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



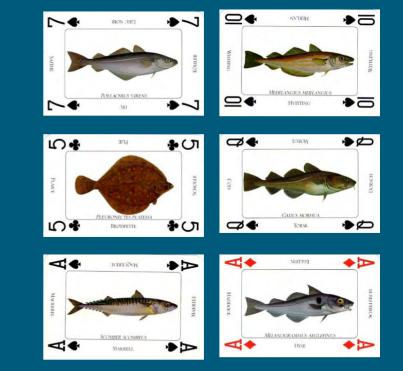
John K. Pinnegar, Steven Mackinson, Kathryn Keeble and Georg H. Engelhard

PICES Science Board Symposium, Jeju - Korea - Monday 26th October, 2009

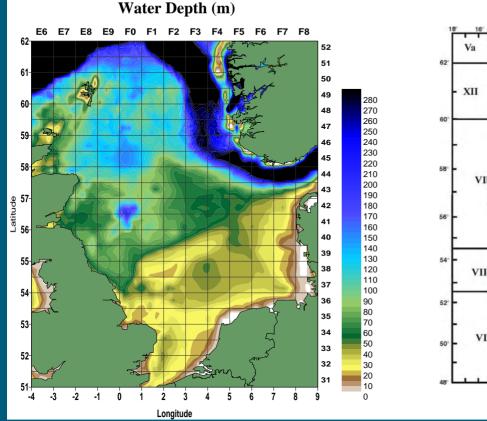


## Programme.....

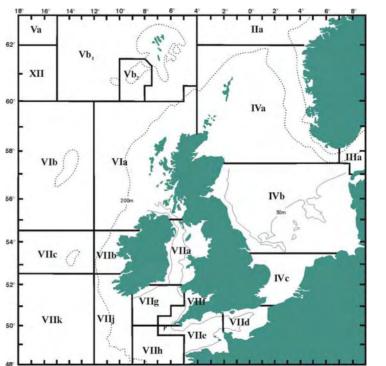
- 1. The North Sea ecosystem
- 2. Changes in fish distribution (fishing versus climate change)
- 3. Changes in food-webs
- 4. Reconstructing a model of ecosystem in the 1880s
- 5. 'Forcing' & 'Fitting' the model
- 6. Can we get from 'there' (1880s) to 'here' (2009)?
- 7. Some conclusions



## The North Sea Ecosystem:



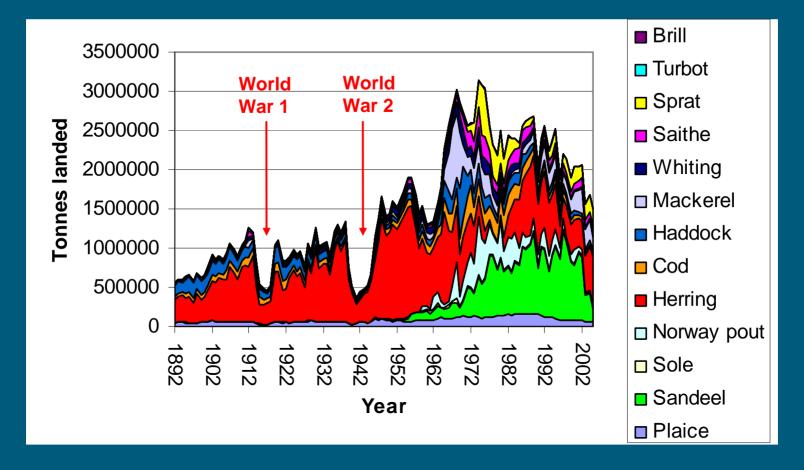
**ICES Stock-Assessment Areas** 



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)

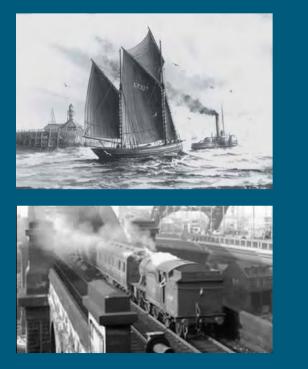
The north Sea harbours a wide range of fish stocks exploited mainly by: France, Germany, Belgium, Netherlands, Norway, England, Scotland, Denmark.

