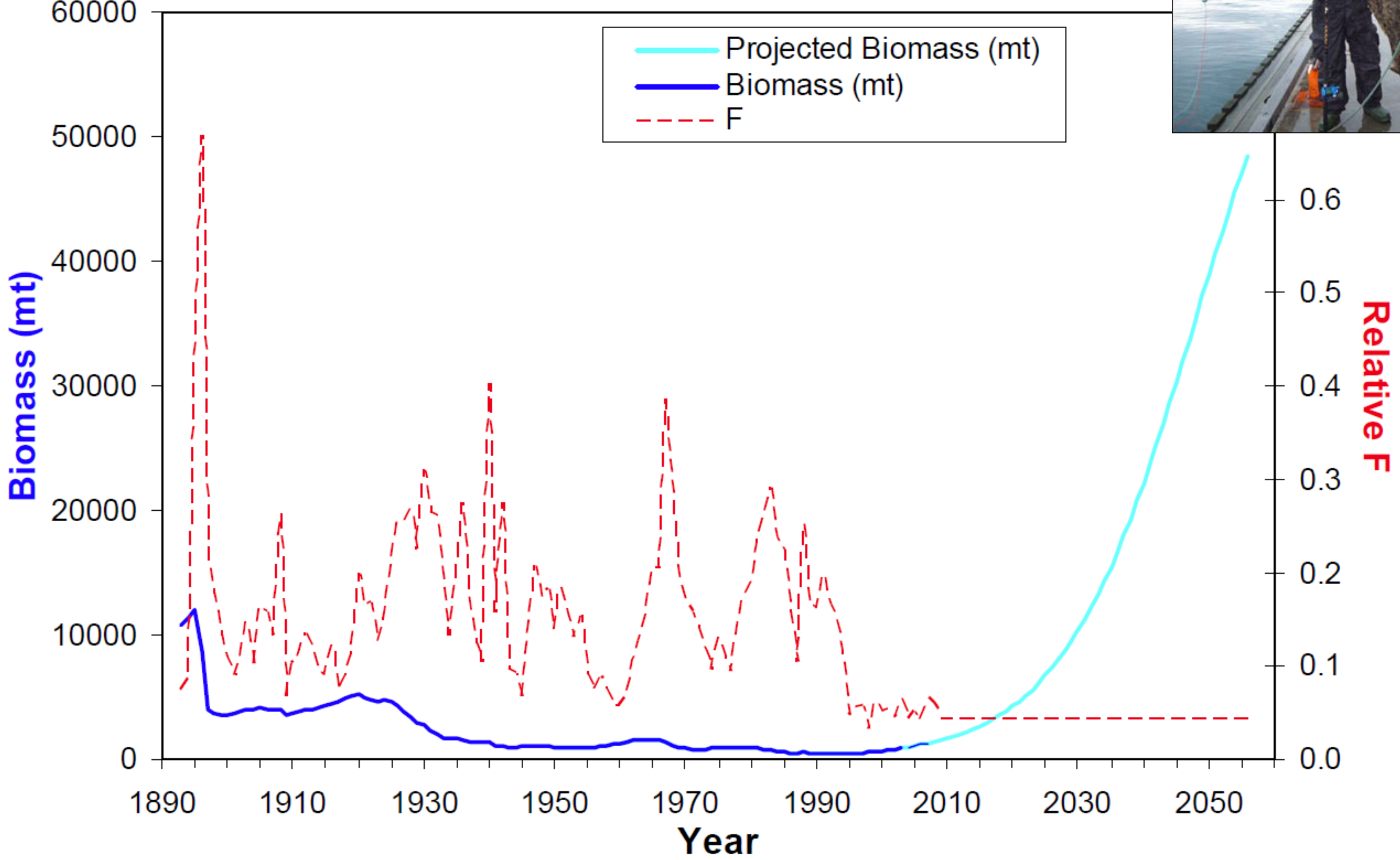
Some places were intensely fished by the early 1800s

- the North Sea
- Mediterranean
- New England

By the late 19th/early 20th century, some stocks were already heavily exploited:

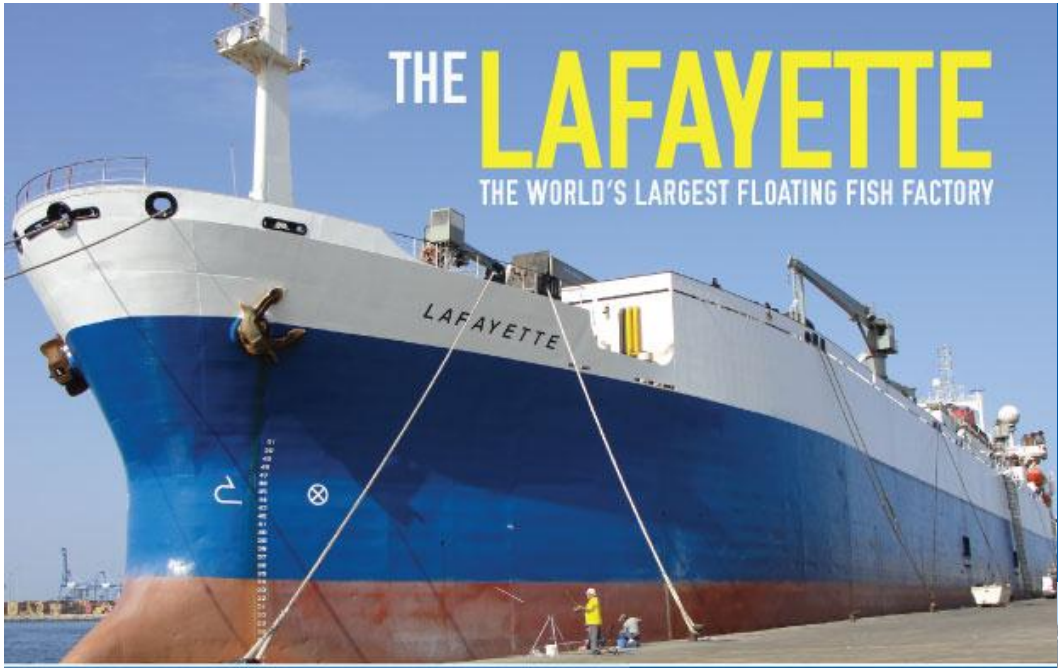
- North Sea herring
- Atlantic Halibut & Cod




Projected Biomass (mt)
Biomass (mt)
F
Biomass (mt)
Relative F
Year
60000
50000
40000
30000
20000
10000
0
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1890
1910
1930
1950
1970
1990
2010
2030
2050

THE LAFAYETTE

THE WORLD'S LARGEST FLOATING FISH FACTORY



FREEZES

1,500

METRIC TONS PER DAY

COST

$100

MILLION

For its remodeling in 2008

STORES

14,000

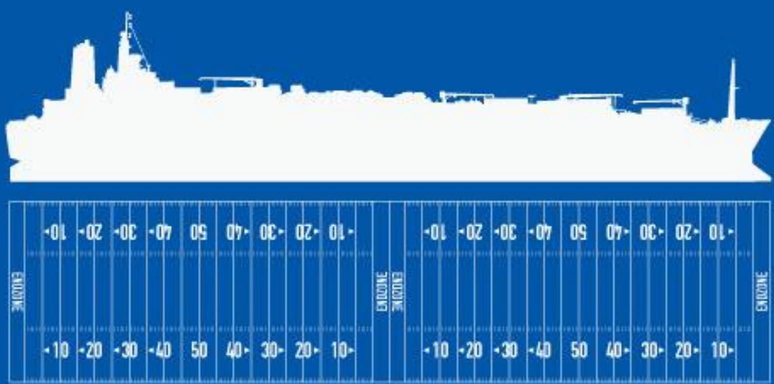
METRIC TONS OF FISH

Enough to fill 32.9 million 15oz cans

228 METERS LONG

(Longer than two Football fields)

32 METERS WIDE



THE LAFAYETTE'S COMPANIONS

The Lafayette uses a giant hose to suck up fish from attending trawlers. These vessels worked alongside the Lafayette in the South Pacific in 2010.

