Back to the Future: 115 years of climate and fisheries in the North Sea

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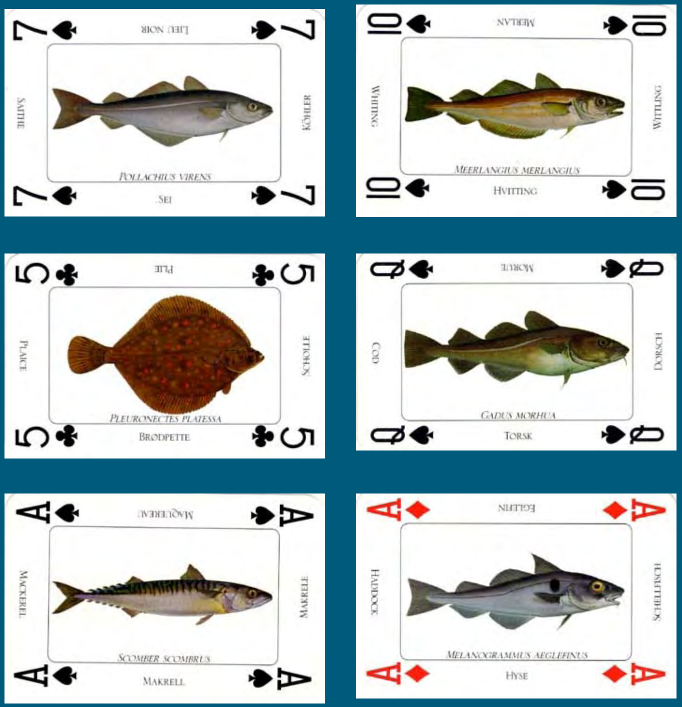
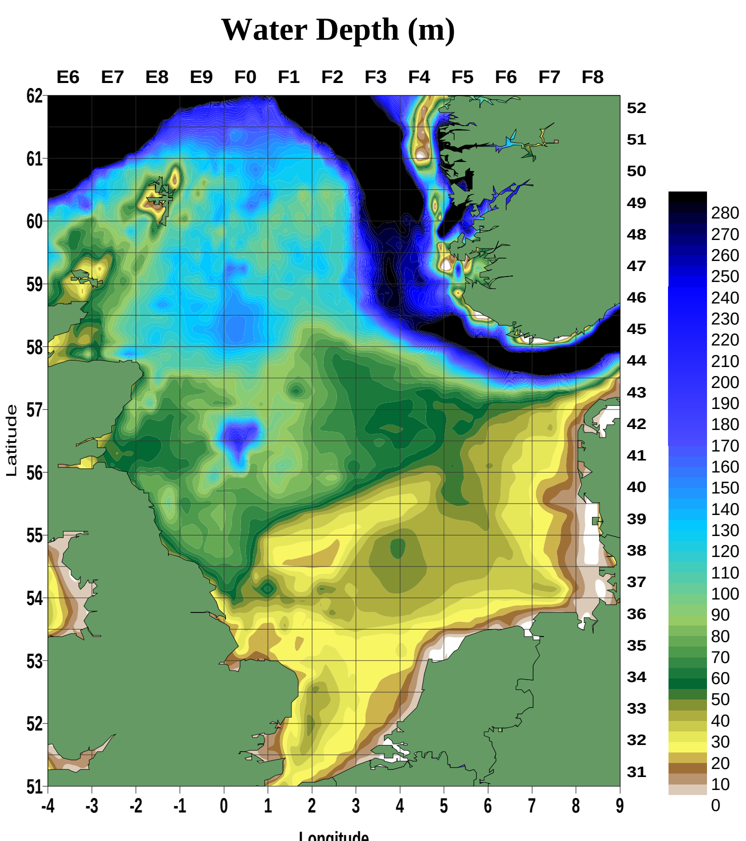
Cefas

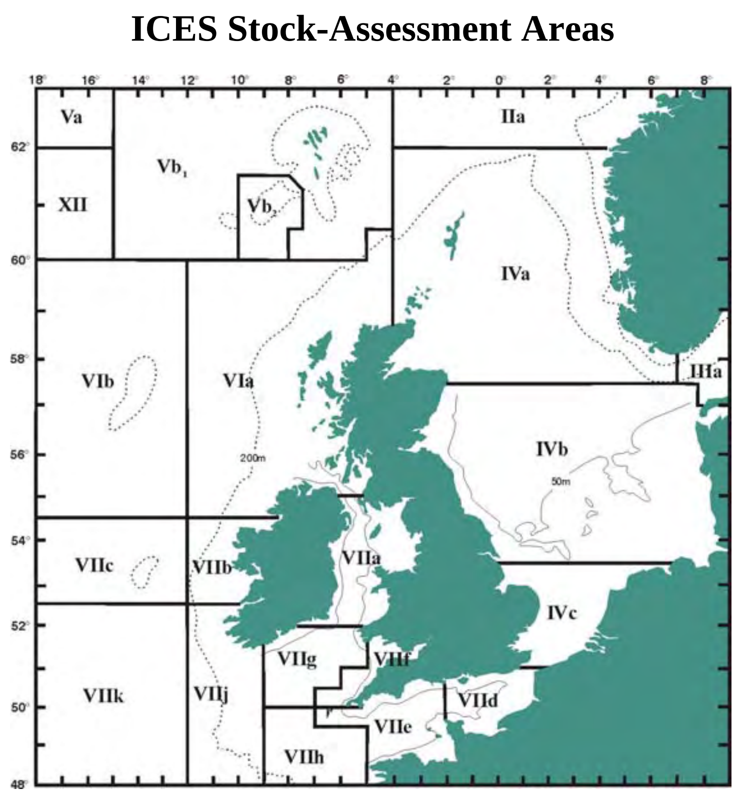
Programme……

1. The North Sea ecosystem
2. Changes in fish distribution (fishing versus climate change)
3. Changes in food-webs
4. Reconstructing a model of ecosystem in the 1880s
5. ‘Forcing’ & ‘Fitting’ the model
6. Can we get from ‘there’ (1880s) to ‘here’ (2009)?
7. Some conclusions



The North Sea Ecosystem:



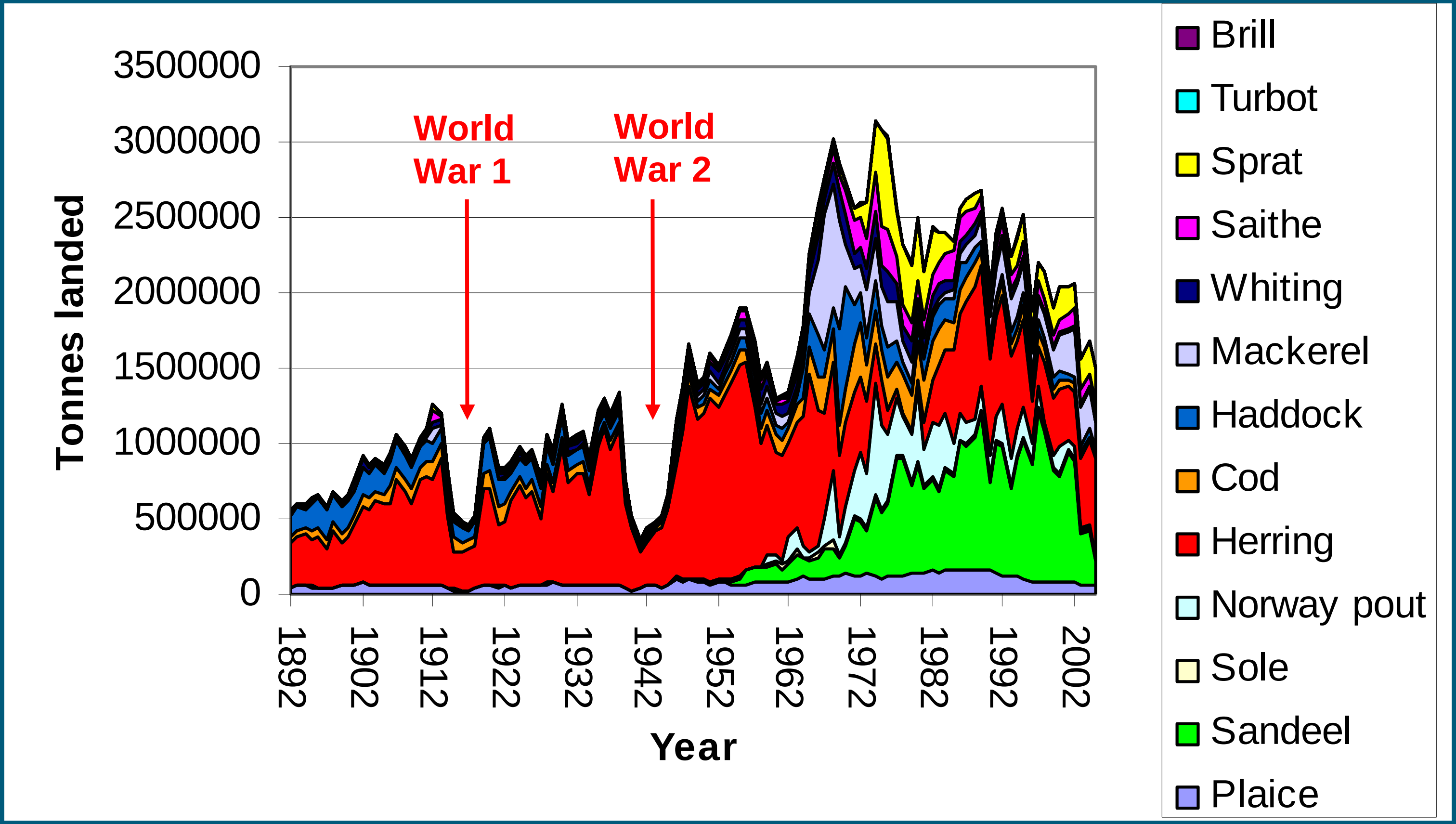


•The North Sea is a semi-enclosed basin with a depth ranging from 30m – 200m

•The ecosystem is dominated by soft-bottom habitats (sand, mud, gravel)