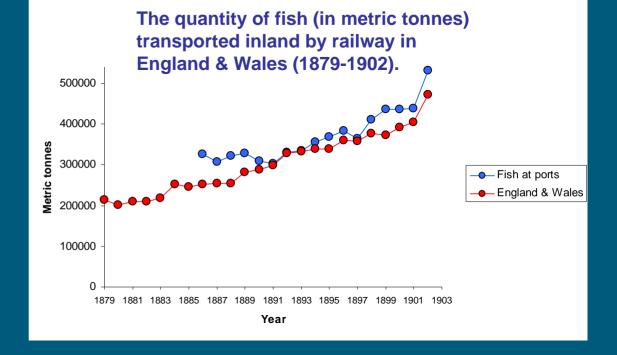
## 115 years of North Sea fisheries catches



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!*



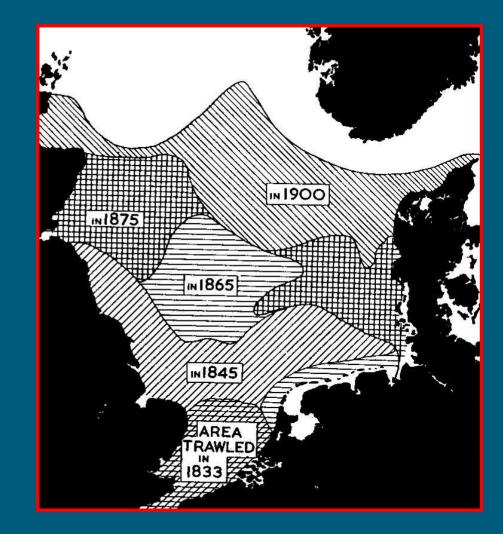


Note that the tonnage in 1902 (473274 metric tonnes) was 3<sup>1</sup>/<sub>2</sub> times that landed at English and Welsh ports in 2002 (128300 metric tonnes).

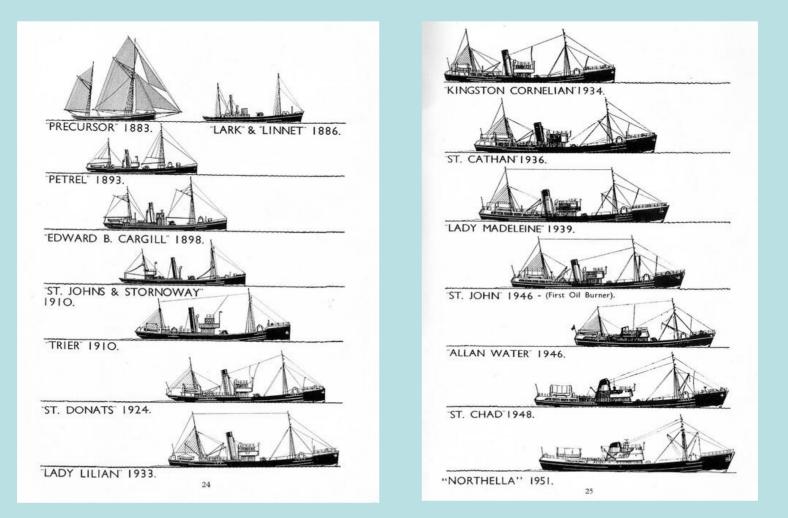
As early as 1893 the UK parliament felt the need to convene a special 'Select Committee on Sea Fisheries', in response to fears of overfishing in the North Sea.

