How has climate change impacted marine food-webs in the past, and how might we predict changes in the future?





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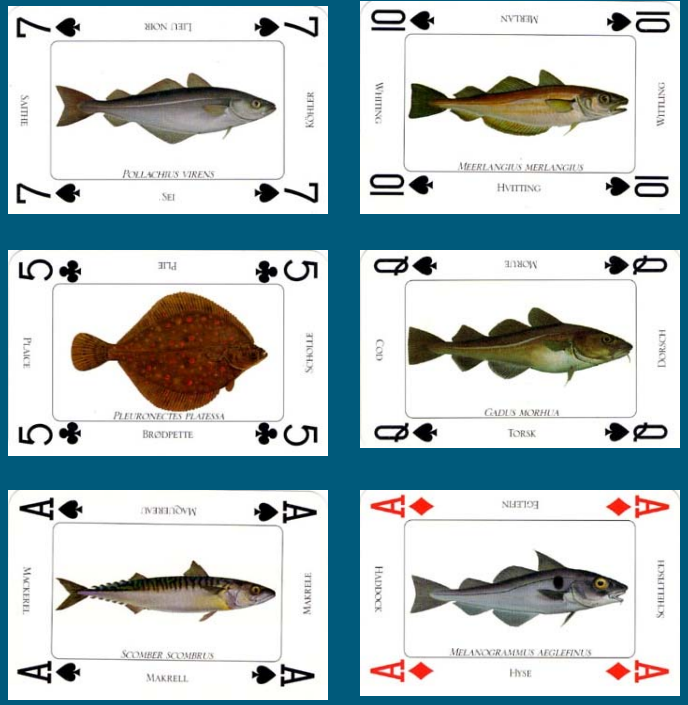
International Symposium: Climate Change Effects on Fish & Fisheries, Sendai, Japan. Session A2