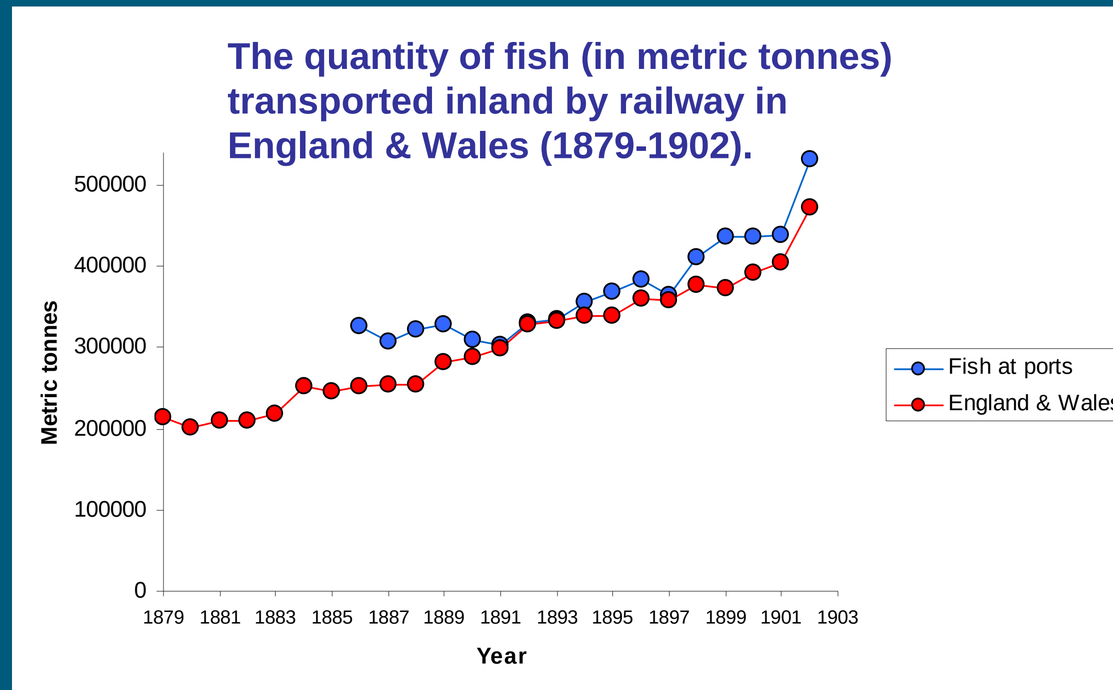
The north Sea harbours a wide range of fish stocks exploited mainly by: France, Germany, Belgium, Netherlands, Norway, England, Scotland, Denmark.

115 years of North Sea fisheries catches



- Herring was the most important species in the North Sea until the 1970s, when the fishery was closed and the stock collapsed
- Industrial fisheries for sandeel, norway pout, mackerel and sprat developed in the 1960s and 1970s.

Fish stocks were already heavily exploited 100 years ago!



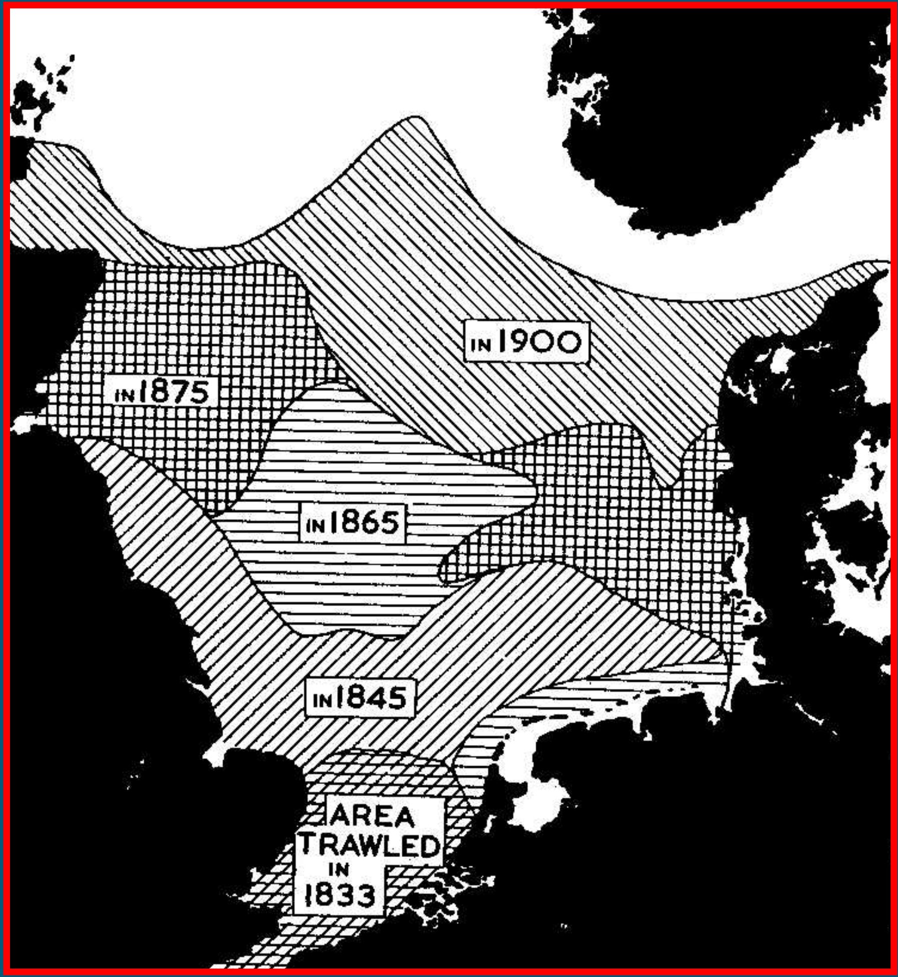
Note that the tonnage in 1902 (473274 metric tonnes) was 3½ times that landed at English and Welsh ports in 2002 (128300 metric tonnes).

As early as 1893 the UK parliament felt the need to convene a special 'Select Committee on Sea Fisheries', in response to fears of overfishing in the North Sea.

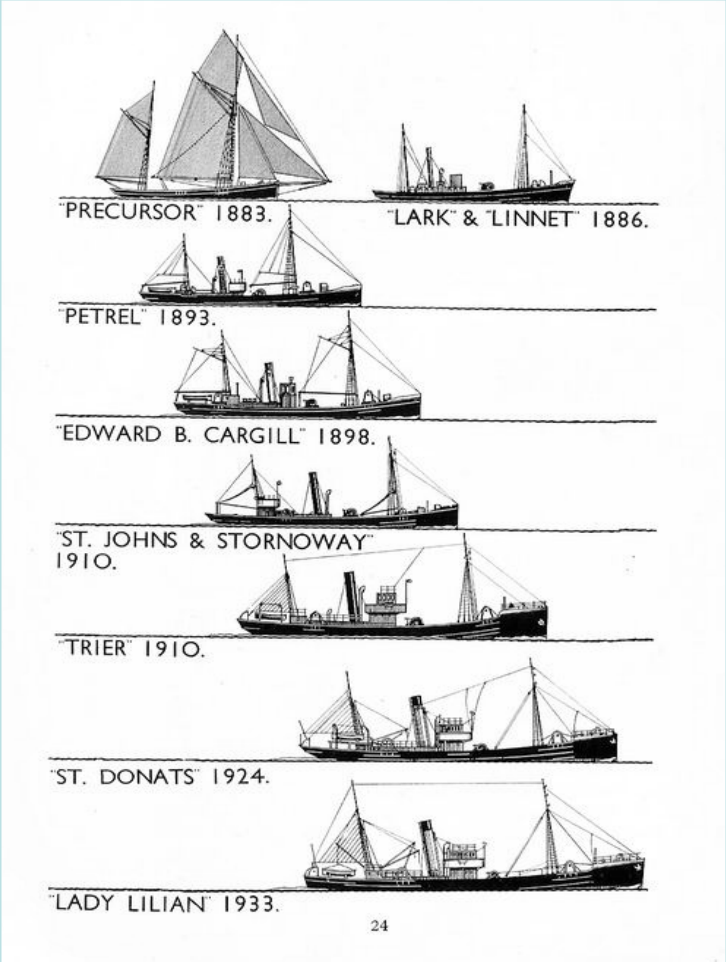
19th Century expansion of trawling

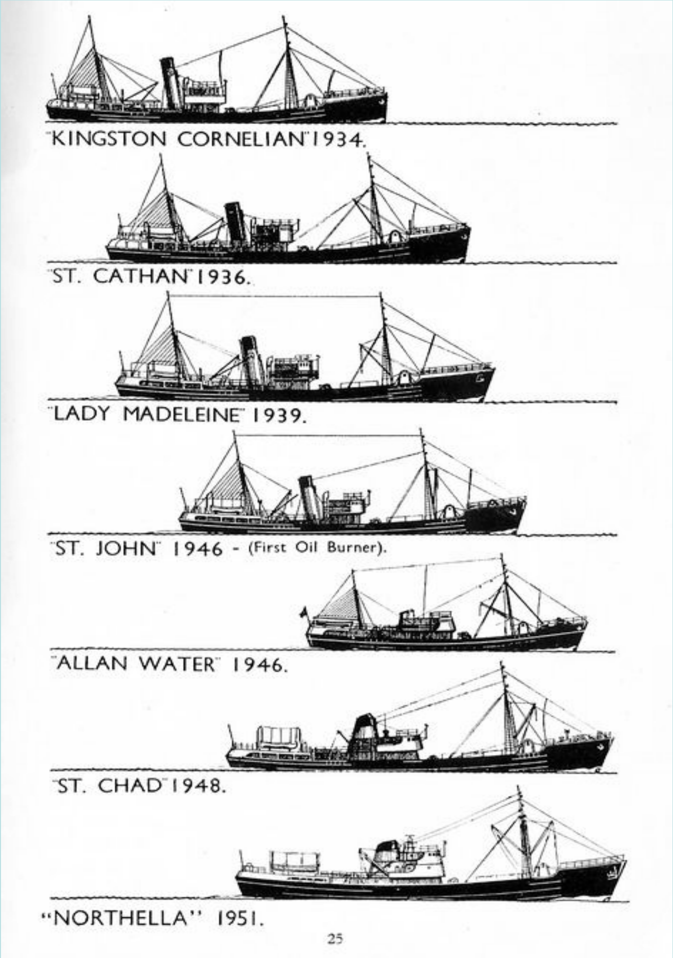
- By 1900, most of the North Sea had been exposed to intensive trawling pressure

- Consequently we would expect big changes in communities, food-webs and ecosystems



How has fishing power changed over 120 years of trawling the North Sea?