# 19<sup>th</sup> 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

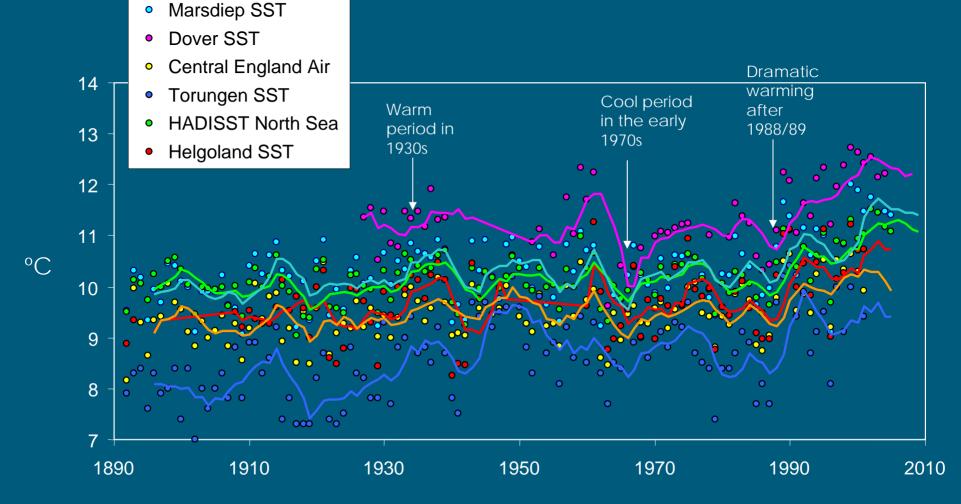


# How has fishing power changed over 120 years of trawling the North Sea?



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Note the generally close correlation between time series & the overall warming trend during the 20<sup>th</sup> 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. Parry 1" Paula I. Low 27 Em R. Bills " John D. Reynolds"

We show that the dotniketons of both excepted and representated North Sea fores make responded markedly as recent increases in sea armperature, with made two floods of gracies shifting in magning buildate widenth or both over 25 years. For species with northerly or southerly harve margins in the filtree Sea had have shown boundary shifts with warning, and all but one shifted northund Storie with diffici distributions have famin its mater and tendle loody sizes that fronth/fileg species. Further temperature / see an Moly to have conferred concerts on pressooned) fichation through contributed stills to distribution and alterations in community interactions

Chesse change is predicted to drive species rations is ward the price (7) promisely result-ing in widespread extinctions where dispersal invited or suitable habits is uncessible (7) For Sales commendation may sweap by influence dooribution and abandiance ( 5, 4) through changes in growth, surtrack anotherized or extension to changes to other unphile levels (5, 6). These changes may investigation on the many and value of oursneretal Ederice Species-specific responses are Budy to vary according to name of population turnstver. Fish seconds with stress sized turnstver formerations, may also wild most rared dente graphic responses to temperature charges, contractions in second which belowing in antidations wantrant. We used for large-saile, thread-orbital changes of marrier foll dive has tions and examined whether the disc business of one has seen instanting he flow one enough life history characteristics are particulariy responsive to temperature changes.

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Centre for Ecology, Birdutton and Conservation, Education of Biological Sciences, University of East Angle, Normida MR4 7T; LK. <sup>1</sup>Centre for Environment, Altherits and Aquitations Science, Lowershit Laboratory Low stict Mades OHT, LINC "To show componence should be addressed 5-real appropriate stud (ALP); symbol function (D.P.)

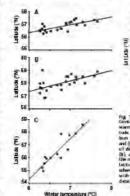
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species range was emirely confined to the North Sea. Measures of distribution were

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24 JUNE 2005 VOL 508 SCIENCE www.scimoum.gt.org

[Science, 308: 1912-1915]

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#### Journal of Applied Ecology

Janual of Amilaid Surface 2006 45, 1020-1070

doi:10.1111/0.1345.3/644.2008.01468.7

P.

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

Nicholas K, Dulvy<sup>12\*</sup>, Stuart I, Rogers<sup>1</sup>, Simon Jenhincs<sup>1</sup>, Vanessa Stetzenmüller<sup>1</sup>, Stephen R. Dve<sup>1</sup> and Heim R. Skioldal®

Centre for Environment, Fisherkes and Aquaculture Solence, Lowestoff Laboratory Lowestoff NR33 DHT, UK <sup>3</sup>Simon Preser University, Department of Biological Sciences, Burnapy, BC, Canedo VSA 156: and <sup>4</sup>institute of Marine Research, Box 1870 Nordhes, N-5817 Bergen, Norway

#### Summary

1. Climate change impacts have been obterved on individual species and species subsets; however, if 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 shell seav are warming to ster than the adjustent land masses and inster than the slabol average. We explore the year-by-year distributional response of North Sea bottom-lwelling. demenual, fishes to temperature change over the 2.5 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 tub monitoring survey.