PACIFIC VOYAGER

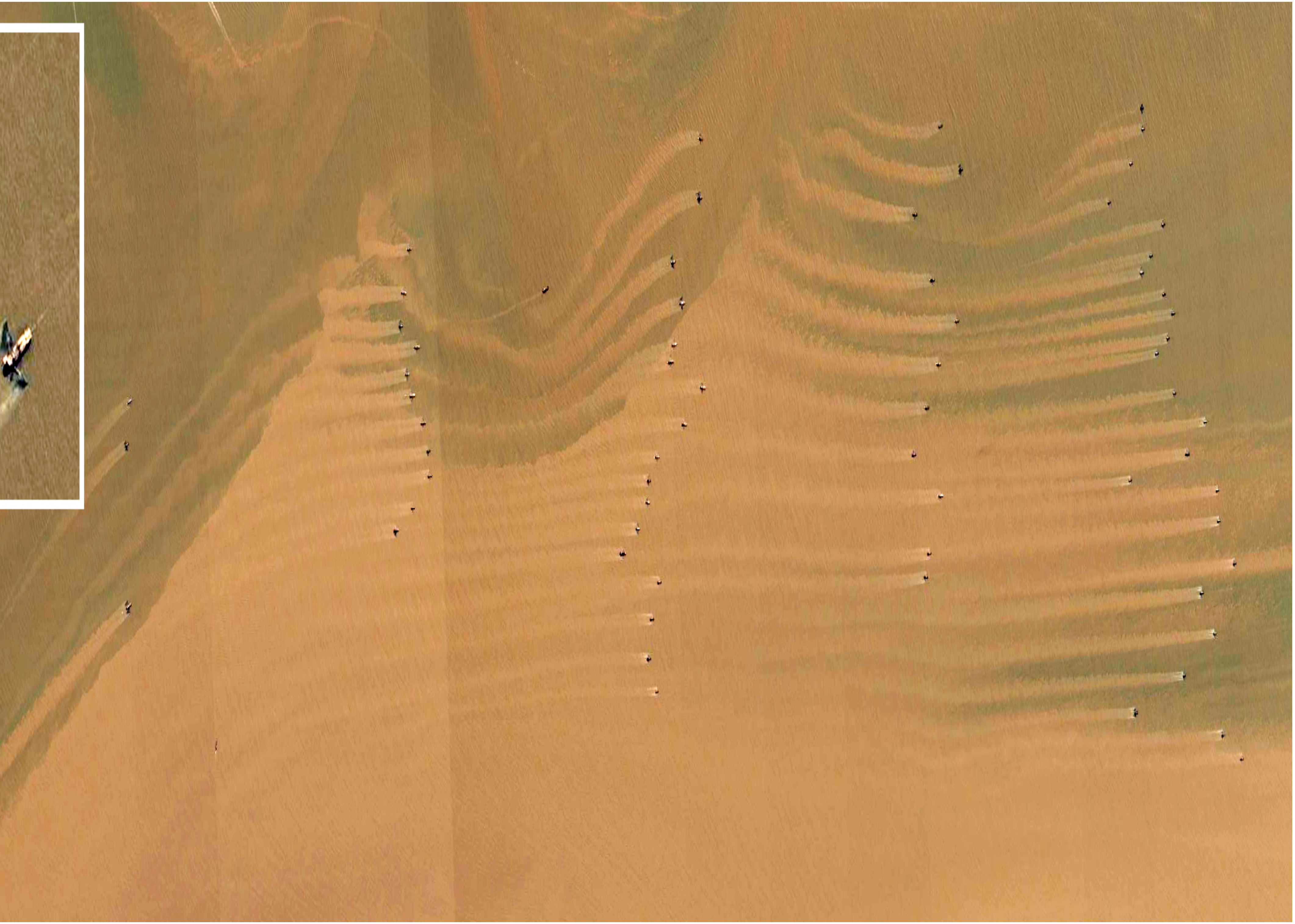
71 meters long

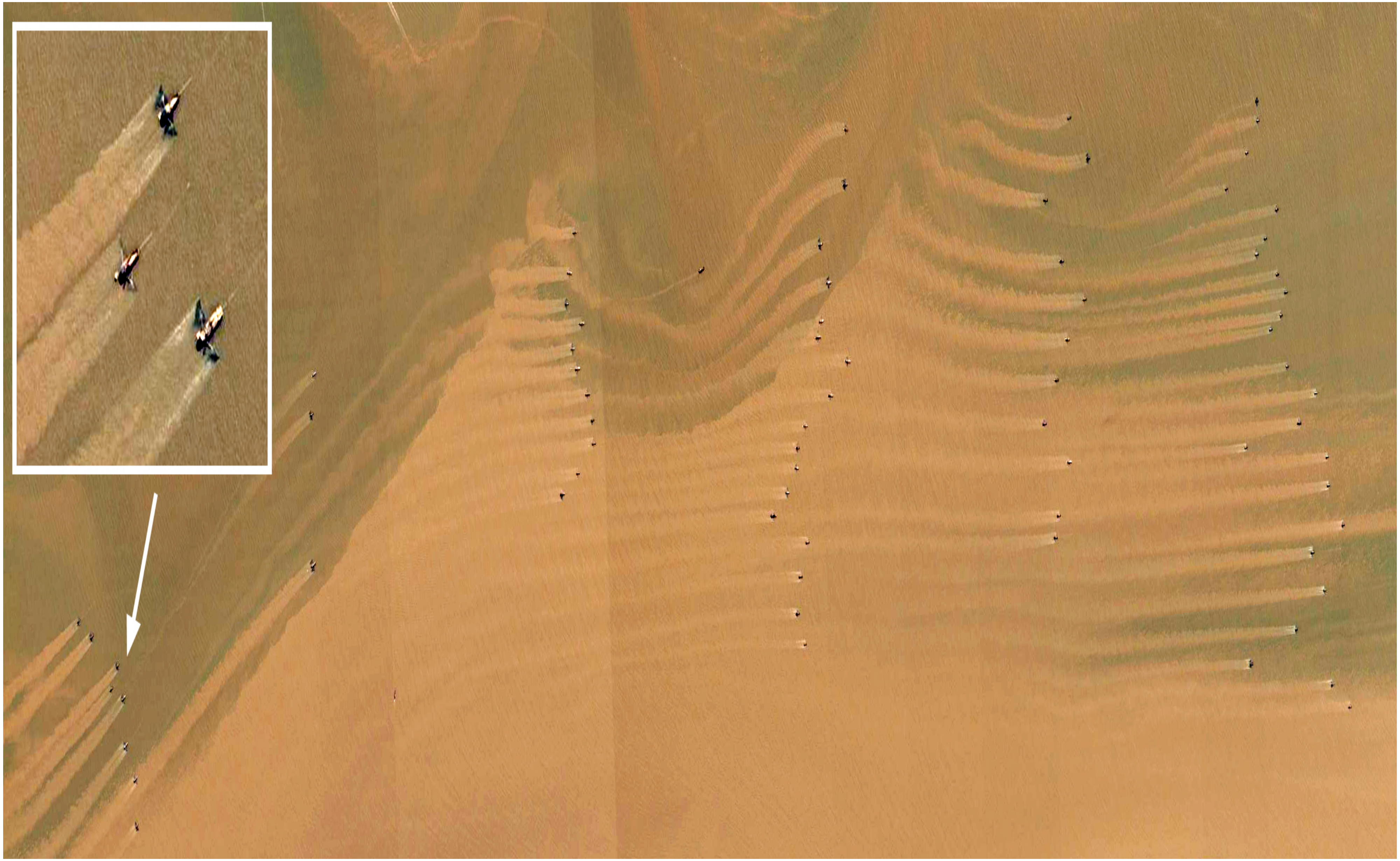
PACIFIC HUNTER

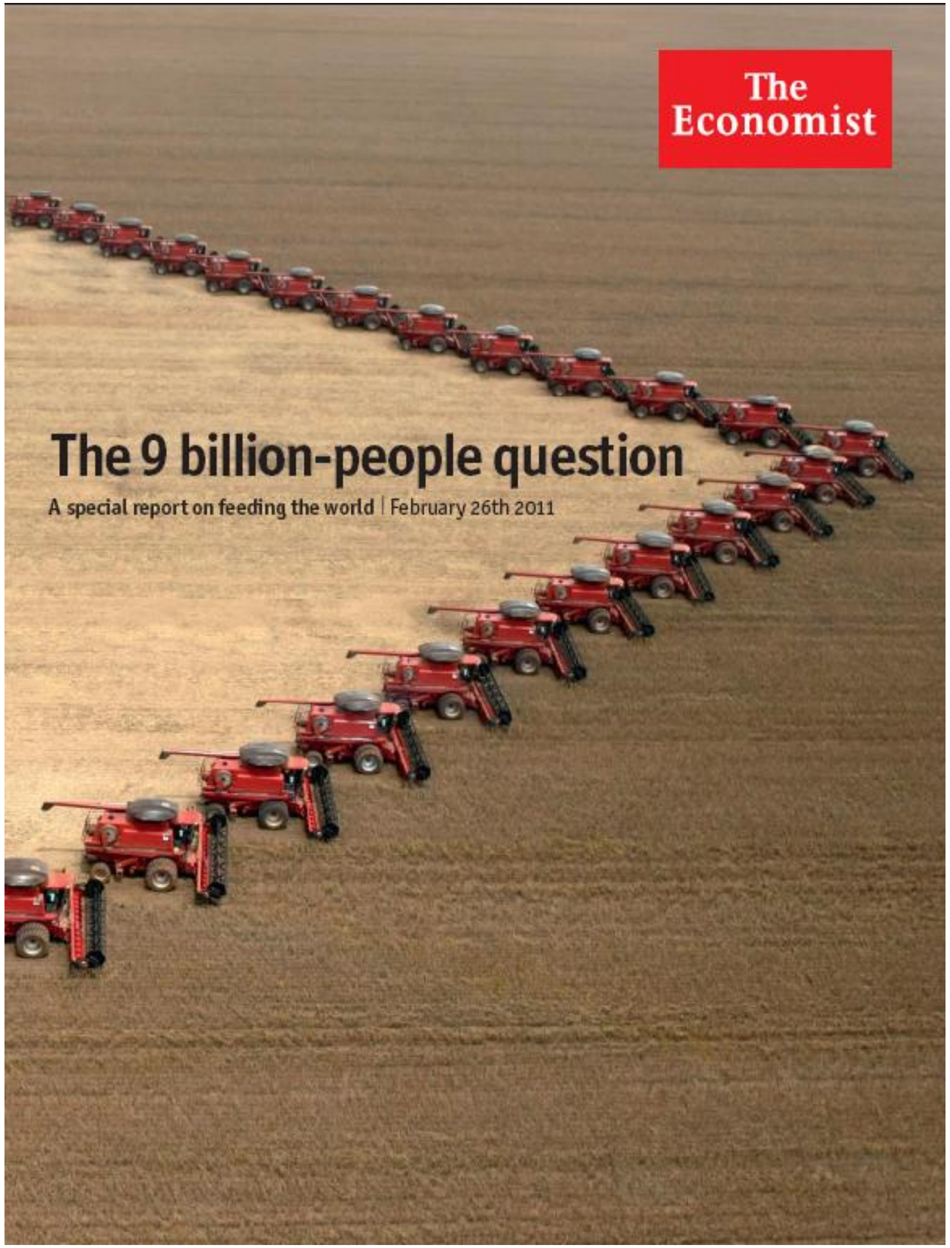
67 meters long

TWO YEARS AT SEA

Vessels that catch small pelagics like jack mackerel roam the oceans in search of fish. Here we follow the Lafayette as it traverses from the South Pacific to West Africa and Northern Europe in 2010 and 2011.






The Economist
The 9 billion-people question
A special report on feeding the world | February 26th 2011

Fisheries science

"...provide for the utilisation of fisheries resources while ensuring sustainability" NZ Fisheries act, 1996

Two aspects:

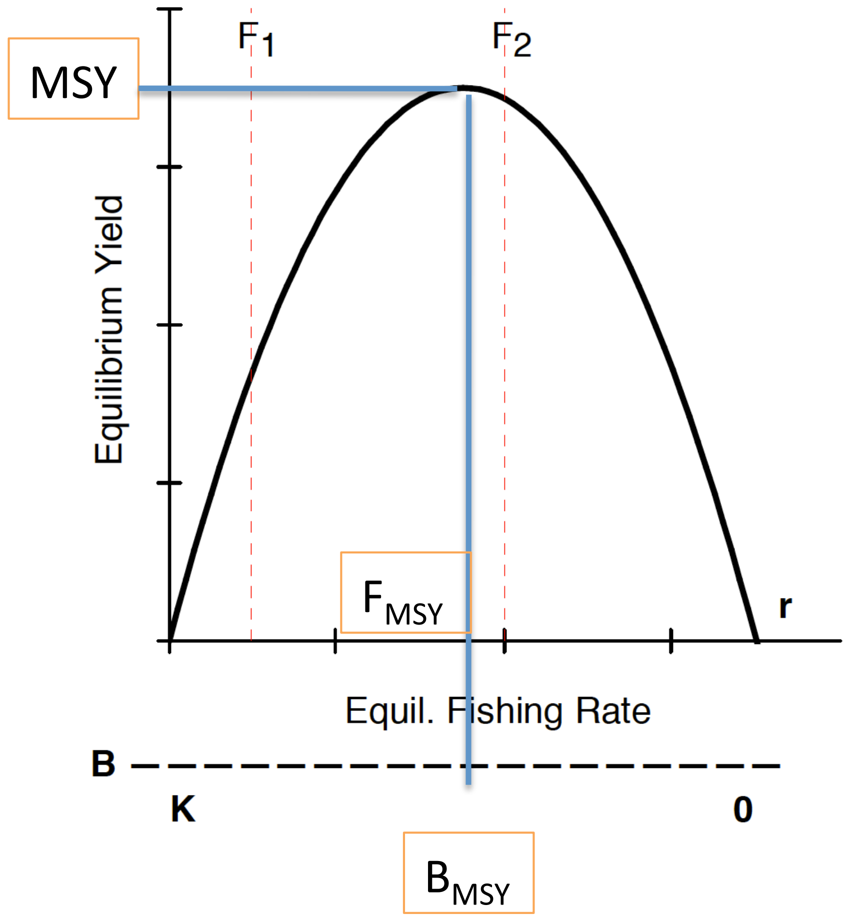
1. **Food Security**
2. **Sustainability**

Management strategies = stock assessment + harvest strategy attempt to address both

Fisheries 101

$$\frac{dB}{dt} = r \cdot B \cdot \left(1 - \frac{B}{K}\right) - F \cdot B$$

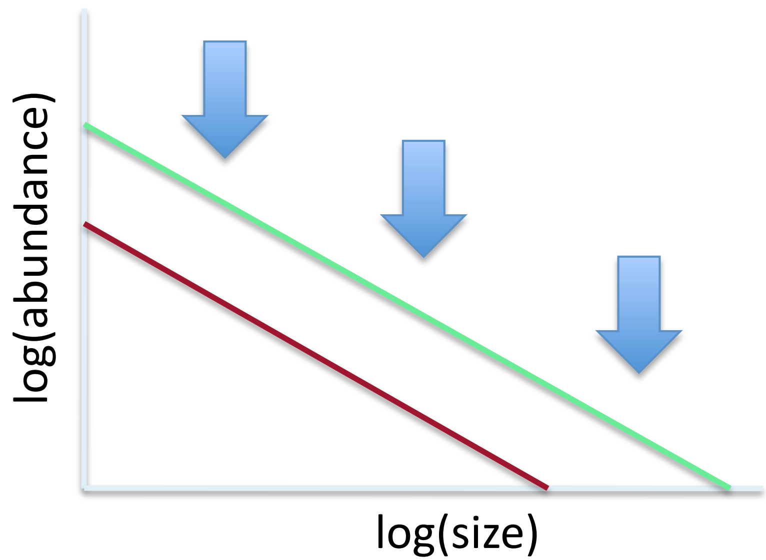
Natural Growth - *Harvest*



Impacts of fishing

Fishing reduces biomass: 40% of virgin biomass is a common target

Fishing alters the age/size structure of fished populations



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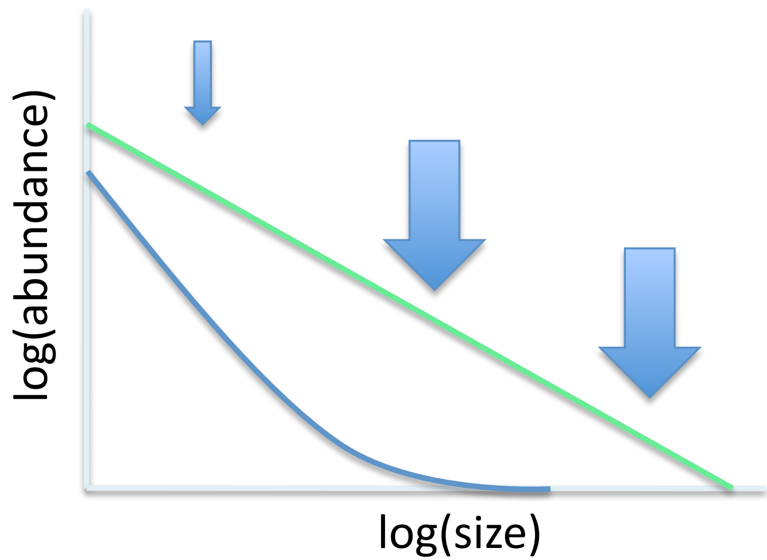


Impacts of fishing

Fishing reduces biomass: 40% of virgin biomass is a common target

Fishing alters the age structure of fished populations

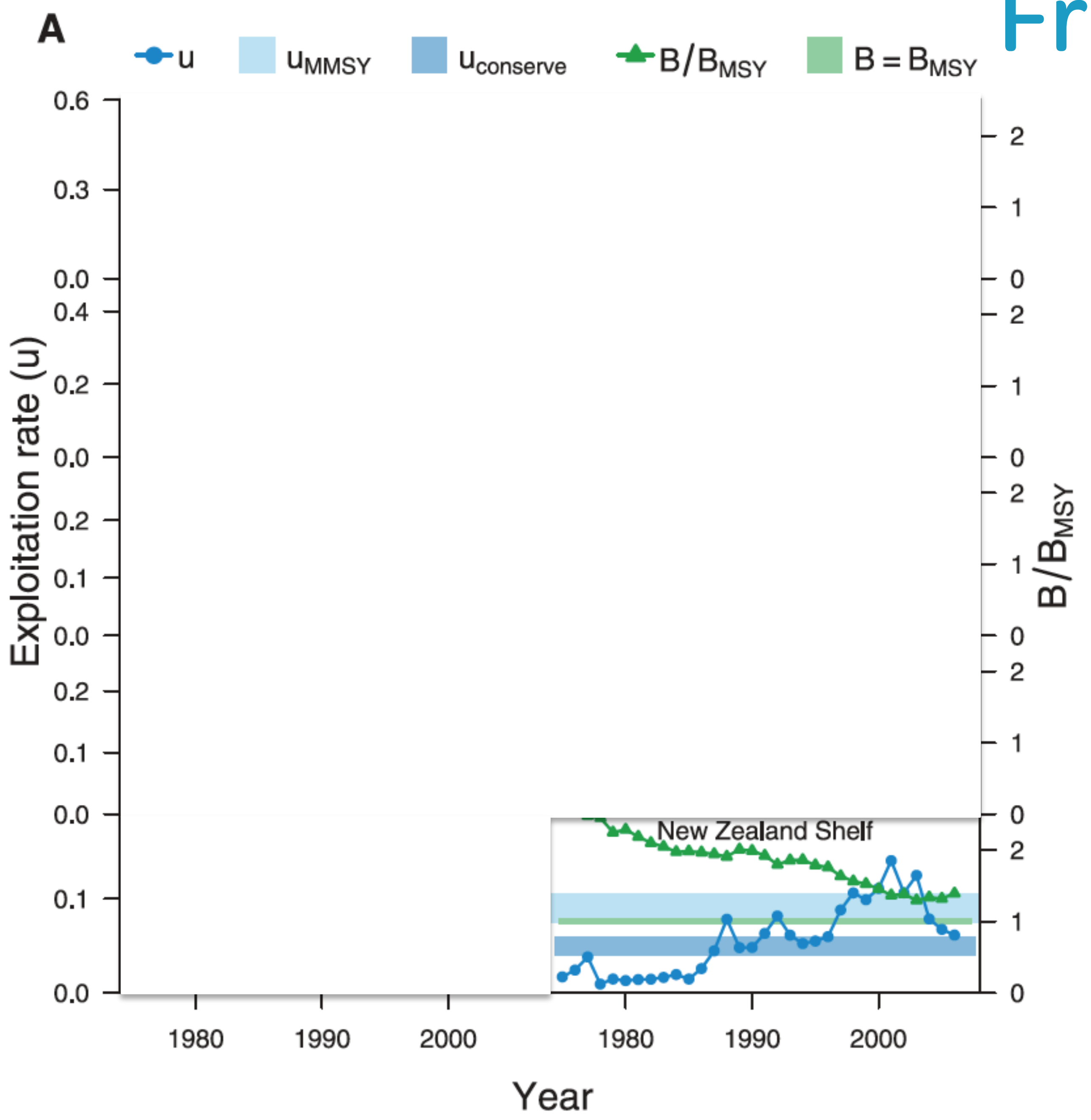
Fished populations are more variable than unfished ones[1-3]