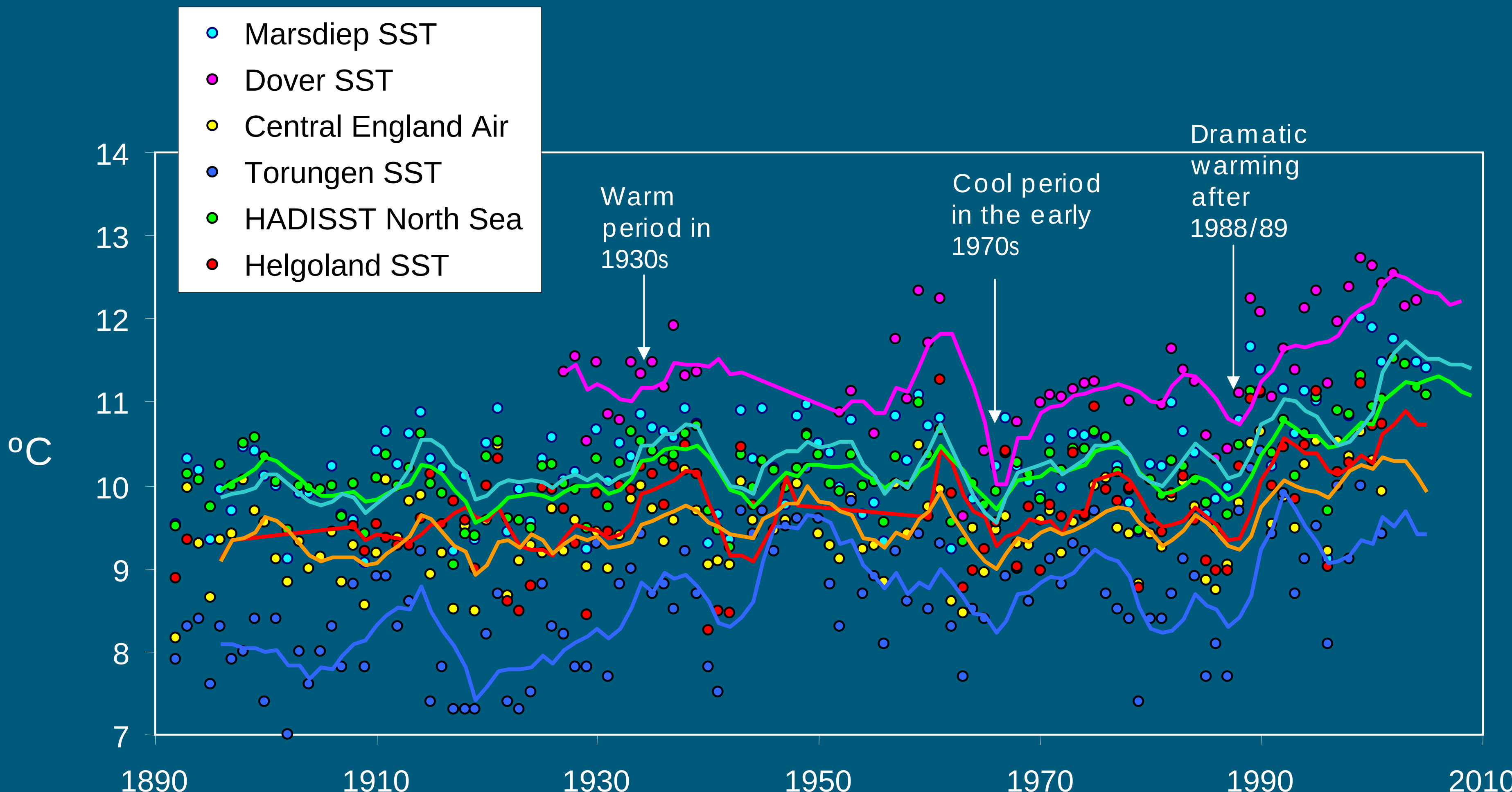
Steam trawlers exhibited about *4x higher fishing power* … and *10-20x higher fishing power* relative to sailing trawlers

…beam trawlers in 2000s have *~100x higher plaice & sole fishing power*

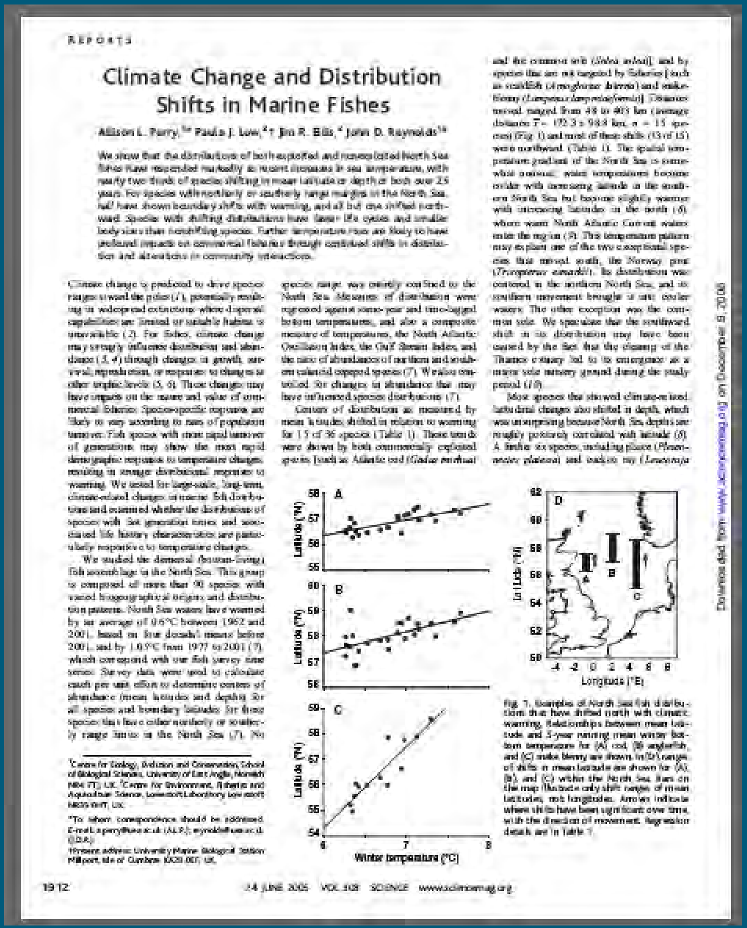
…otter trawlers in 2000s have *~50x higher cod fishing power*

At the same time there have been big changes in the climate……

Note the generally close correlation between time series & the overall warming trend during the 20th Century



Several high-profile papers have documented **a 'northward shift' in the distribution of North Sea fish** over the past 40 years

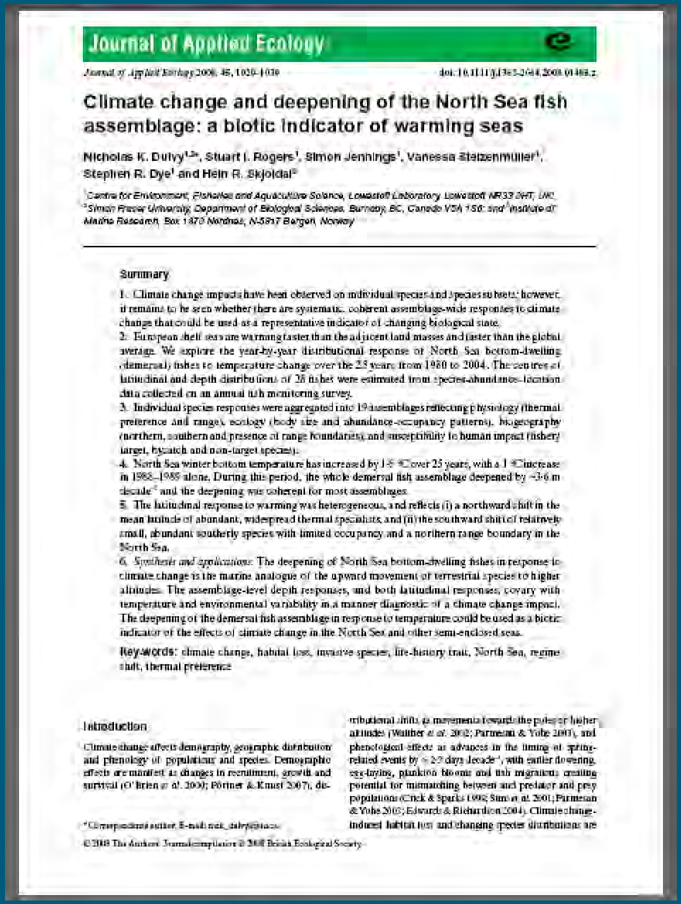


REPORTS

Climate Change and Distribution Shifts in Marine Fishes

Allison L. Perry,[1*] Paula J. Low,[2†] Jim R. Ellis,[2] John D. Reynolds[1‡]

[*Science*, 308: 1912-1915]



Journal of Applied Ecology

Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas

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Summary

1. Climate change impacts have been observed on individual species and species subsets; however, it remains to be seen whether there are systematic, coherent assemblage-wide responses to climate change that could be used as a representative indicator of changing biological state.
2. European shelf seas are warming faster than the adjacent land masses and faster than the global average. We explore the year-by-year distributional response of North Sea bottom-dwelling (demersal) fishes to temperature change over the 25 years from 1980 to 2004. The centres of latitudinal and depth distributions of 28 fishes were estimated from species-abundance-location data collected on an annual fish monitoring survey.
3. Individual species responses were aggregated into 19 assemblages reflecting physiology (thermal preference and range), ecology (body size and abundance-occupancy patterns), biogeography (northern, southern and presence of range boundaries) and susceptibility to human impact (fishery target, bycatch and non-target species).
4. North Sea winter bottom temperature has increased by 1·6 °C over 25 years, with a 1 °C increase in 1988–1989 alone. During this period, the whole demersal fish assemblage deepened by ~3·6 m decade⁻¹ and the deepening was coherent for most assemblages.
5. The latitudinal response to warming was heterogeneous, and reflects (i) a northward shift in the mean latitude of abundant, widespread thermal specialists, and (ii) the southward shift of relatively small, abundant southerly species with limited occupancy and a northern range boundary in the North Sea.
6. *Synthesis and applications.* The deepening of North Sea bottom-dwelling fishes in response to climate change is the marine analogue of the upward movement of terrestrial species to higher altitudes. The assemblage-level depth responses, and both latitudinal responses, covary with temperature and environmental variability in a manner diagnostic of a climate change impact. The deepening of the demersal fish assemblage in response to temperature could be used as a biotic indicator of the effects of climate change in the North Sea and other semi-enclosed seas.