3. Individual species responses were accretated into 19 international species reflecting of Waterlogy (thermal preference and range's ecology (body size and abundance-occupancy patients), biogeography (northern, nouthern and presence of range boundaries), and susceptibility to human impact (fisher/ target, hypatch and non-target species).

4. North Sea winter bottom temperature has increased by J.S. Cover 25 years, with a J. Cincrease in 1988-1985 alone, During this period, the whole demersal fish assemblage deepened by ~3.6 m decade" and the deepening wir coherent for most assemblages.

5. The latitudinal response to warming was heterogeneous, and reflects (i) a northward shift in the mean littlinds of abundant, widespread thermal specialists and fill the southward shift of relatively small, abundant southerly species with limited occupancy and a northern range boundary in the South Sea.

6. Southesis 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 chimate change impaci. 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.

Rey-words: climate change, habital loss, invisive species, life-history trait, North Sea, regime that, thermal preference

#### latenduction

Climate thatter affects demography, geographic distribution and phenology of populations and species. Demographic effects are manifest as changes in recruitment, arowith and survival (O'Brien # al. 200); Portner & Kmust 3:07), duwithoutiental shifts as measurements towards the redestor hasher. altindes (Walther et al. 2012; Parmetan & Yohe 2017), and phenological effects as advances in the limits of artime related events by ~ 27 days decade ', with earlier dowering exclusion, punkton bloom: and the meration: creditte potential for minimatching between and predator and prey population of net & Sparks 1992 Similar at 2001 Parmeter & Yohs 2003) Edwards & Richardion 2004), Climate changeinduced labitations and changing mexics distributions are

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#### [*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 coldadapted 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

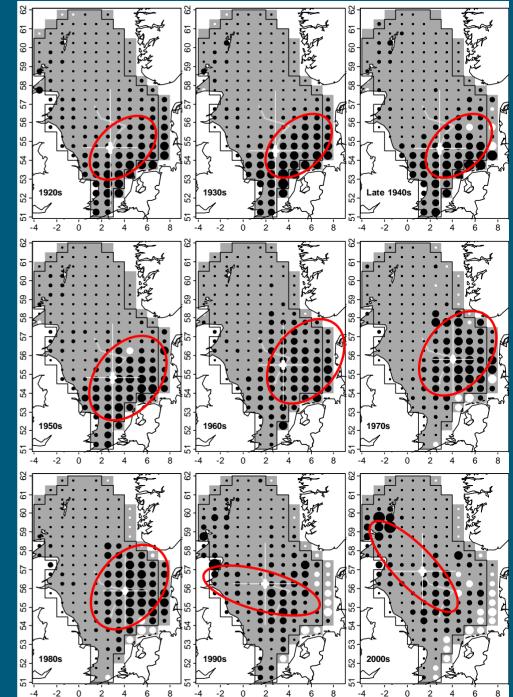


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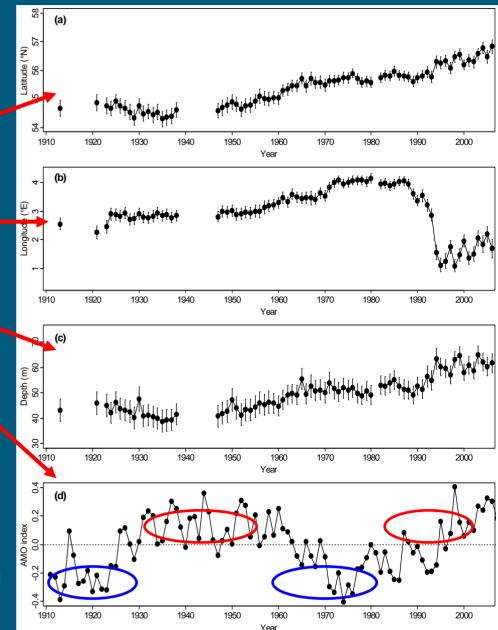
## 1920s-2000s: *plaice* distribution (cpue normalised by year)