Fishing exerts selective pressure & reduces genetic diversity – a Darwinian debt?[4,5]

[1] Hsieh et al 2006 – Nature, [2]Anderson et al 2008 – Nature, [3] Shelton & Mangel 2011 – PNAS, [4] Jorgensen et al. 2007 – Science, [5] Pinsky & Palumbi, in press – Molecular Evolution

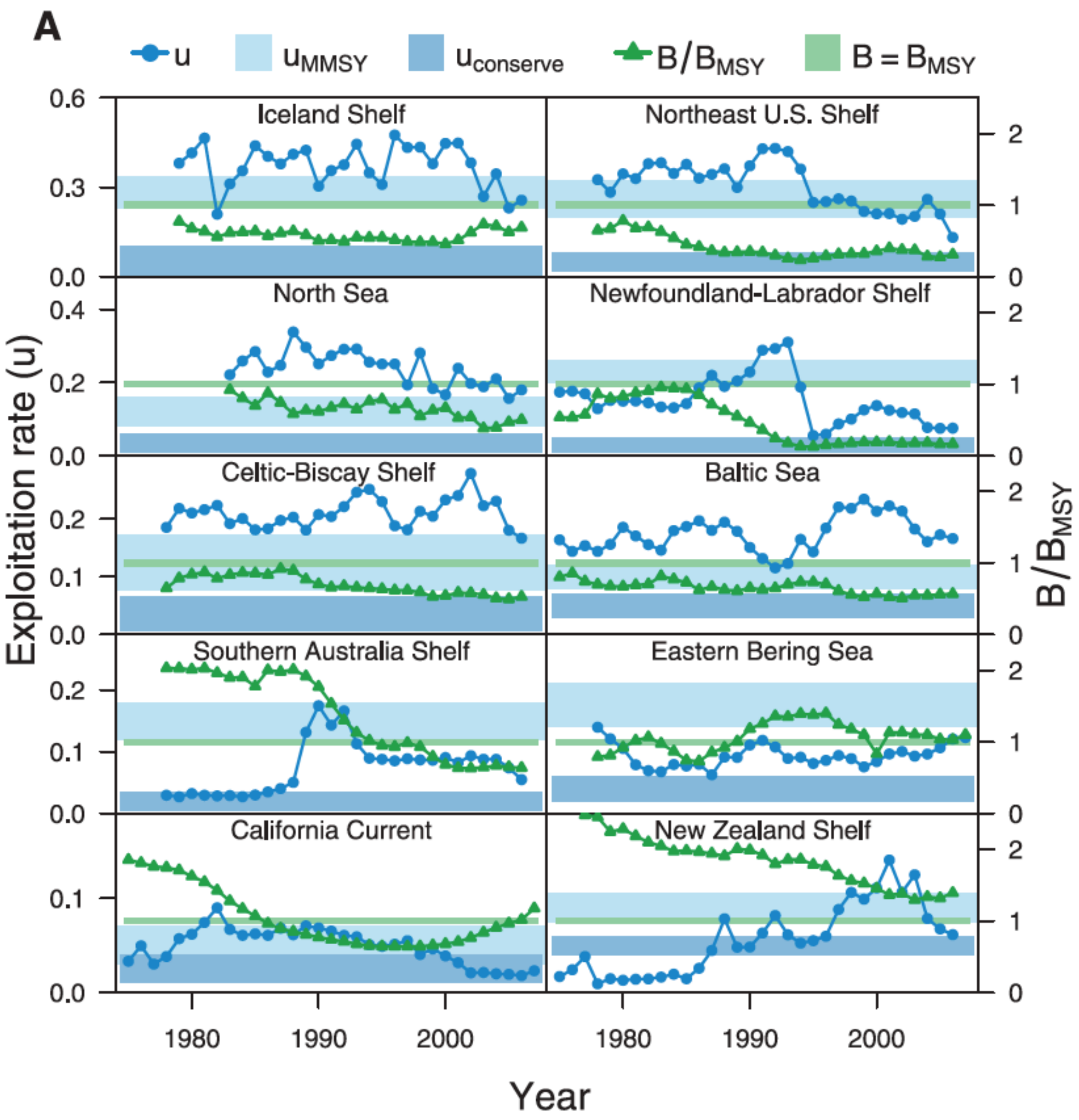
Global trends in fisheries

From local...

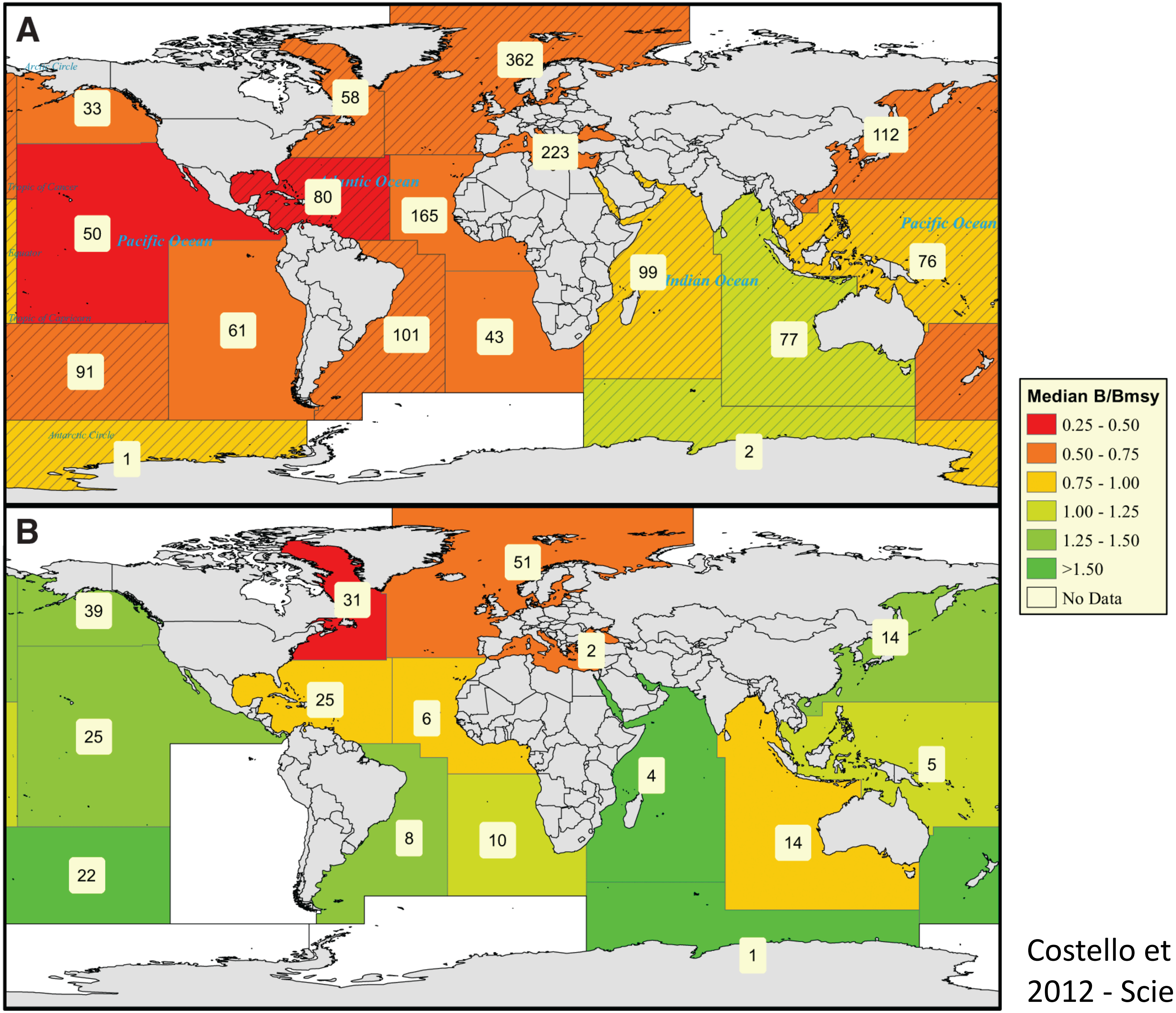


Worm et al. 2009 -Science

...to global

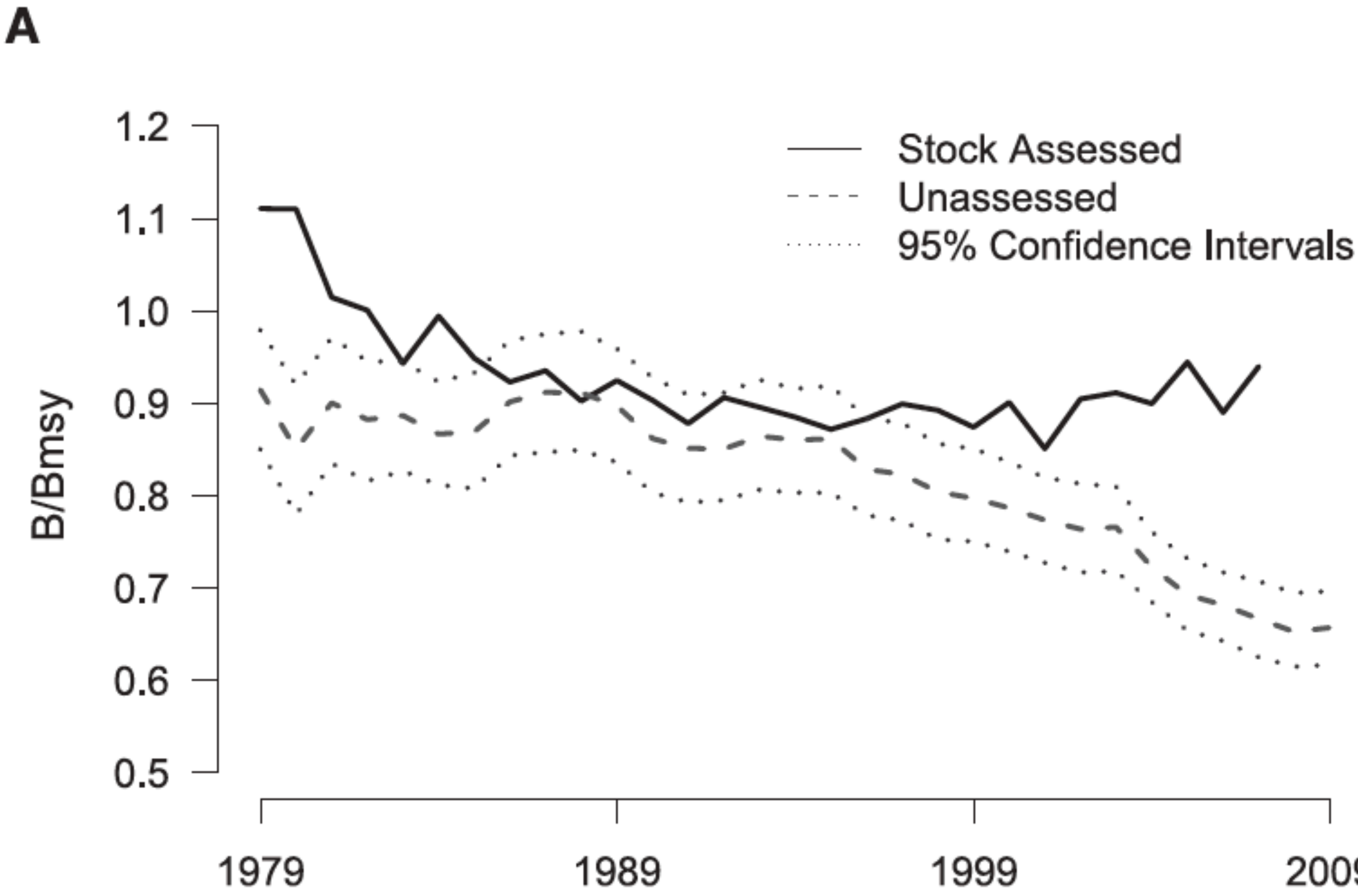


Worm et al. 2009 -Science



Costello et al.
2012 - Science

More worrying yet...