Key-words: climate change, habitat loss, invasive species, life-history trait, North Sea, regime shift, thermal preference

Introduction

[*J App Ecol*, 45: 1029-1039]

All these papers have implicated **'climate change'** as the main driver

Distribution shifts: climate versus fishing?

There is much ***controversy*** around distribution shifts of North sea fishes over past 3 decades:

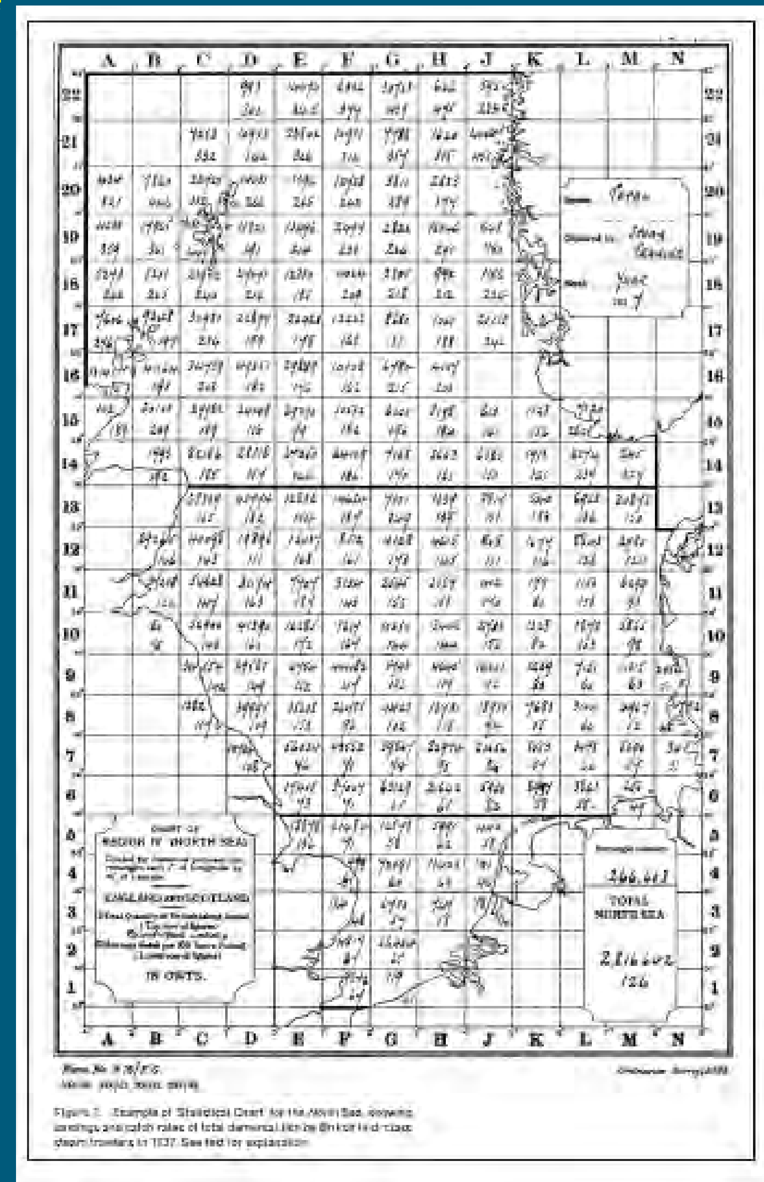
- ***‘Climate change hypothesis’*:** warming climate causes warm-adapted species to expand northward, and/or cold-adapted species to contract at south-end of range
- ***‘Fishing pressure hypothesis’*:** fishing pressure has been consistently higher in the southern compared to northern North Sea, causing higher mortality in the south and hence, an ‘apparent’ distribution shift
- **Other possible drivers** include *eutrophication*, habitat modification

- So far studies on North Sea fish distribution shifts have been based on survey data limited to most recent 3 decades:
- Here, 9 decades of **sole and plaice** distribution data were analysed

The data

- 1913-1980: ‘Statistical Charts’ with sole & plaice cpue by rectangle, for British steam and motor otter trawlers

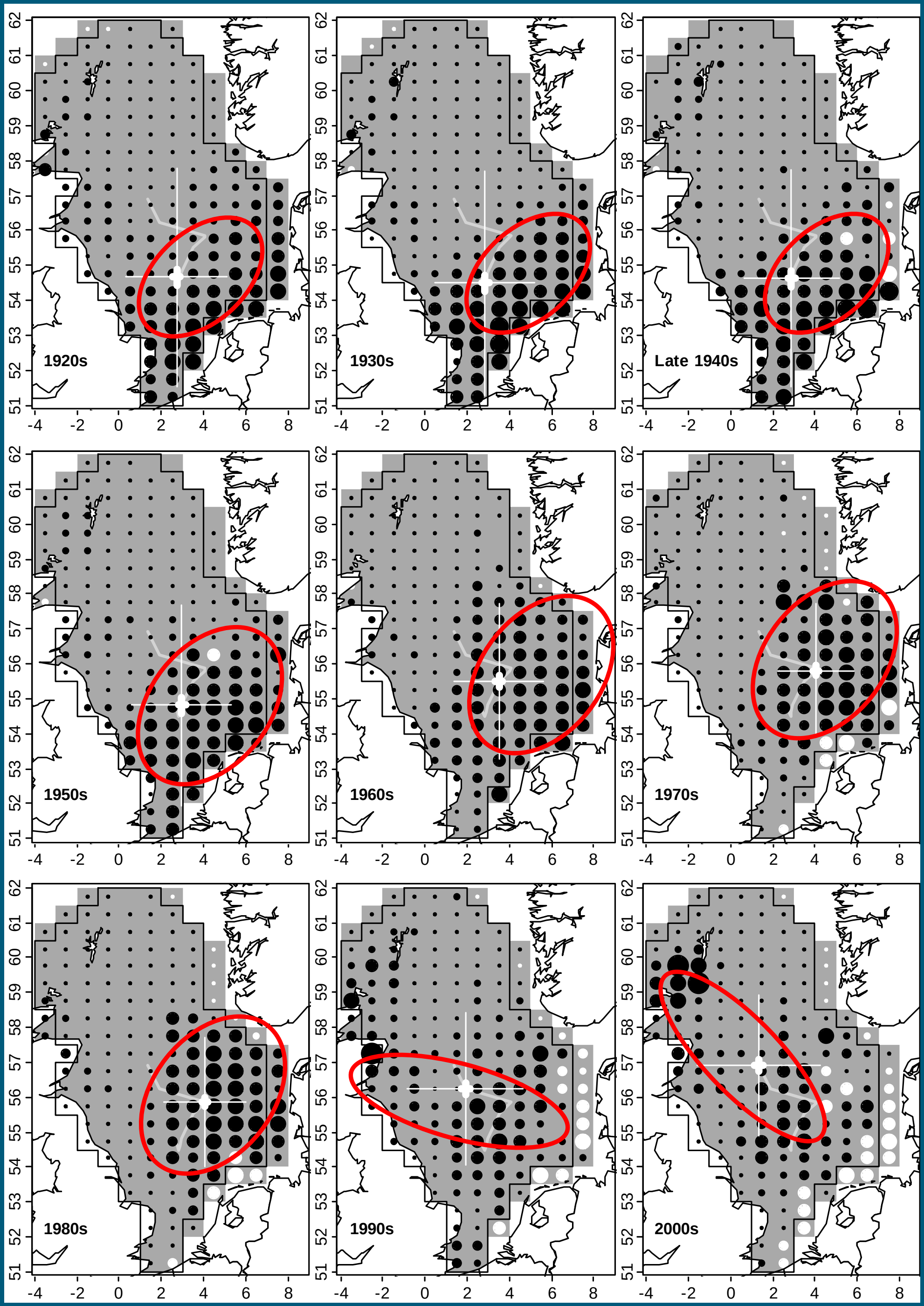
- 1982-present: sole & plaice cpue from electronic fishery activity databases for British motor otter trawlers



1920s-2000s: ***plaice*** distribution

(cpue normalised by year)

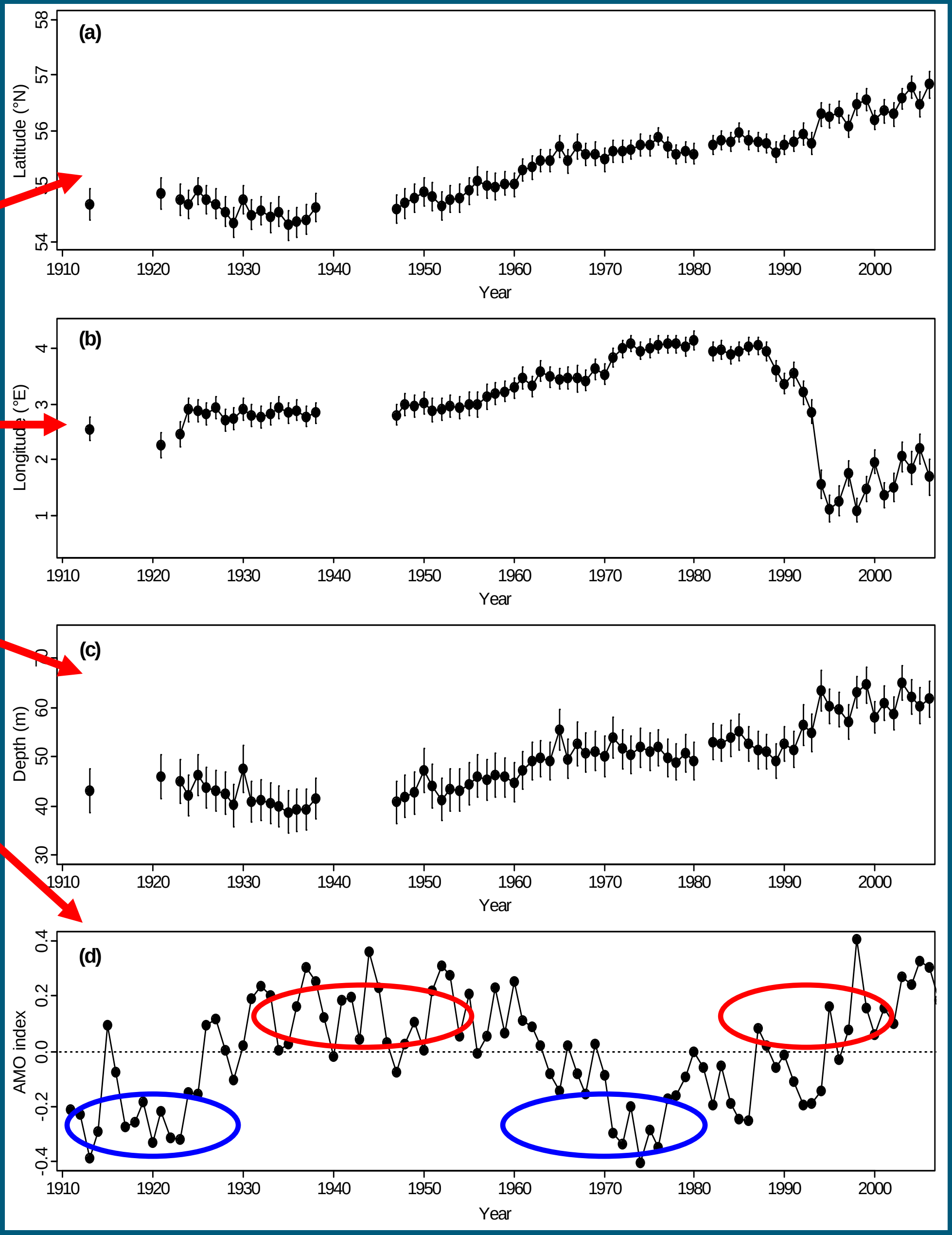
- 1920s–1940s: stable in S and SE North Sea
- 1950s–1980s: shifting NE-ward and expanding more offshore
- 1990s–2000s: collapse in E, especially inshore, but increased in NW (Scotland, Orkneys)