- 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

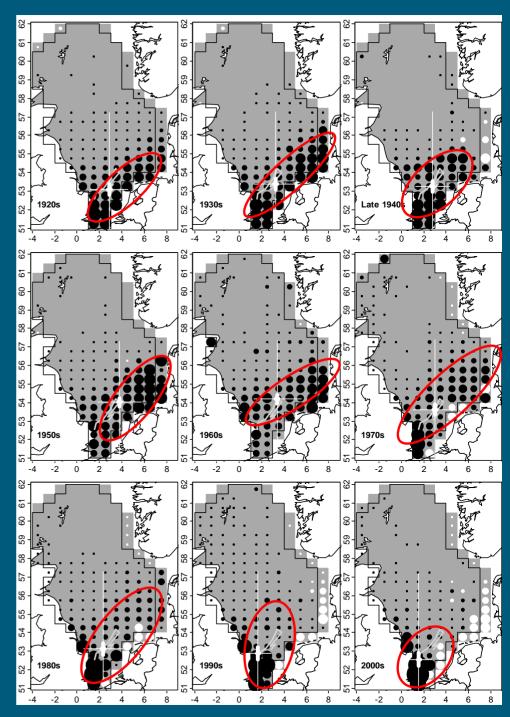
- Latitudinal
- Longitudinal
- Depth
- AMO index
- Since WWII, near-continuous northward shift (and eastward up to 1990s), depth shift mimics N-S depth gradient
- Plaice distribution shifts *not* obviously linked to warmer/colder temperature regimes
- Linked to higher and increasing fishing effort in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





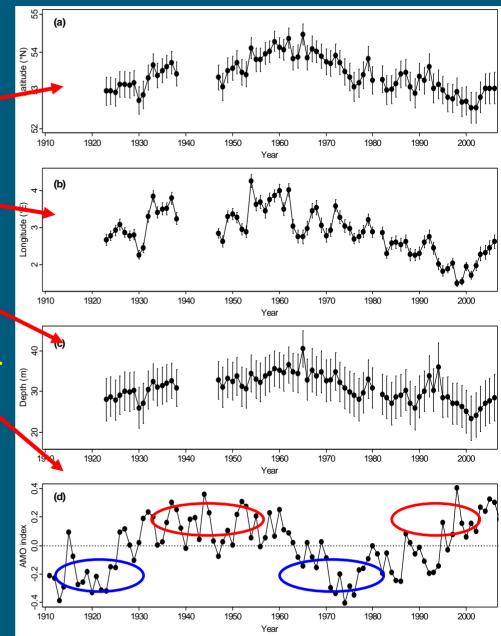
## 1920s-2000s: **sole distribution** (cpue normalised by year)

- 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

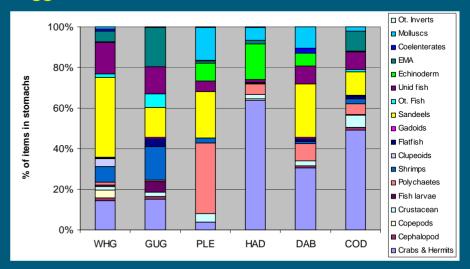
Mobile prey (e.g. crabs, hermit crabs) are now more important prey items

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

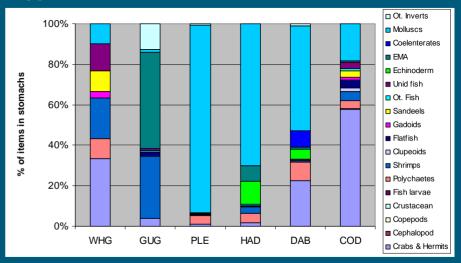
Callaway et al. (2007) demonstrated that crabs have dramatically increased in abundance since 1902, whereas many slow-growing bivalves have declined.