Costello et al.
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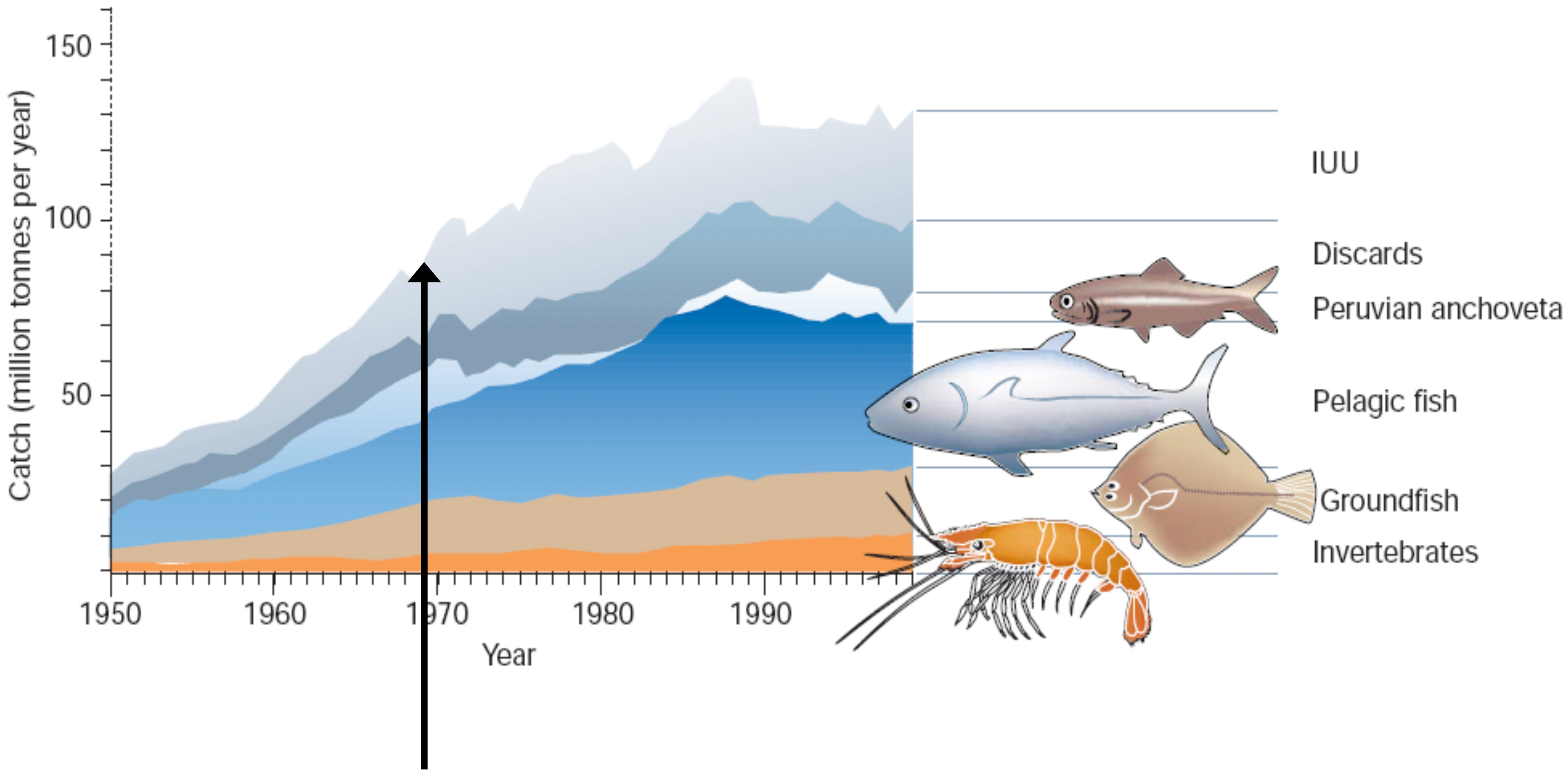
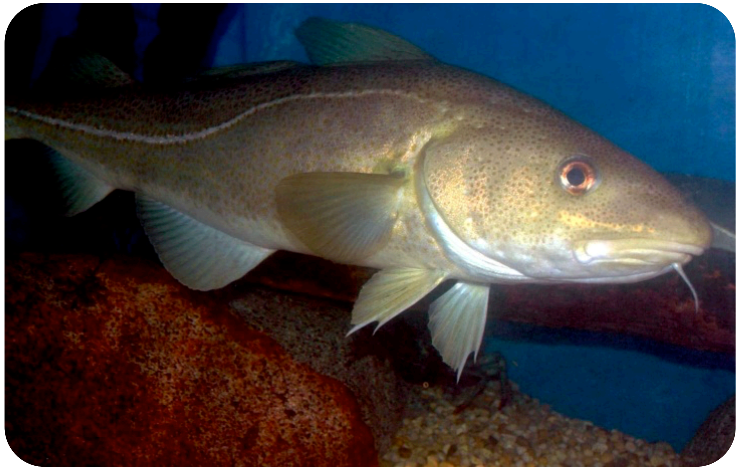


…it seems unlikely that the potential sustained yield of fish to man is appreciably greater than 100 million tons. - Ryther 1969, Science

FAO – The State of World Fisheries and Aquaculture

Where are we today?

Fishing mortality (F) is declining in many parts of the world, but often still too high



Around 2/3 of global fisheries are below target biomass levels[1]

An estimated 15% of fished stocks are collapsed[1] (<0.2x Target Biomass (@MSY))

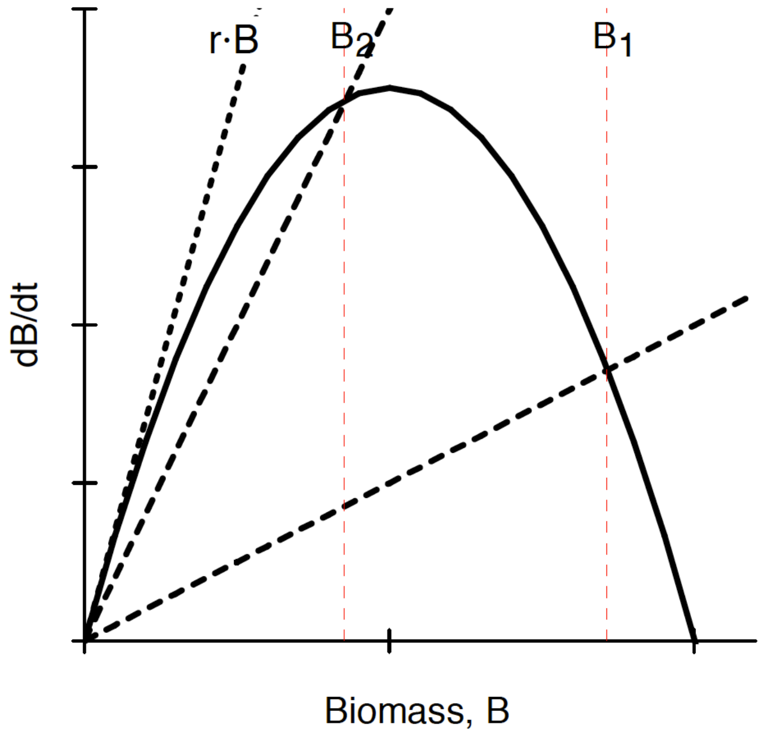
[1] Worm et al 2009 – Science

Recovering over-fished stocks

What does it take to recover stocks?

$$\frac{dB}{dt} = r \cdot B \cdot \left(1 - \frac{B}{K}\right) - F \cdot B$$

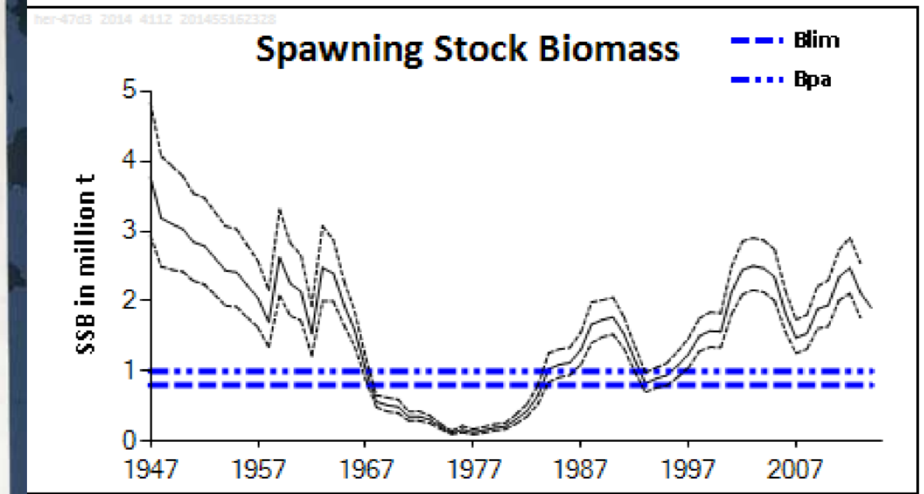
Natural Growth - *Harvest*



Resilience: Ability of populations to recover from low biomass

Depletions and recoveries...

Many well known depletions and subsequent recoveries: e.g., North Sea Herring



ICES advice 2013

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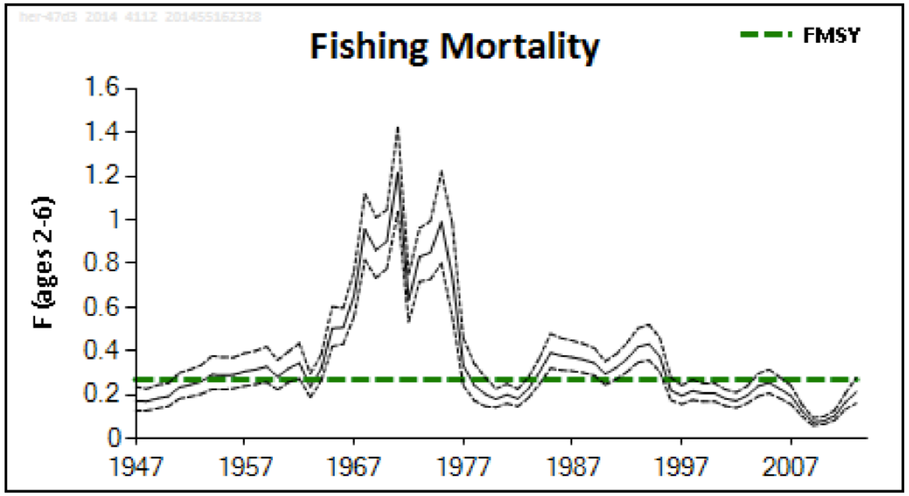

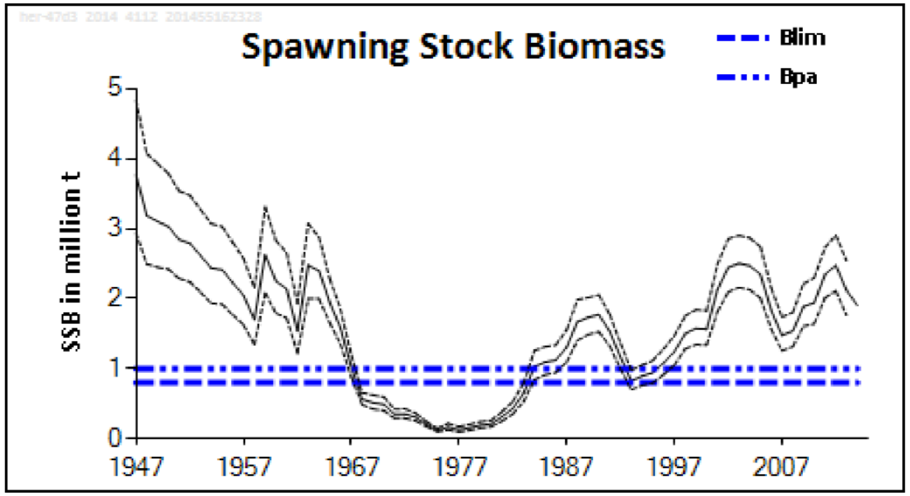

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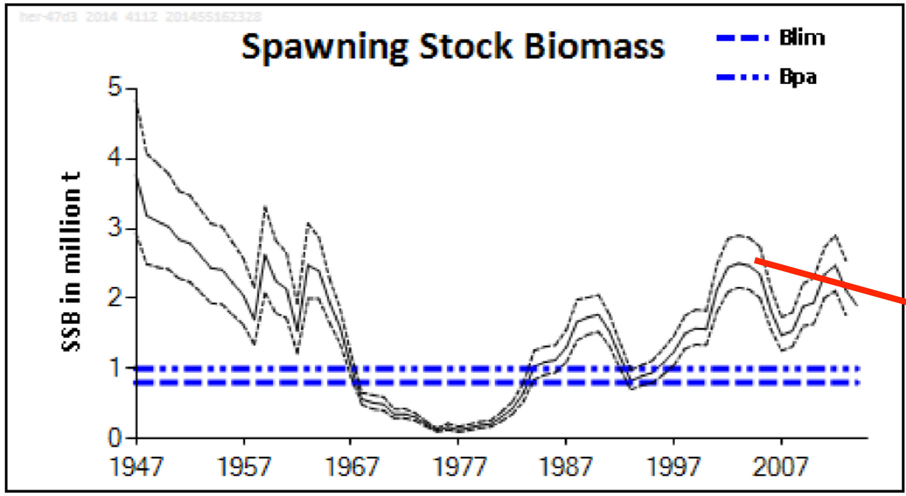
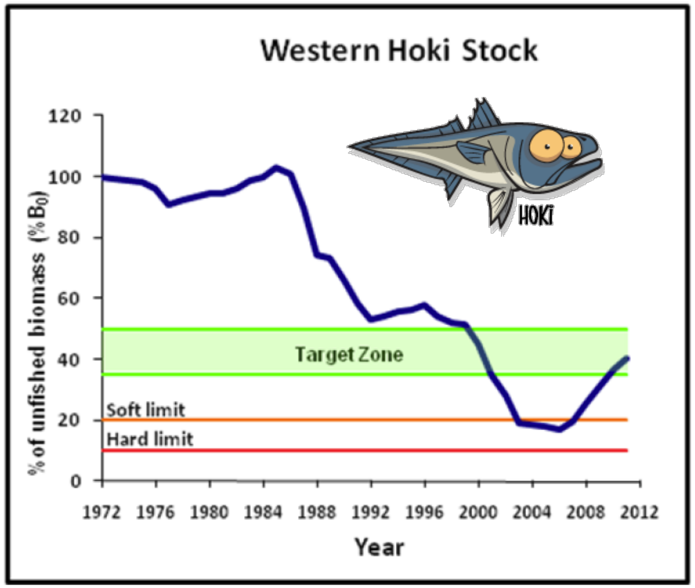


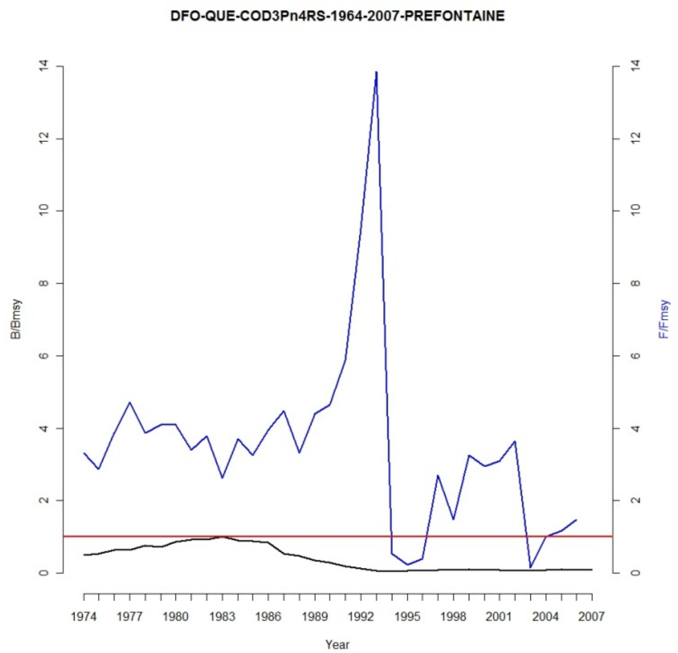
Depletions and recoveries...