Changes in the centre of gravity of plaice distribution

- Latitudinal
- Longitudinal
- Depth
- AMO index

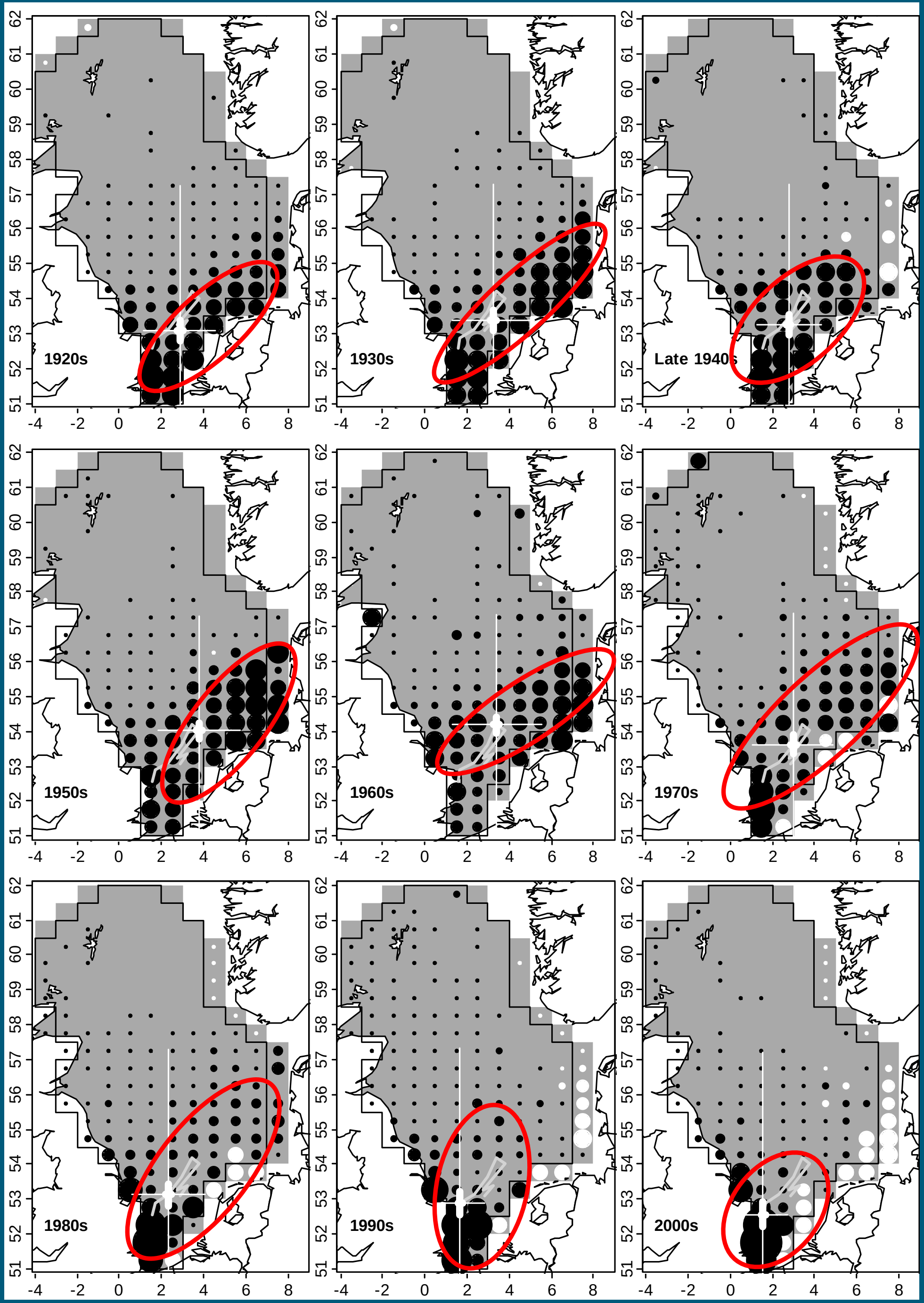
- Since WWII, ***near-continuous northward shift*** (and eastward up to 1990s), depth shift mimics N-S depth gradient
- Plaice distribution shifts ***not*** obviously linked to warmer/colder temperature regimes
- Linked to higher and increasing fishing effort in S, and/or to indirect effects?



1920s-2000s: ***sole*** distribution

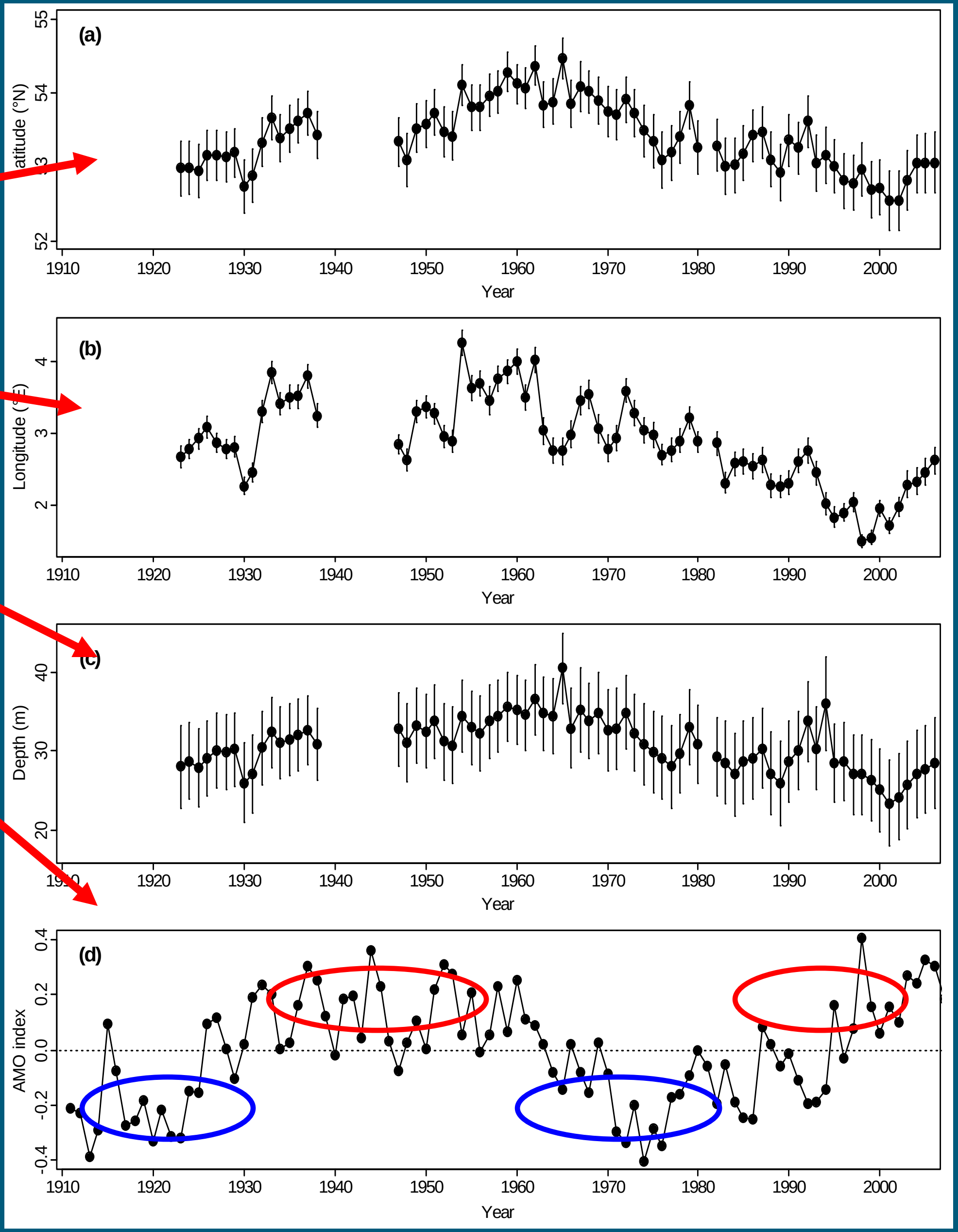
(cpue normalised by year)

- 1920s: very inshore distribution in SW
- 1930s–1960s: shift/expansion more offshore and more NE (esp. German Bight)
- 1980s–2000s: contraction away from NE and again more inshore, but more limited to SW



Changes in the centre of gravity of ***sole*** distribution

- Latitudinal
- Longitudinal
- Depth
- AMO index



- Pre-1980s, **shifts in CoG of sole appear linked to warmer and cooler climate regimes**
- Cold 1910s–1920s: sole limited to (shallow) SW, then during warm 1930s–1950s expansion N- and E, then during cold 1960s–1970s contraction to shallower SW
- But climate–distribution **links appear to fall apart in warming 1980s–2000s,** when sole *contract* rather than expand

Changes in the North Sea Food-Web

The *RV Huxley* was a commercial steam trawler that was commissioned in 1902 to assist the newly-created fisheries laboratory in Lowestoft.