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

#### Dogger Bank 2004 - 2007



#### Dogger Bank 1902 - 1909



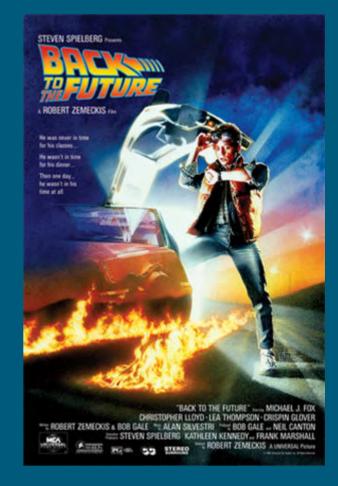
# 'Back to the Future"

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?

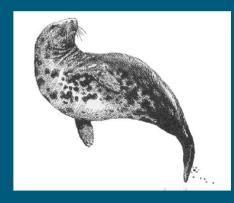
46 Functional groupings of organisms, including:

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)









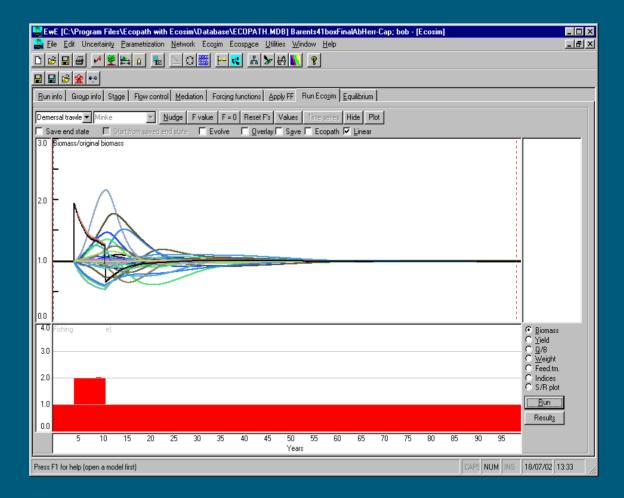


## How Ecosim works.....

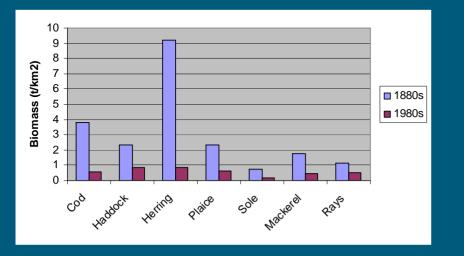
The foundation of the EwE (Ecopath with Ecosim) suite is an Ecopath model which creates a static mass-balanced snapshot of the foodweb.

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'.

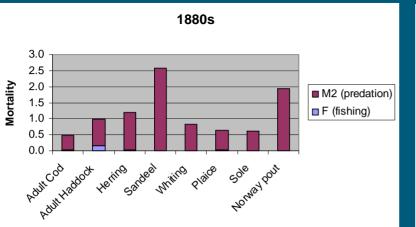


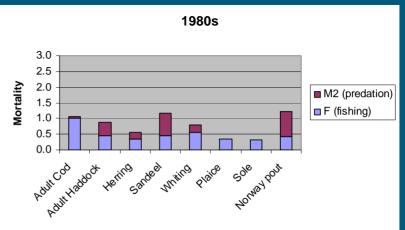
# Comparing an Ecopath model for the 1880s with one for the 1980s



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

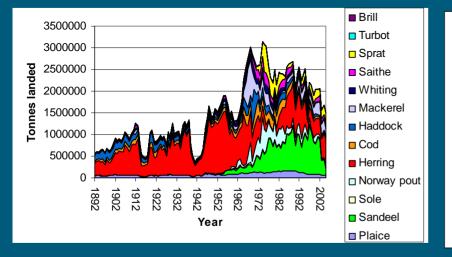
•Fishing mortality (F) was much higher in the 1980s compared to the 1880s when predation (M2) was the dominant cause of mortality



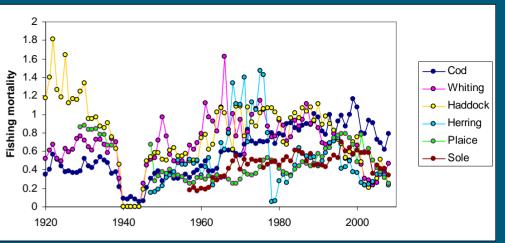


Fishing 'Forcing functions'