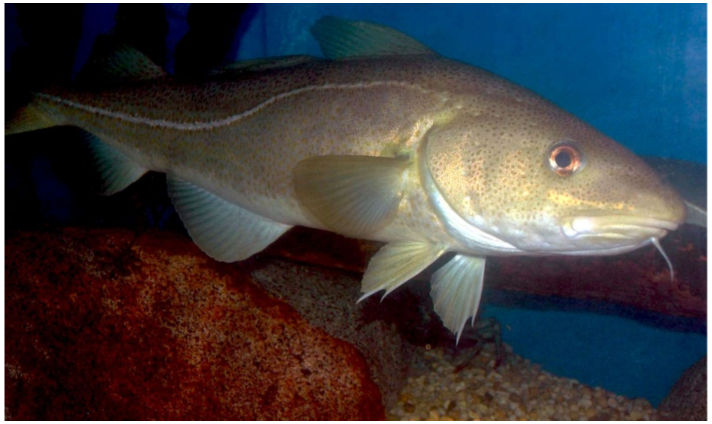
Local depletions and subsequent recoveries:
Western Hoki



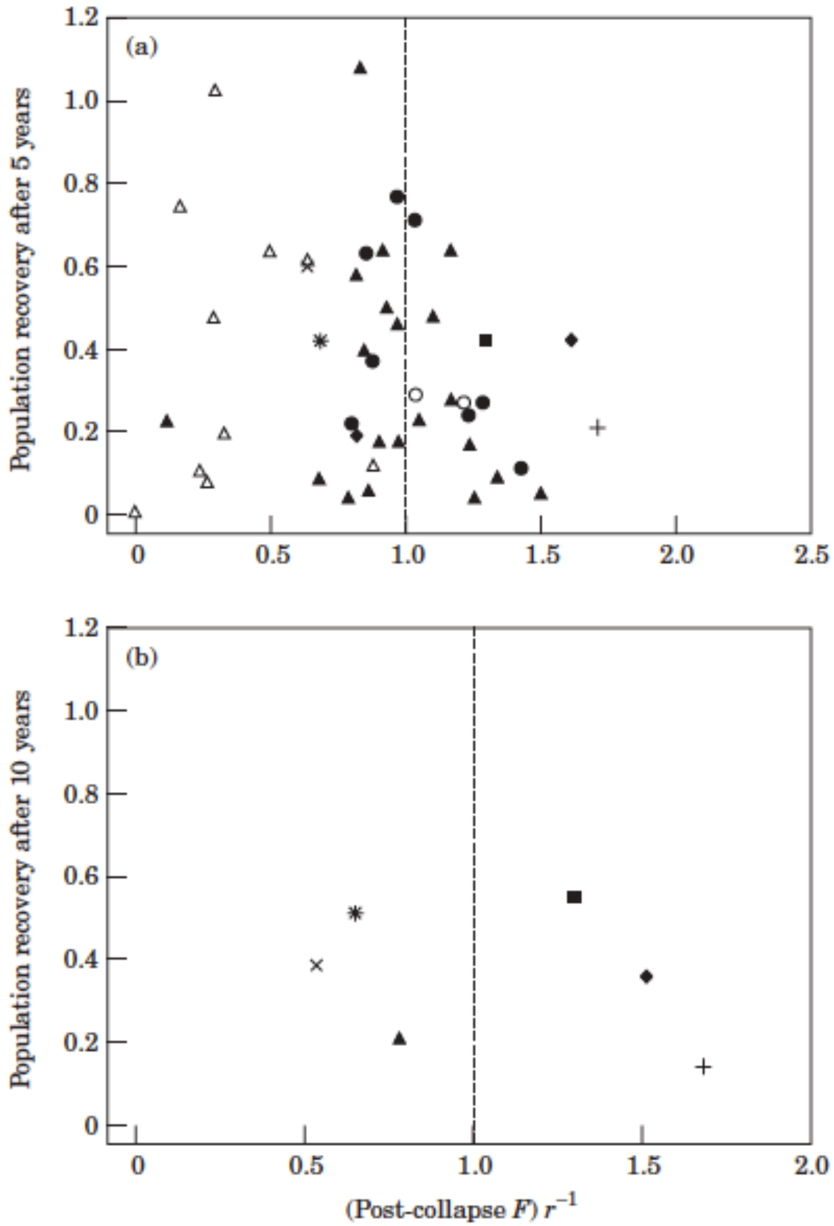
Depletion and no recoveries…

A notorious depletions without recovery: North West Atlantic Cod





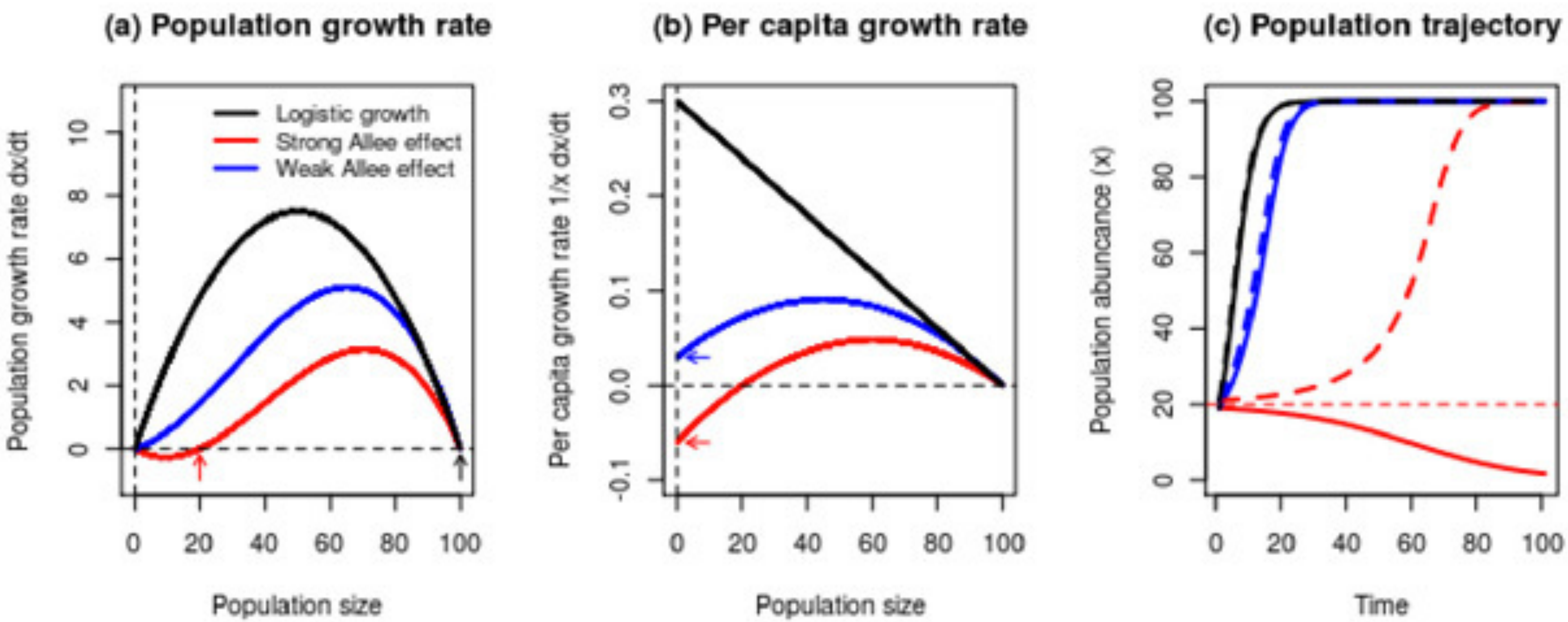
...too simplistic?



Hutchings 2000 – Nature
Hutchings 2001 – J.Fish.Bio

What could be missing?