Logbooks for these research cruises still exist and some of this information has now been digitized.

On the early cruises information was collected on **the 'food of fishes'.**

Pinnegar & Blanchard (2008) compared stomach contents of fish (of similar size) in the Dogger Bank region of the North Sea in 1902-1909 with those in 2004-2006

'Then' versus 'now'

Sandeels represent a greater proportion of the diet now compared to 100 years ago

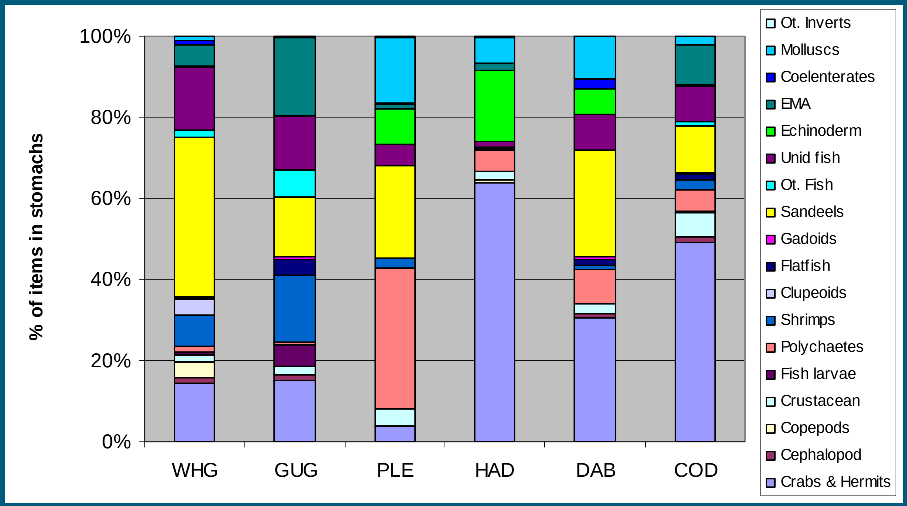
Mobile prey (e.g. crabs, hermit crabs) are now more important prey items

Bivalves (in particular *Solen* spp. and *Mactra* spp.) were more important in the past

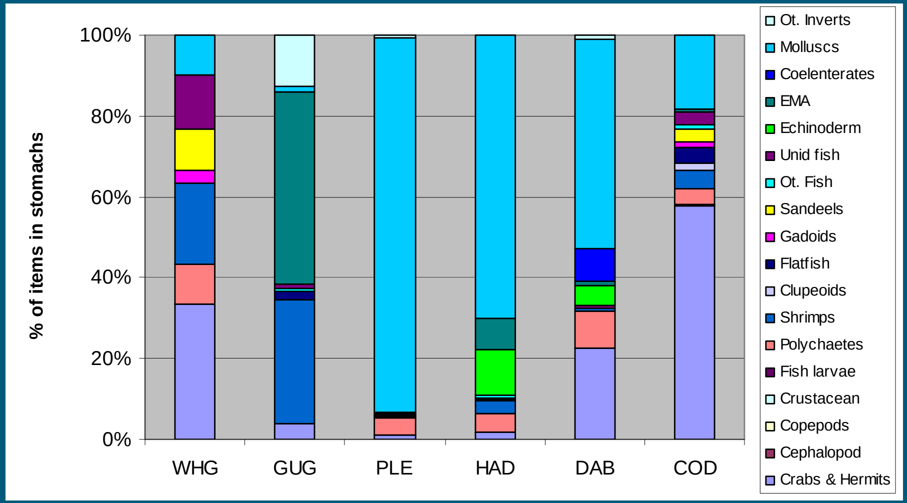
Callaway et al. (2007) demonstrated that crabs have dramatically increased in abundance since 1902, whereas many slow-growing bivalves have declined.

Were these changes driven by fishing pressure, habitat modification or climate????

Dogger Bank 2004 - 2007



Dogger Bank 1902 - 1909



‘Back to the Future’’

Mackinson (2001) attempted to construct a representation of what the North Sea ecosystem may have been just prior to the development of industrialized fisheries.

The period marks the end of the era of sailing trawlers and the appearance of the first steam trawlers *Zodiac* and *Aries* of 1881.

Is it possible to get from ‘there’ (1892) to ‘here’ (2009) by ‘forcing’ the model using only observed fisheries catch data?

Or… do you need additional explanatory variables such as climate indices (NAO, Temperature etc.)?

What is included in the model for the 1880s?

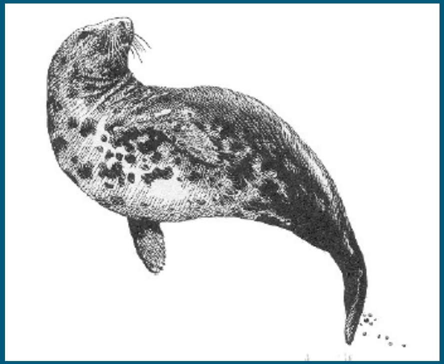
46 Functional groupings of organisms, including:

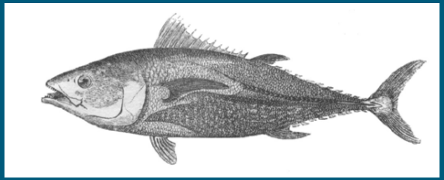
- •Cetaceans
- •Seals
- •Seabirds
- •Sharks (adult & juvenile), skates (adult & juvenile)
- •Bluefin tuna
- •Sturgeon

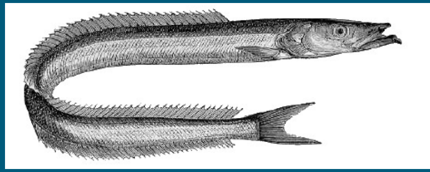
•23 other fish groups (inc. cod, herring, haddock, saithe, whiting, mackerel, horse mackerel, sprat, pout, sandeel, sole, plaice, halibut, turbot, brill, salmon)

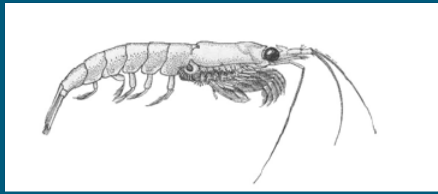
- •Cephalopods
- •2 zooplankton groups
- •5 benthos groups
- •3 microbial groups
- •Phytoplankton
- •2 detritus groups

•5 fishing fleets (trawlers, drifters, potters, seal hunting, others)







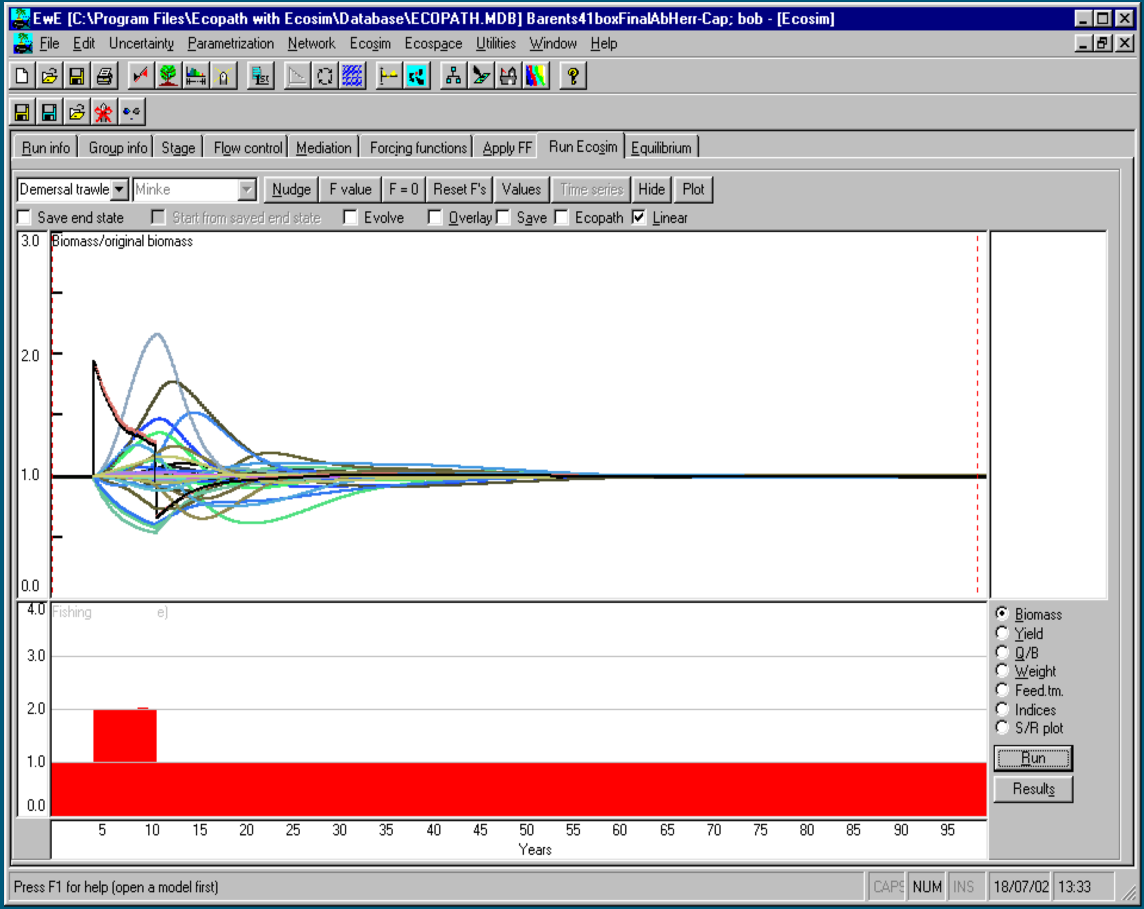


How Ecosim works…….