#### **Reported fisheries catches**



### Fishing mortality (F) estimates

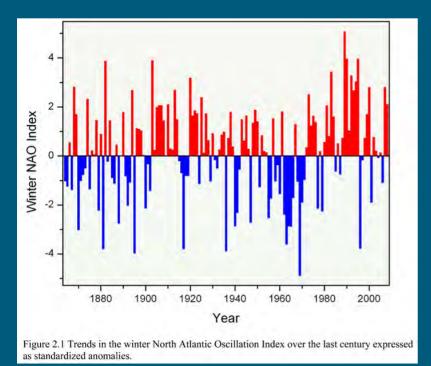


Available for 20+ species and covering the whole 118 year time period (1892-2009) Stock assessments only available for selected species and for part of the 188 year time period

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

## Environmental 'Forcing functions'

### NAO (North Atlantic Oscillation)



#### AMO (Atlantic Multidecadal Oscillation)

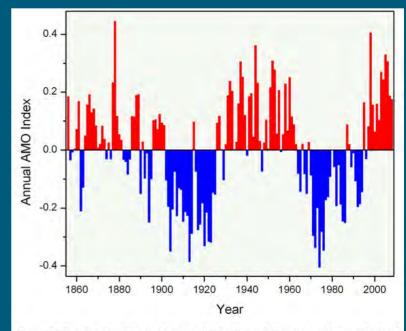


Figure 2.2 Trends in the Atlantic Multidecadal Oscillation Index expressed as standardized anomalies.

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

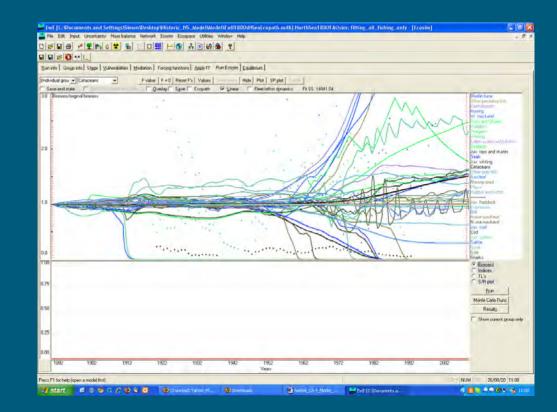
*Results*....

Still quite a long way to go with the analyses

So far ... forcing with the 118 year time-series of <u>recorded</u> <u>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

Run info Group info Stage Vulnerabilities Mediation Forcing functions Apply FF Run Ecosim Equilibrium ▼ Nudge F value F = 0 Reset F's Values Time series Hide Plot Tracer (Individual grou 👻 Herring Save end state Start from saved end state Overlav Save Ecopath Biomass/original biomass almon and seatrout N.sea mackerel / W. i enhalonods alibut and turbot Norway nout Cetaceans andeel Juv whiting Seals Salmon & uv saithe Sea-trout lorse mackere uv sharks Sharks Bluefin tuna Herrina Herring 2.72 Biomass biomass Indices TL's 2.04 S/R plot 'crashes' Run 1.36 Monte Carlo Buns Results 0.68 Show current aroup Bluefin 0.00 **Tuna decline** Press F1 for help (open a model first) NUM 01/07/20 22:42 📓 Back to the Fu.. FULL LANDING. Kyle Catches . HALIBUT.SLK EwE [C:\Docu. 🔇 🖸 强 🔛 🔁 22:42 🛃 start

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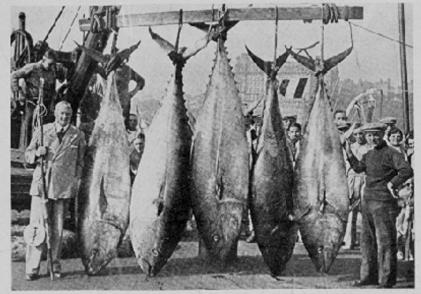
# *Relics of the past : Bluefin tuna*

*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.....

- 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 longterm climate change from the effects of fishing and habitat modification
- 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
- The prospects of certain species are highly dependent on other species in the ecosystem (e.g. blue-fin tuna and herring)

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