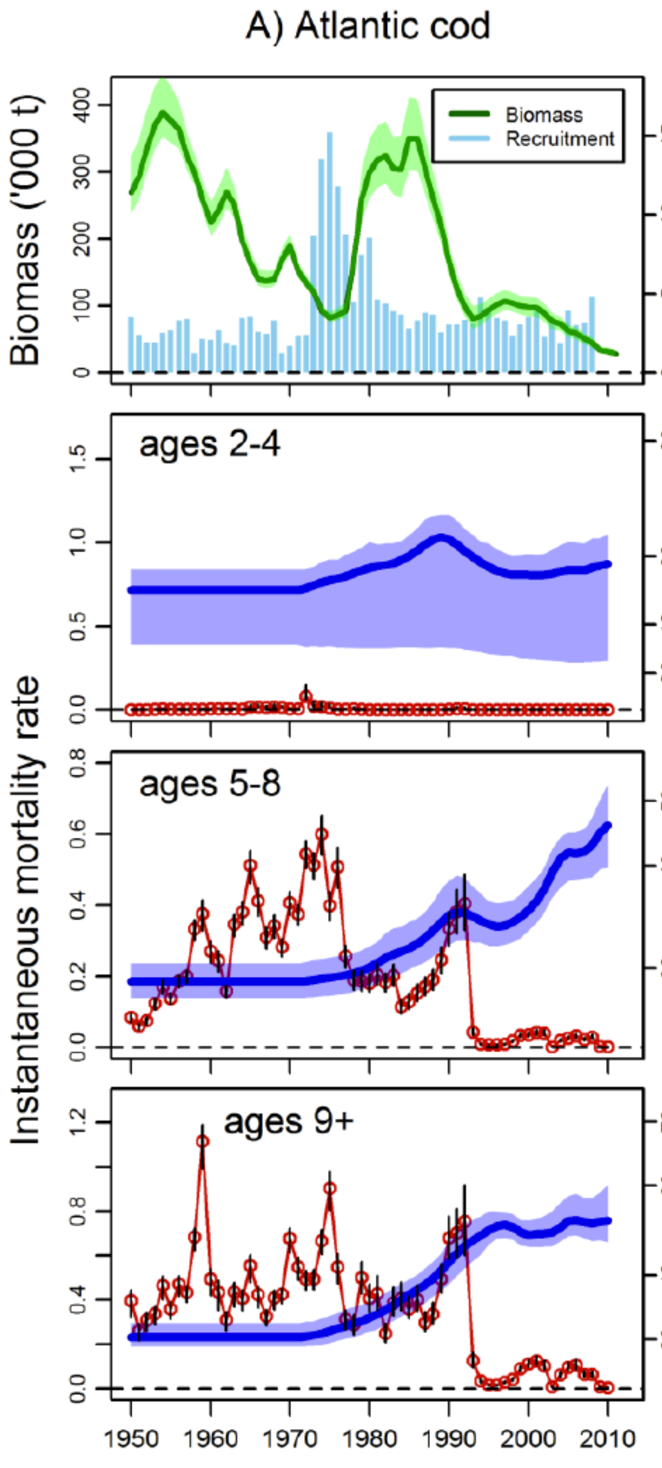
Allee effects/depensation

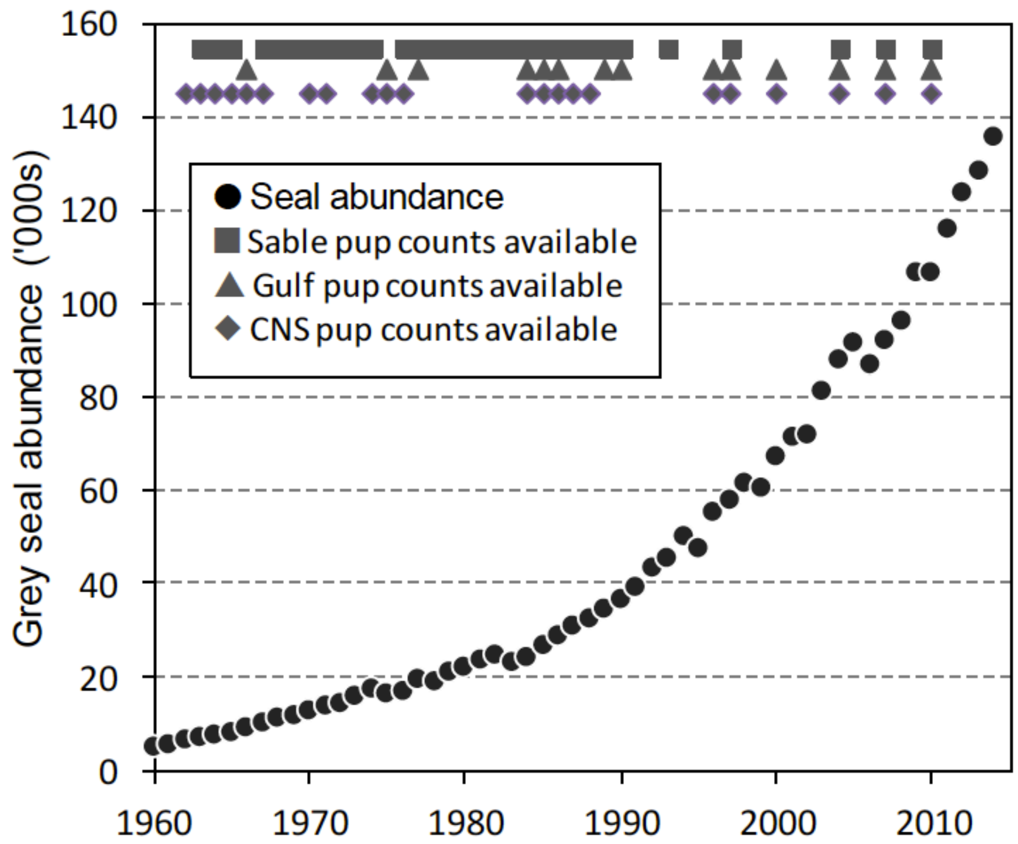


Cultivation/Depensation

Walters & Kitchell 2001 - CJFAS

Predator trap





Swain & Benoit 2015 – MEPS

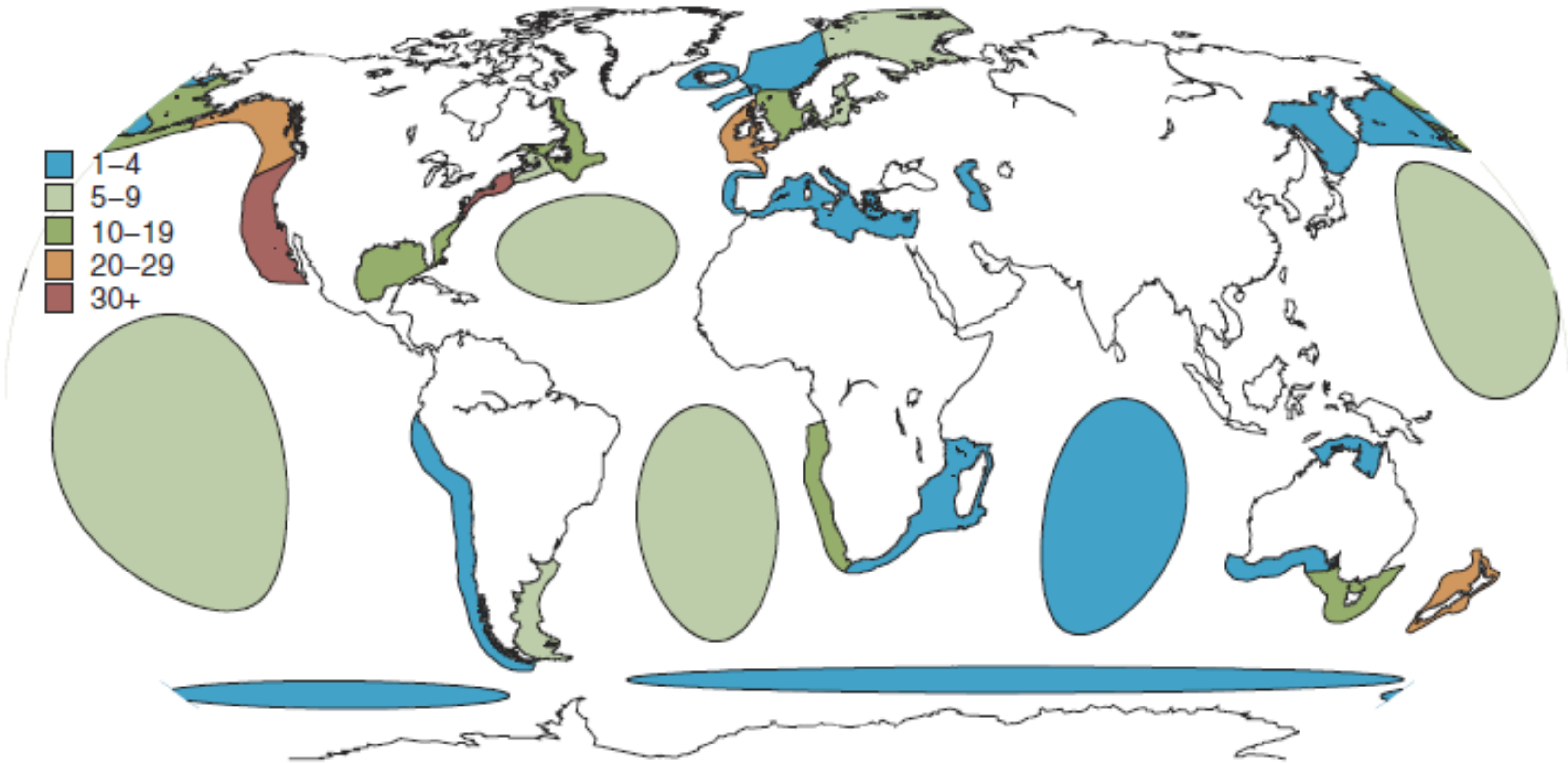
How resilient are fish stocks to over-fishing?

or

How predictable are recoveries?

Data

RAM Legacy Stock Assessment Database: over 360 stock assessments from around the globe



Ricard et al. 2012 – Fish & Fisheries

Data

RAM Legacy Stock Assessment Database: over 360 stock assessments from around the globe

153 stocks that had been depleted at least once to below 0.5x target (MSY)

Survival analysis of overfished stocks: **Does overfishing reduce population resilience?**

Stocks as sick patients

Bayesian **survival-analysis** regression model of **time-to-recovery:**

Assumes that biomass dynamics is a stochastic process

$$dB_t = \varphi_t B_t dt + \sigma B_t dW_t$$

Which leads to in inverse-Gaussian model for recovery times

$$f_{IG}(t) = \frac{c'}{\sigma\sqrt{2\pi}}\, t^{-3/2} \exp\left[-\frac{(c' - \nu' t)^2}{2\sigma^2 t}\right]$$

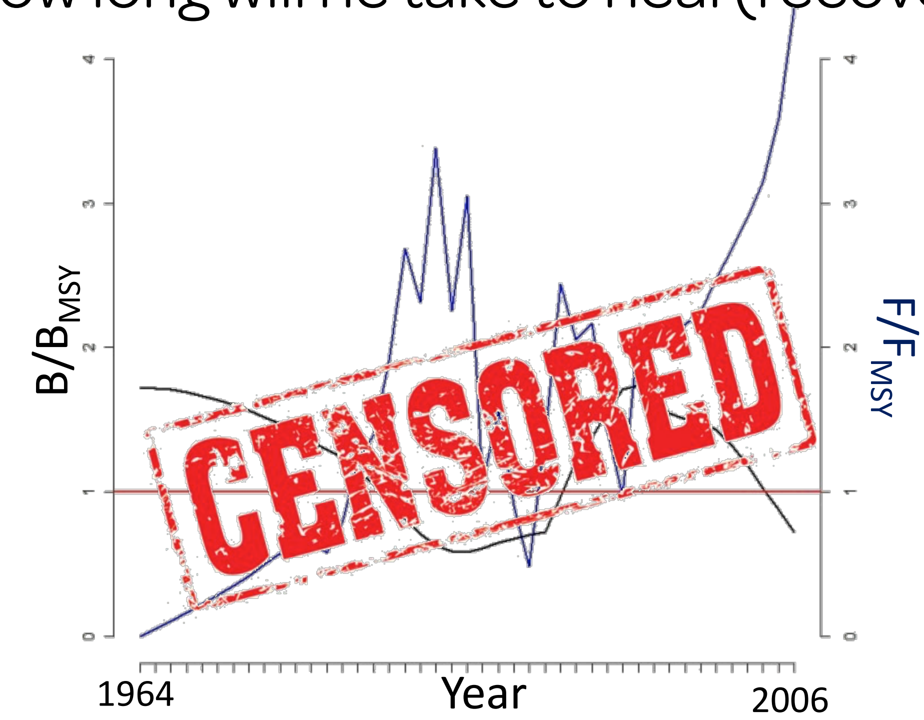
$$c' = f(B_{\min}, \ldots)$$

$$\nu' = f(F / F_{msy}, \ldots.)$$

Stock as sick patients

Bayesian **survival-analysis** regression model of **time-to-recovery.**

Survival analysis: Will the patient (stock) survive the illness (collapse), how long will he take to heal (recover) and why ?



Stocks as sick patients

Bayesian **survival-analysis** regression model of **time-to-recovery**

Survival analysis: Will the patient (stock) survive the illness (collapse), how long will he take to heal (recover) and why ?

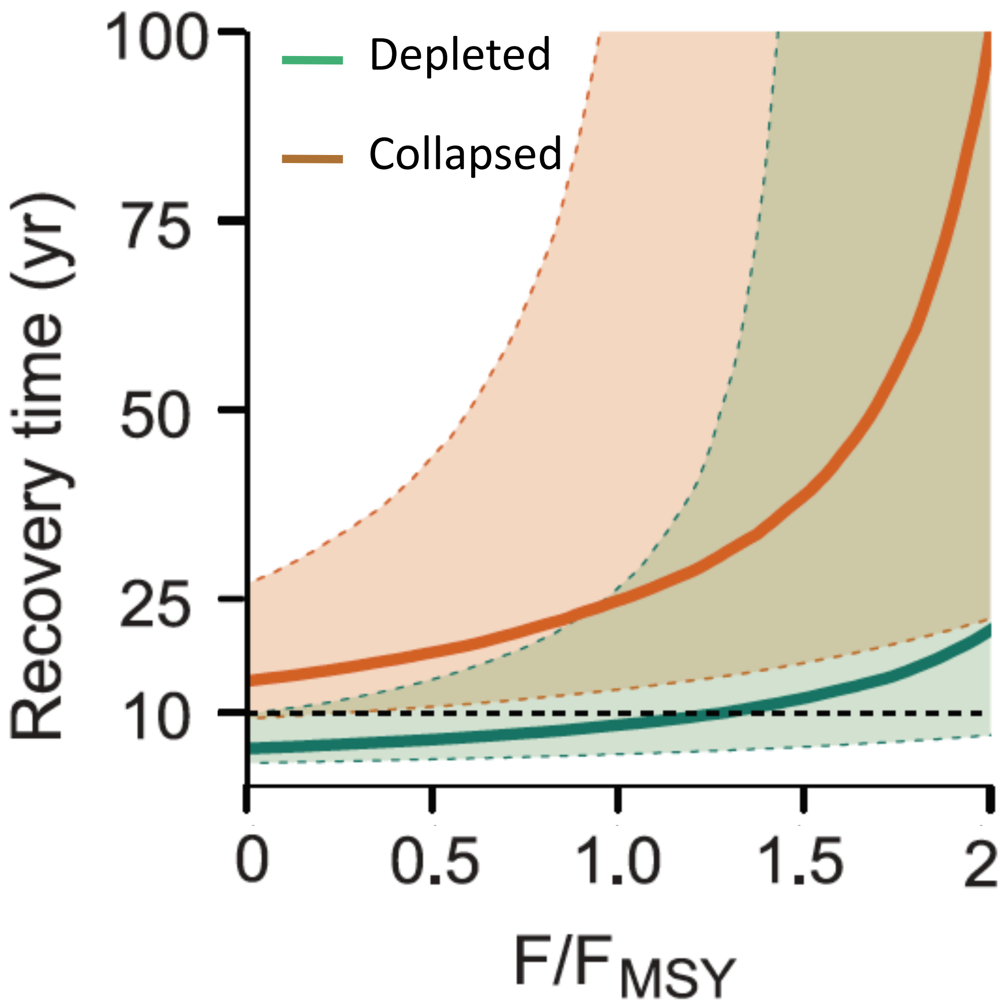
Includes covariates for management, life-history and exploitation history

Allowed us to estimate the effect of covariates on median recovery times and the probability of recovery within a given timeframe