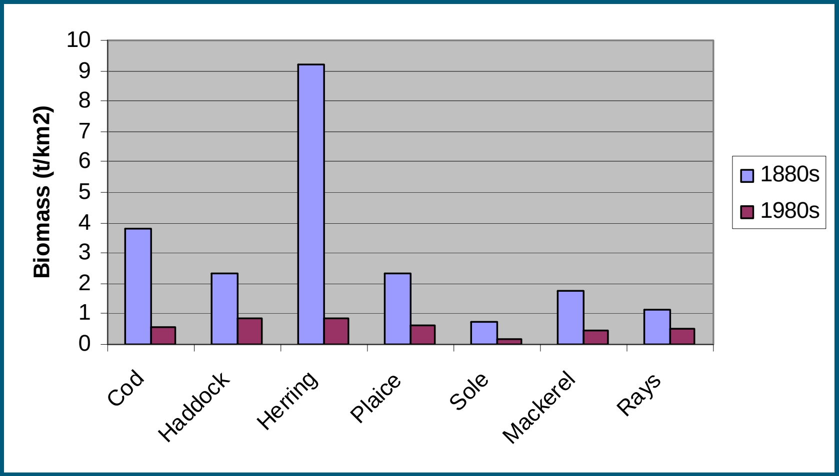
The foundation of the EwE (Ecopath with Ecosim) suite is an Ecopath model which creates a static mass-balanced snapshot of the foodweb.

Ecosim provides a dynamic simulation capability, with key initial parameters inherited from the base Ecopath food-web model (for equations, see Walters *et al*., 1997, 2000b).

If nothing changes in the modelled future (fishing pressure or climate etc.), then all organism biomasses will ‘flat-line’.

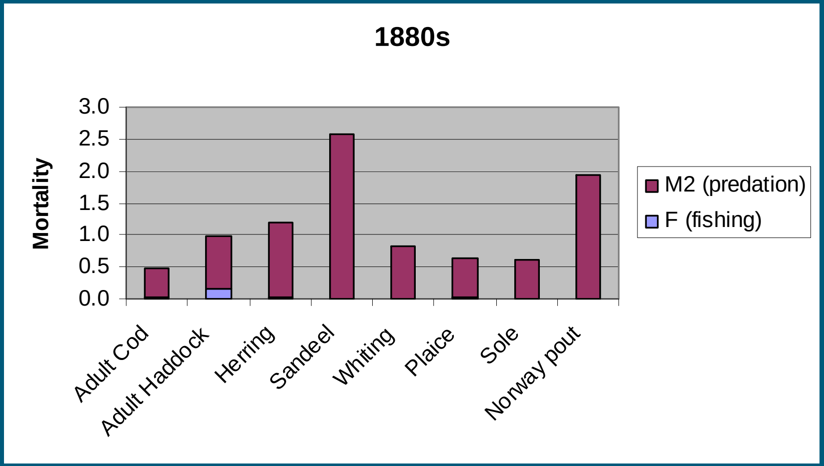


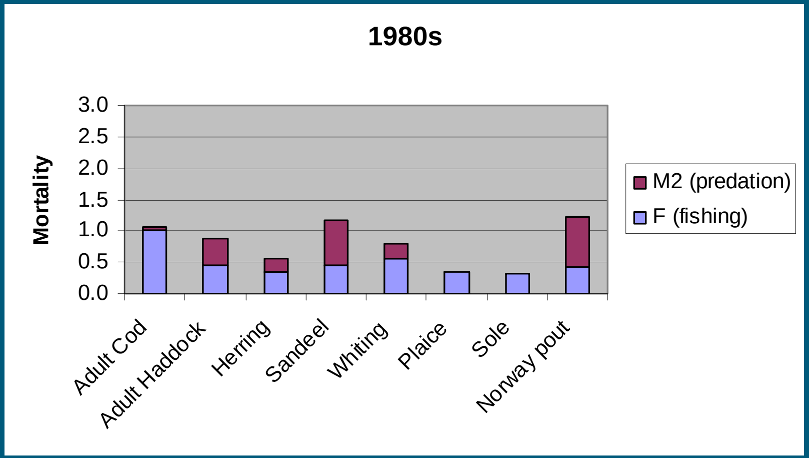
Comparing an Ecopath model for the 1880s with one for the 1980s



- All **commercial fish species were much more abundant in the 1880s** compared to the 1980s

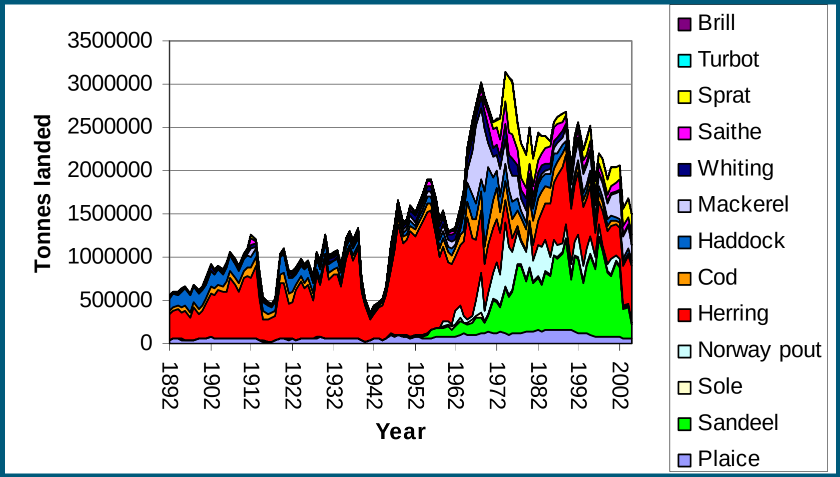
- **Fishing mortality (F) was much higher in the 1980s compared to the 1880s** when predation (M2) was the dominant cause of mortality



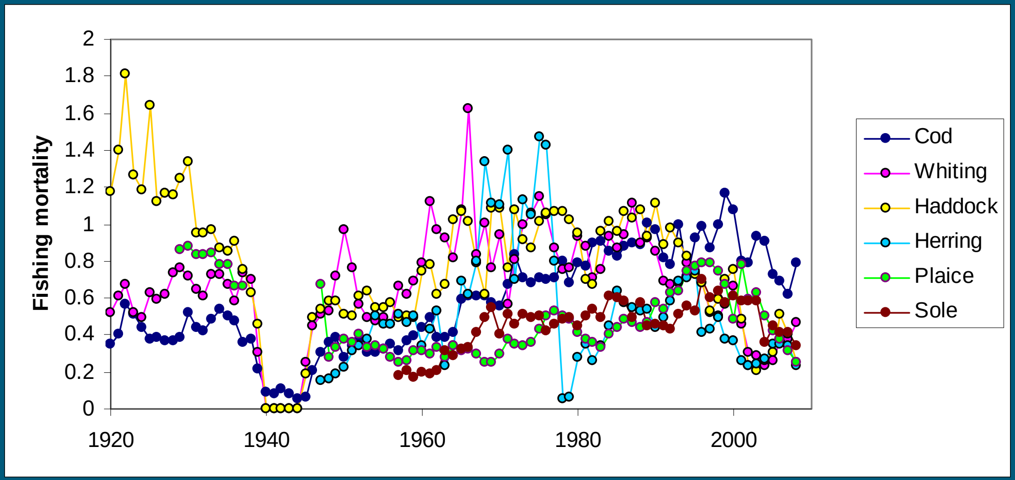


Fishing 'Forcing functions'

Reported fisheries catches



Fishing mortality (*F*) estimates



Available for 20+ species and covering the whole 118 year time period (1892-2009)

Stock assessments only available for selected species and for part of the 188 year time period

From Pope & Macer (1996); Rijnsdorp & Millner (1996)

Environmental 'Forcing functions'

NAO (North Atlantic Oscillation)

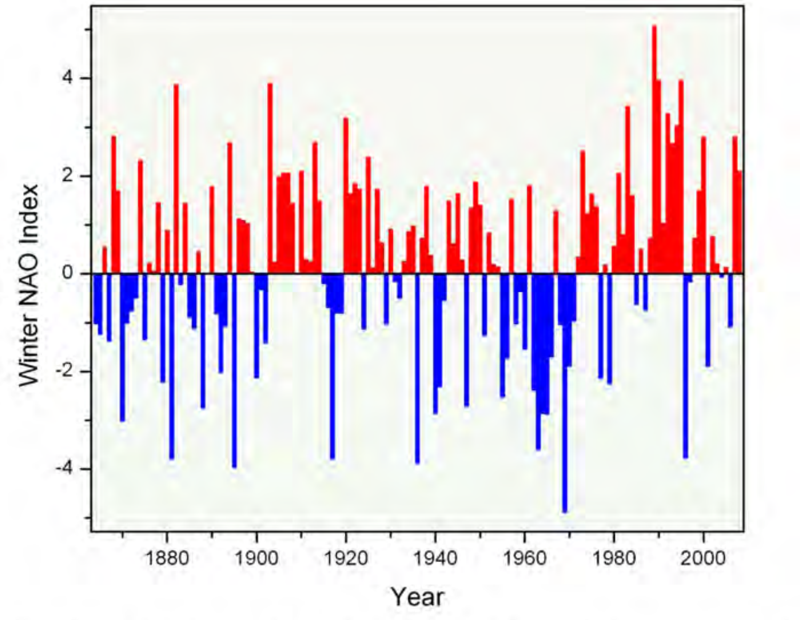


Figure 2.1 Trends in the winter North Atlantic Oscillation Index over the last century expressed as standardized anomalies.

AMO (Atlantic Multidecadal Oscillation)

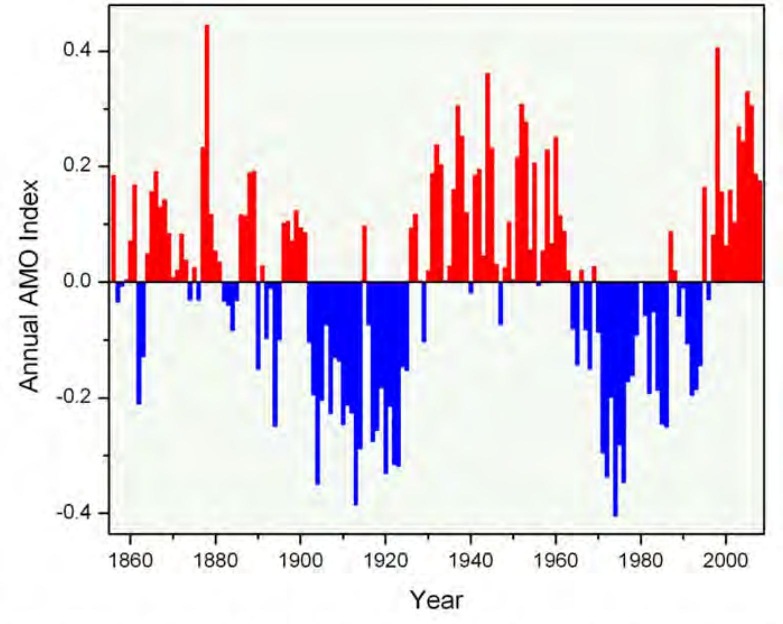


Figure 2.2 Trends in the Atlantic Multidecadal Oscillation Index expressed as standardized anomalies.