Patterns and drivers of resilience

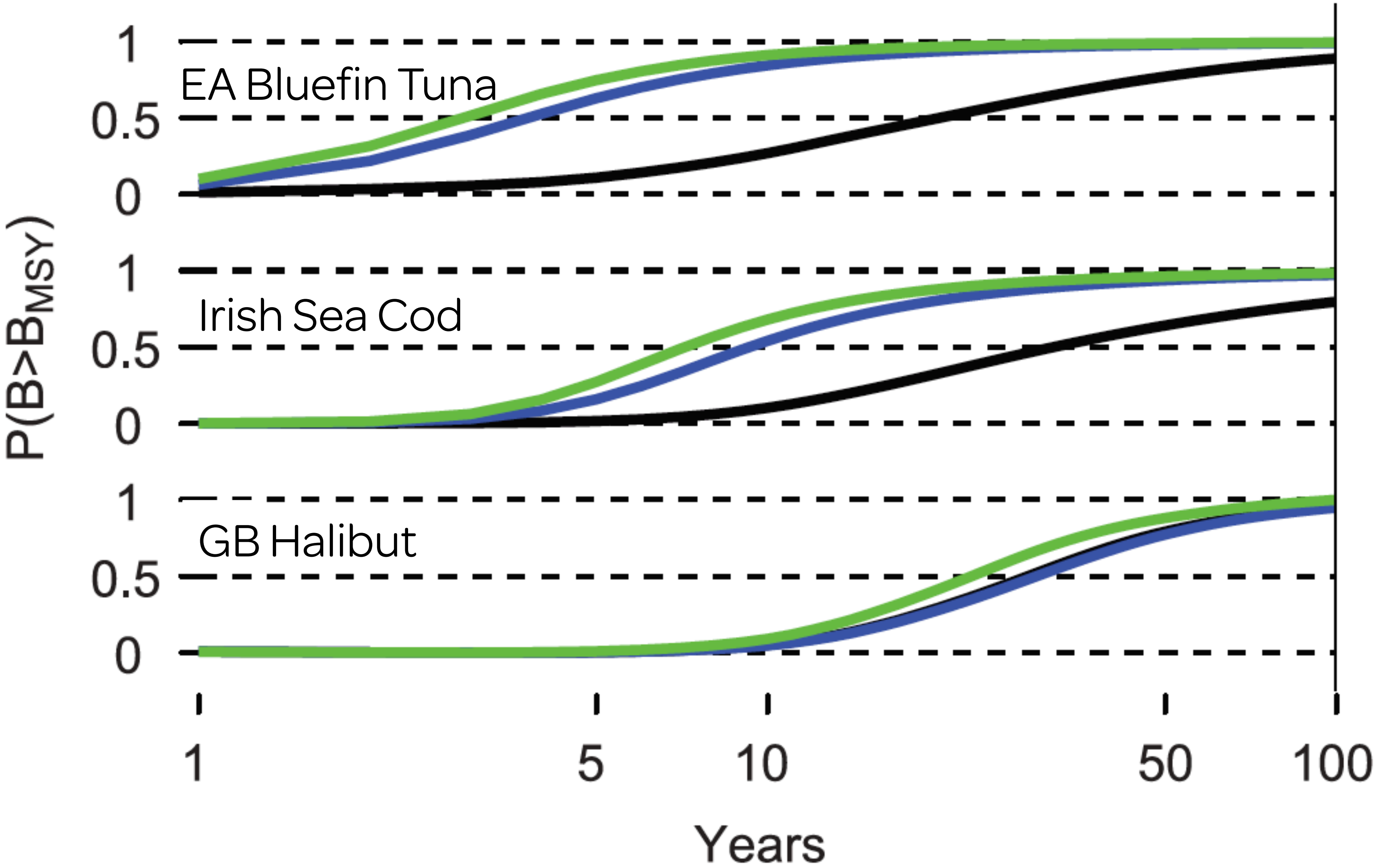
Drivers of resilience

Responsible and responsive management is key to building resilience and recovering overfished populations



Adapted from Neubauer et al. 2013 Science

Examples

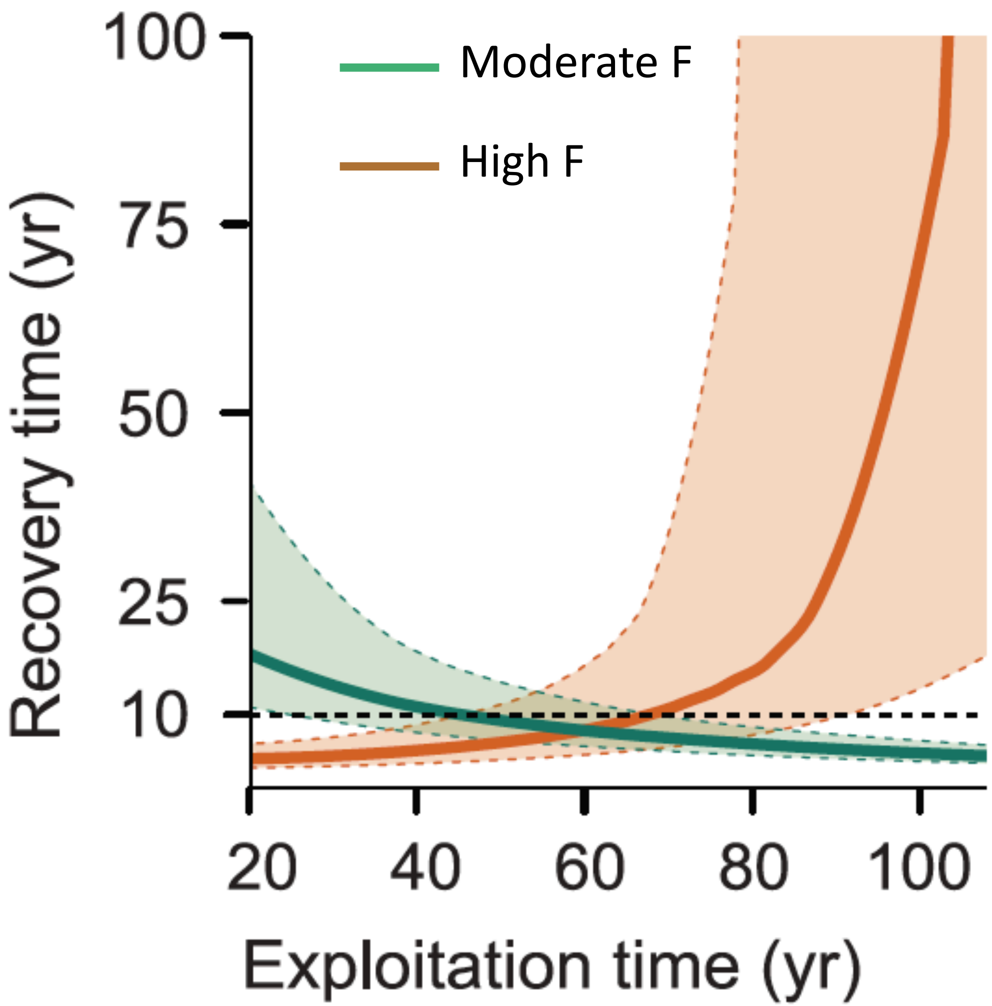


1
0.5
0
1
0.5
0
1
0.5
0
EA Bluefin Tuna
Irish Sea Cod
GB Halibut
P(B>B$_{MSY}$)
1
5
10
50
100
Years

Drivers of resilience

Recovery is accelerated for moderately high historical fishing regimes

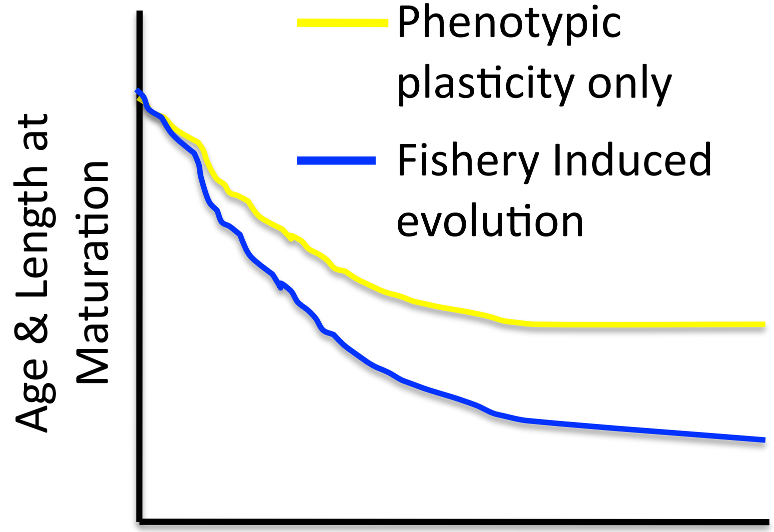
Negative impacts of fishing only for very long and intense fishing regimes



Adapted from Neubauer et al. 2013 Science

Explanations?

Phenotypic plasticity and fishery induced evolution can increase the productivity of fished populations



Adapted from Eikeset et al. 2013 – PNAS,

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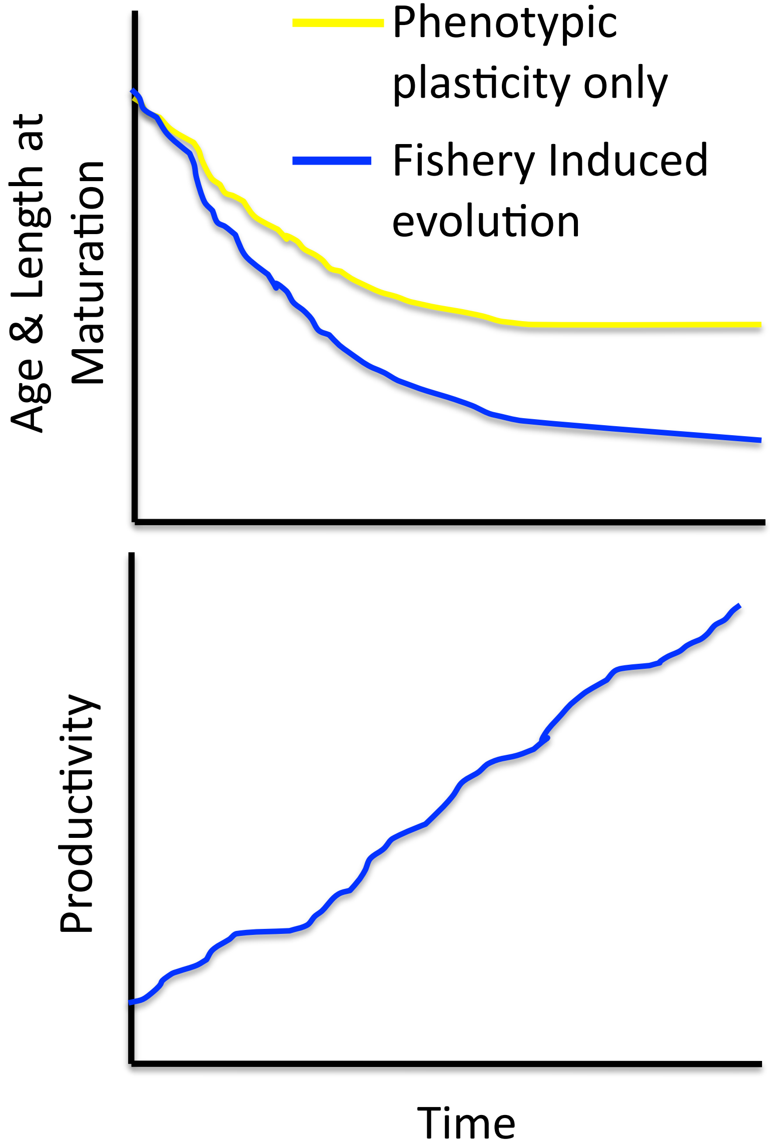
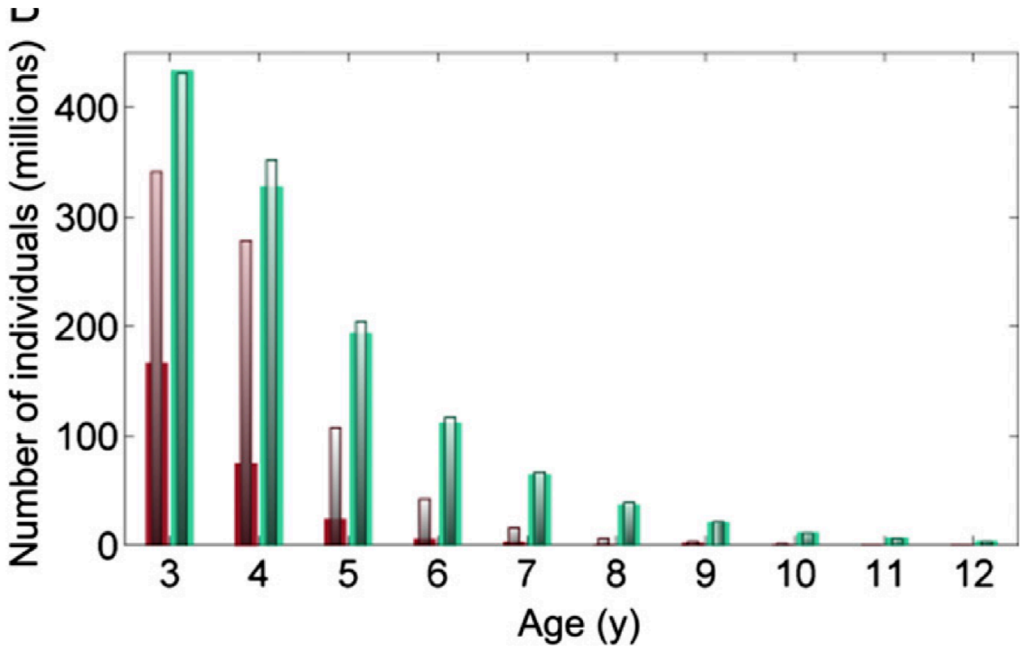


Adapted from Eikeset et al. 2013 – PNAS,

(Some) Limits of resilience

Importance of age/size structure

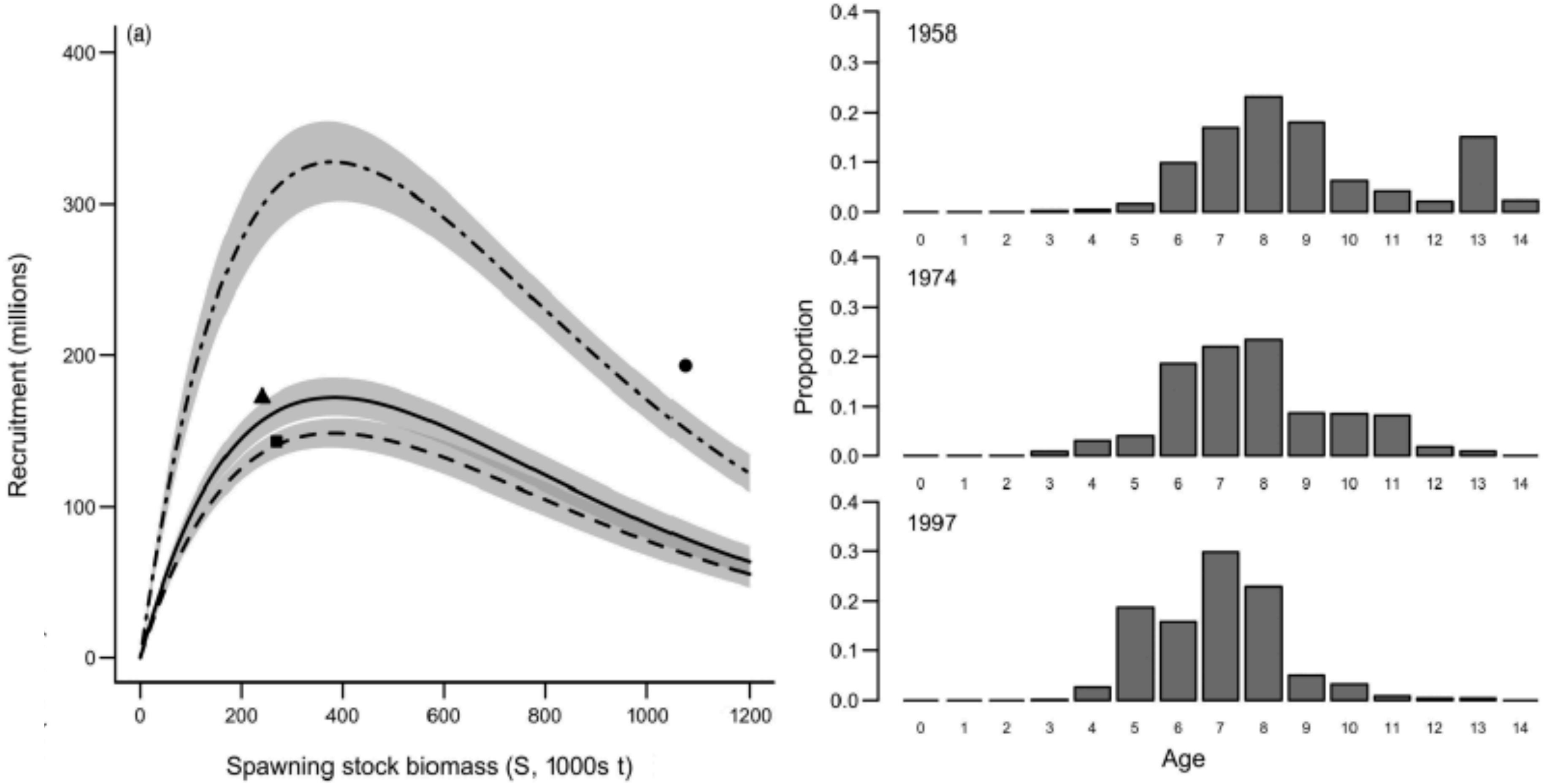
Intense harvest leads to capture of young (and immature) individuals



Age composition needs to ‘fill in’ again after very intense harvest

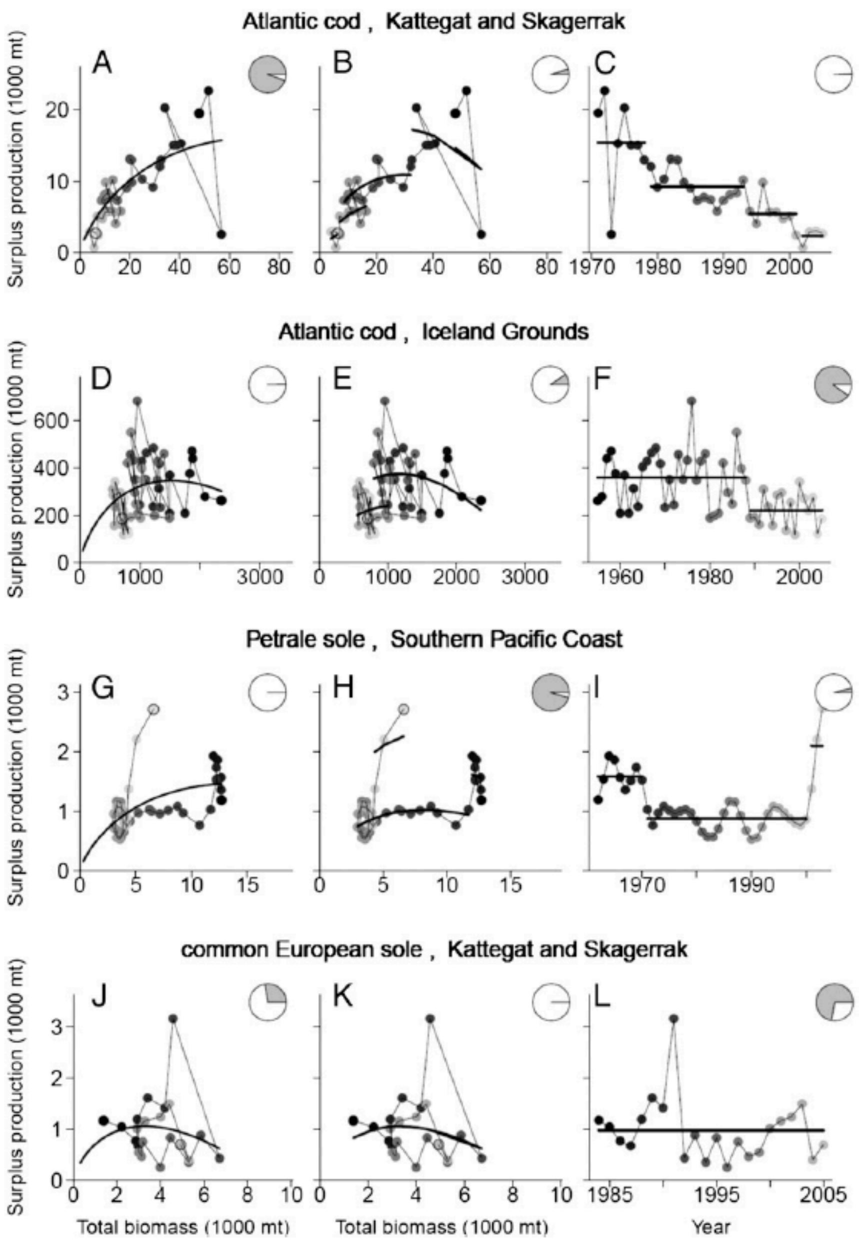
Eikeset et al. 2013 – PNAS

Importance of age/size structure



Shelton et al. 2010 - CJFAS

Adverse environments

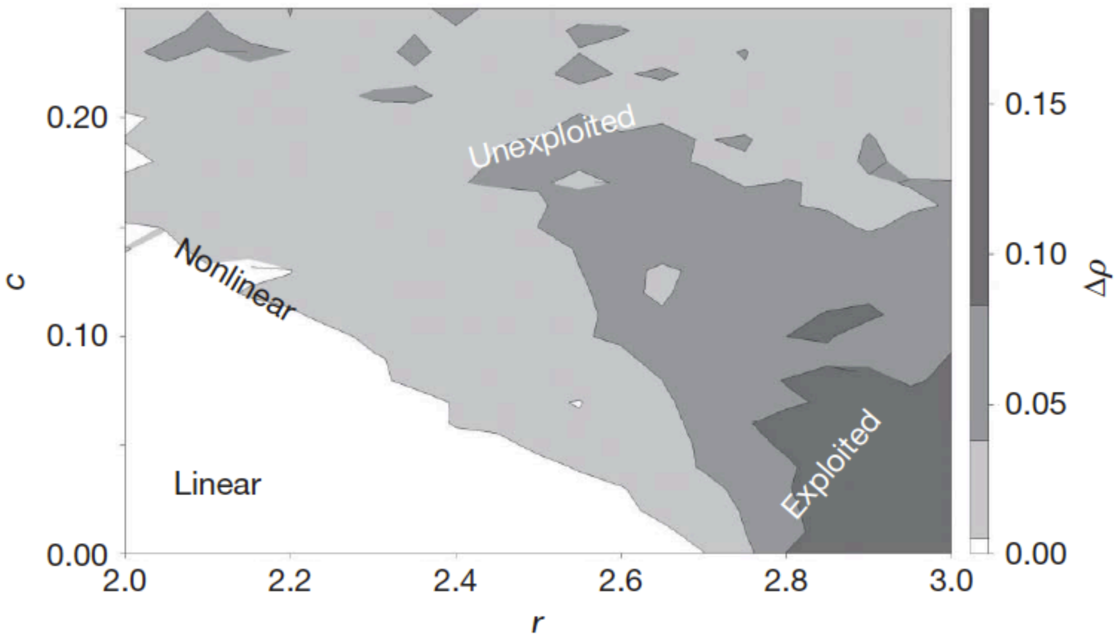


Over-fished stocks can fall into the *environmental trap*

Vert-Pre et al. 2013 – PNAS

Limits of resilience

Increases in productivity can lead to unstable (nonlinear) population dynamics



Anderson et al 2008 – Nature

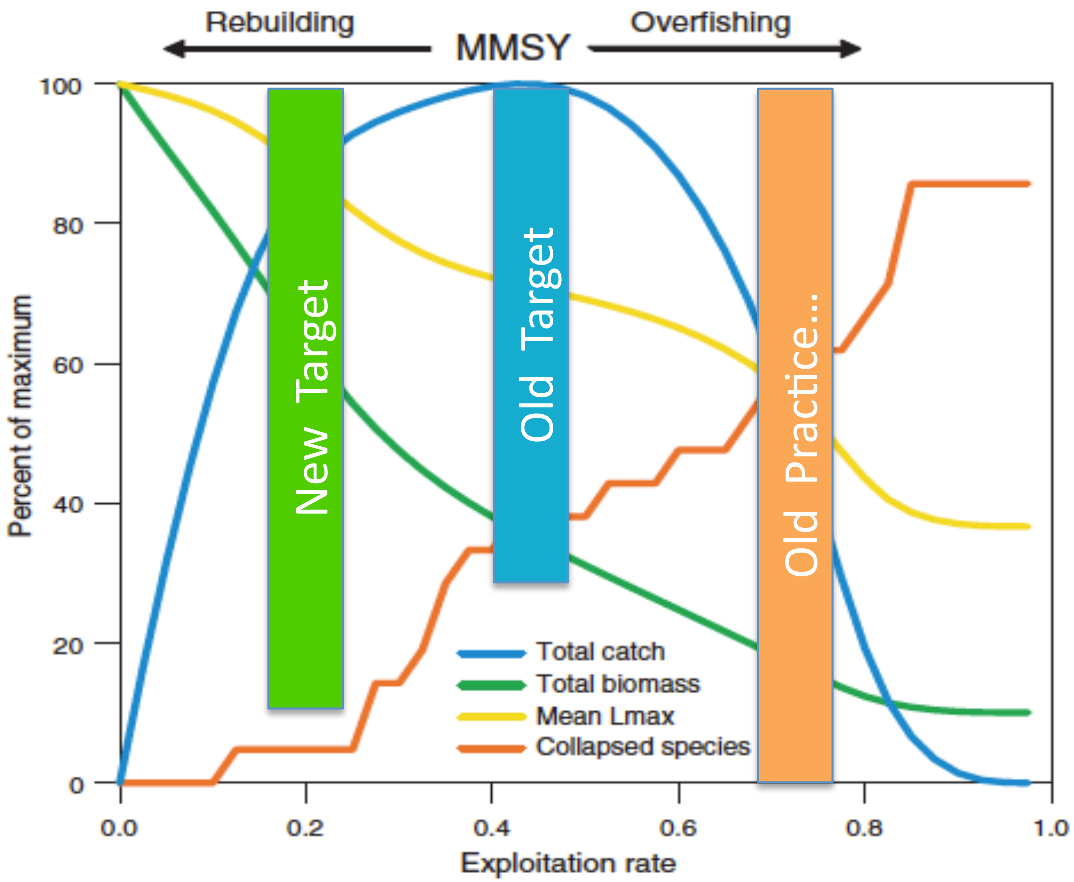
Resilient Fisheries

Building resilience

Precautionary fishing mortality rates limit ecosystem wide risks of over-fishing

Building resilience

Precautionary fishing mortality rates limit ecosystem wide risks of over-fishing



Adapted from Worm et al. 2009 – Science

Building resilience

Precautionary fishing mortality rates limit ecosystem wide risks of over-fishing

Maintaining age/size structure to maintain reproductive and adaptive potential

Acknowledging environmentally/climate driven variability in demographic rates, adjust management advice accordingly

ICES Journal of
Marine Science

ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

ICES Journal of Marine Science (2012), 69(2), 145–150. doi:10.1093/icesjms/fsr207

Food for Thought

Feeding the world: what role for fisheries?

Chris L. J. Frid[1]* and Odette A. L. Paramor[2]

[1]School of Environmental Sciences, University of Liverpool, Brownlow Street, Liverpool L69 3GP, UK
[2]Environmental Sciences, University of Nottingham Ningbo, China, 199 Taikang East Road, Ningbo, Zhejiang 315100, China

ICES Journal of Marine Science (2011), 68(6), 1343–1353. doi:10.1093/icesjms/fsr041

Fisheries, food security, climate change, and biodiversity: characteristics of the sector and perspectives on emerging issues

Jake C. Rice[1]* and Serge M. Garcia[2]

[1]Department of Fisheries and Oceans, Ottawa, ON, Canada K1A 0E6
[2]Former Director, FAO Fisheries Management Division, Rome, Italy

Marsden Questions

How resilient are ecosystems to over-fishing?

How does fishing alter ecosystem responses and resilience to climate change?

MARSDEN FUND

TE PŪTEA RANGAHAU A MARSDEN

Acknowledgements

- NSF/NOAA CAMEO grant

CAMEO
COMPARATIVE ANALYSIS OF MARINE ECOSYSTEM ORGANIZATION

- Olaf Jensen, Jensen lab group, Malin Pinsky

MARSDEN FUND
TE PŪTEA RANGAHAU A MARSDEN

- Mike Plank

Environmental costs per 40g protein

	Water (L)	Fertilizer (g)	Pesticides (mg)	Antibiotics (mg)	Soil Loss (kg)
Beef	2200	50	494	21	16
Chicken	1331	18	163	55	3
Pork	1331	46	422	53	8
Dairy	1178	34	299	50	7
Capture fisheries	low	0	0	0	0

Courtesy of R. Hilborn

Where will the protein come from?

Unless we cut down more forests for beef and soy, it will have to be:

- Well managed fisheries
- Aquaculture of herbivorous fish and bivalves