Applied as a 'forcing function' to all primary producers (bottom up) through the food-web

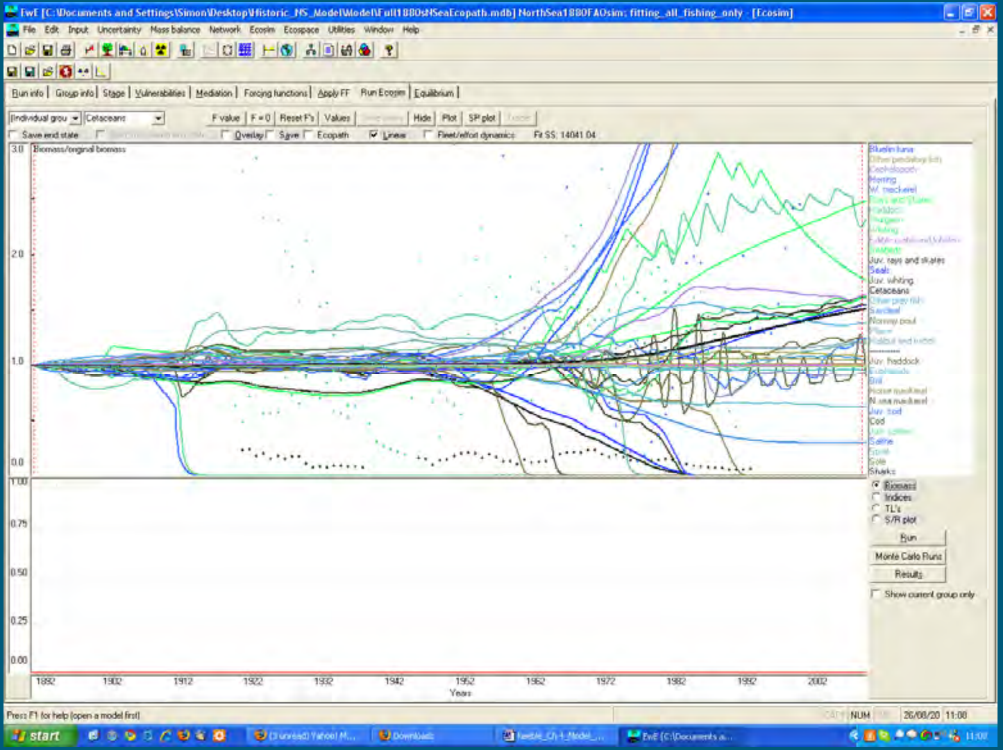
Results…..

Still quite a long way to go with the analyses

So far … **forcing with the 118 year time-series of <u>recorded catch data</u> does not give a good fit to the ‘observed’ biomass data**

‘Fitting’ and ‘forcing’ simultaneously results in only a marginal improvement in fit.

Adding ‘bottom up’ forcing using environmental variables (AMO, NAO, Marsdiep SST), in addition to the recorded catches does not help to improve the fit.



There seems to be a problem that there is not enough biomass (or production) in the model to sustain the ‘observed’ ICES catches

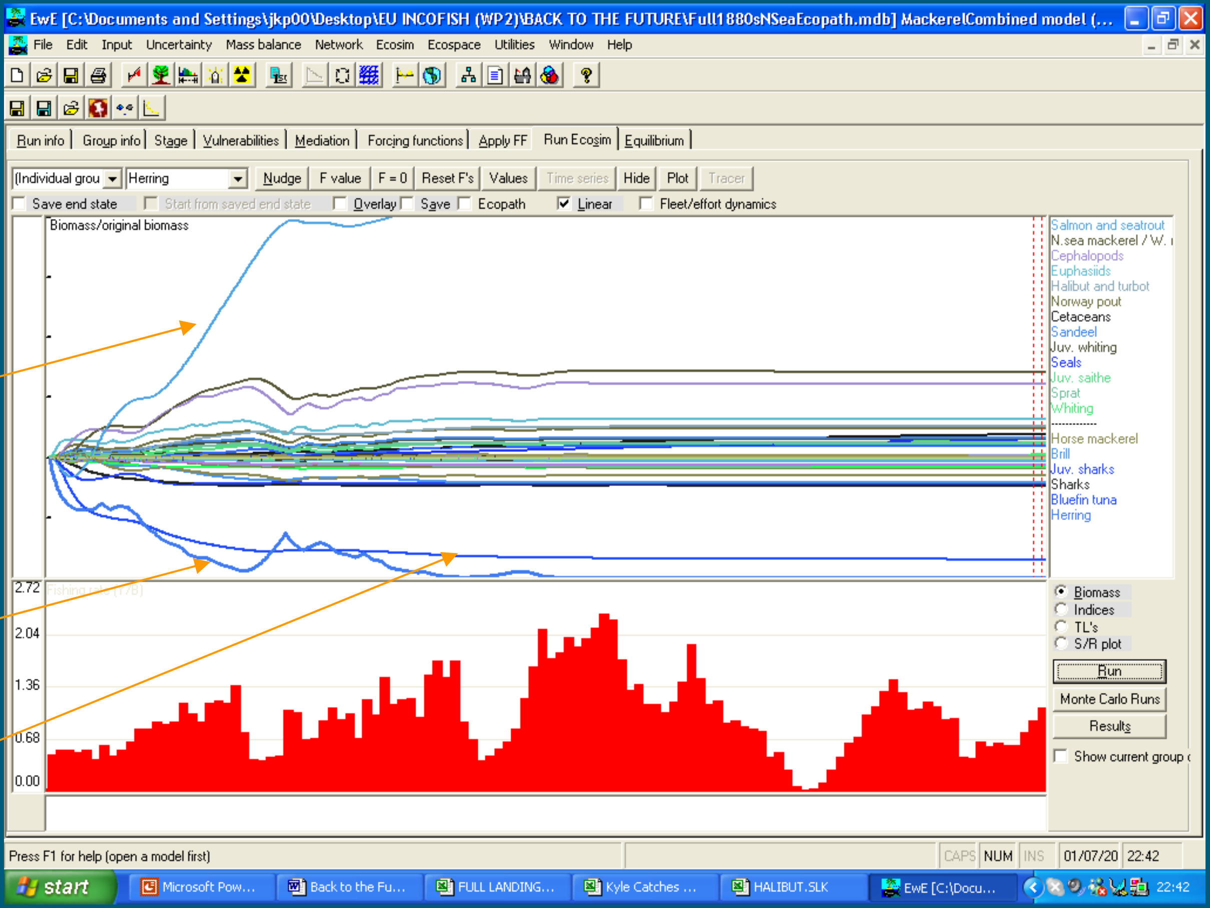
So what happens when we 'force' the model?

Only inputting an 'observed' time series of landings for herring

Salmon & Sea-trout

Herring biomass 'crashes'

Bluefin Tuna decline



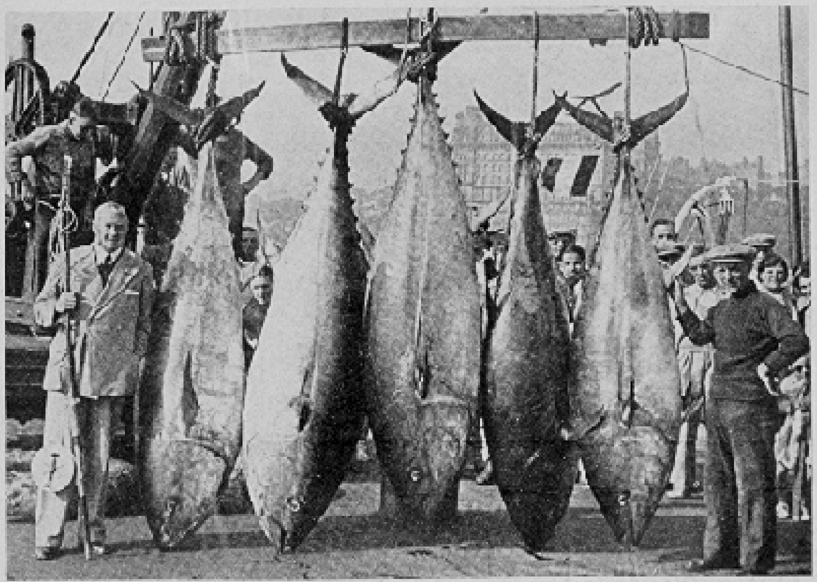
Relics of the past : Bluefin tuna

Thunnus thynnus used to migrate to northern European waters (Norwegian Sea, North Sea, Skagerrak, Kattegat, and Øresund) where it supported important commercial and sport fisheries.

The species disappeared from the region in the early 1960s and observations are now extremely rare.

The factors which led to the development of the fishery and its subsequent decline remain unclear and poorly documented (MacKenzie & Myers, 2008).

TUNNY SEASON, 1938



World Record catch of five Tunny at Scarborough, in one day, by Capt. C. H. Frisby, V.C. These fish weighed respectively 621 lbs., 527 lbs., 461 lbs., 658 lbs. and 545 lbs.

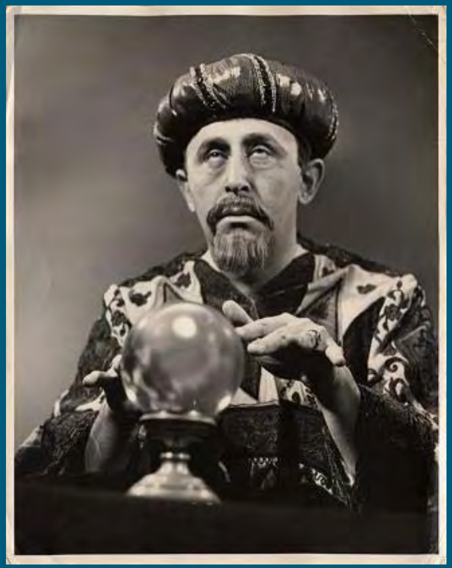
Conclusions & future plans…..

1. There have been major changes in the distribution of North Sea fish species and the prey that they consume

2. It is very difficult to separate the influence of long-term climate change from the effects of fishing and habitat modification

3. Still quite a lot of work to do to see why many stocks collapse in the model, when 'observed' (landings reported to ICES) are applied

4. The prospects of certain species are highly dependent on other species in the ecosystem (e.g. blue-fin tuna and herring)



Acknowledgements

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