Monday 26th April, 2010

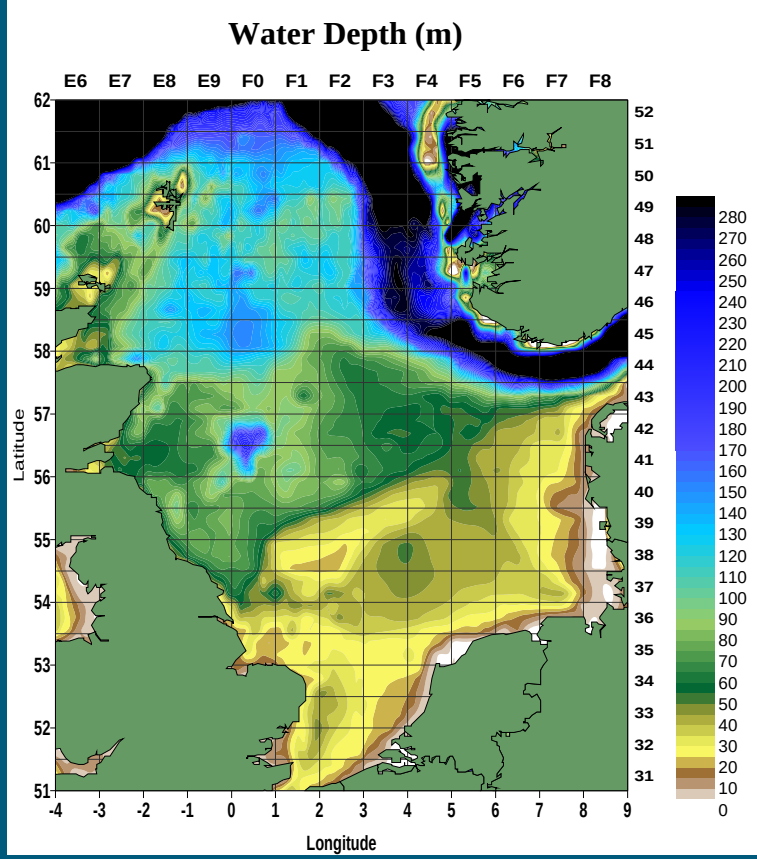
Cefas

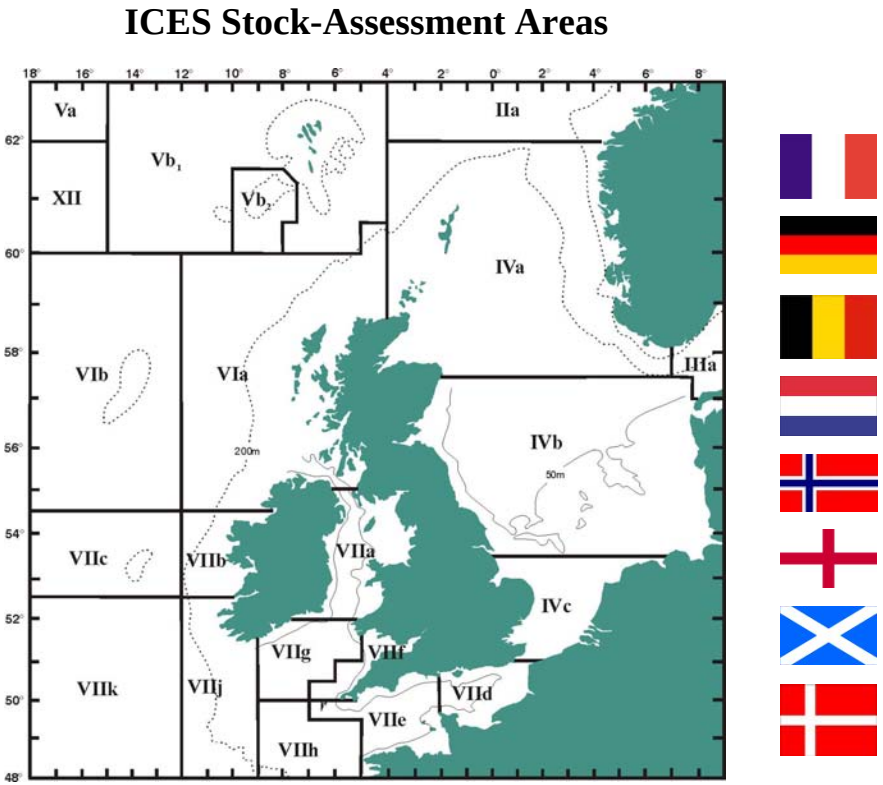
Programme……

1. The North Sea ecosystem
2. Changes in fish distribution (across Europe)
3. Climate vs fishing vs habitat modification
4. Consequences for fisheries
5. Consequences for food-webs
6. Predicting the future
7. Some conclusions



The North Sea Ecosystem:

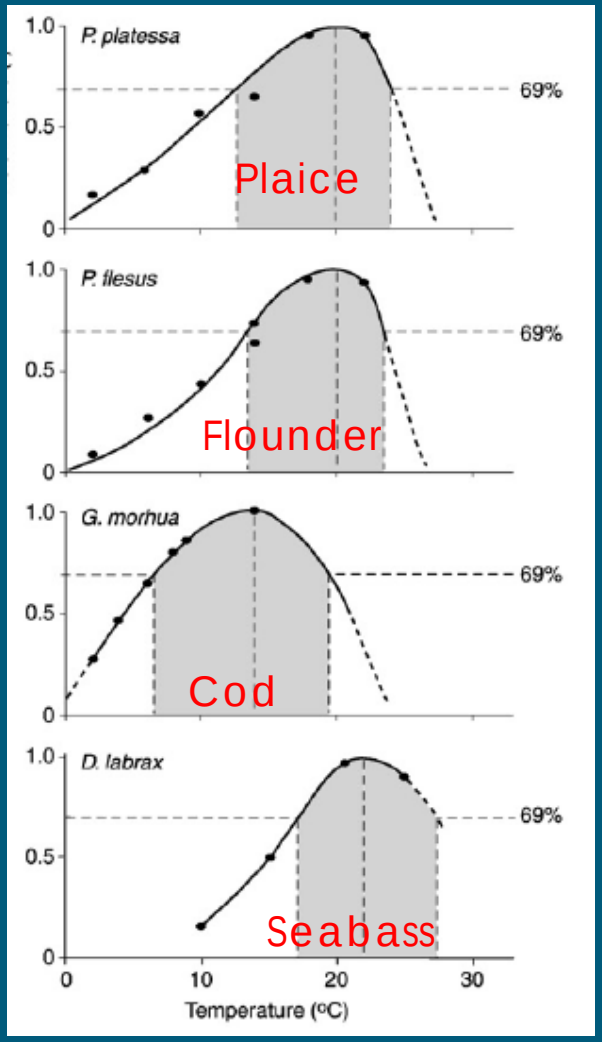




- The North Sea is a semi-enclosed basin with a depth ranging from 30m – 200m
- The ecosystem is dominated by soft-bottom habitats (sand, mud, gravel)

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

Changes in fish distribution (across Europe)

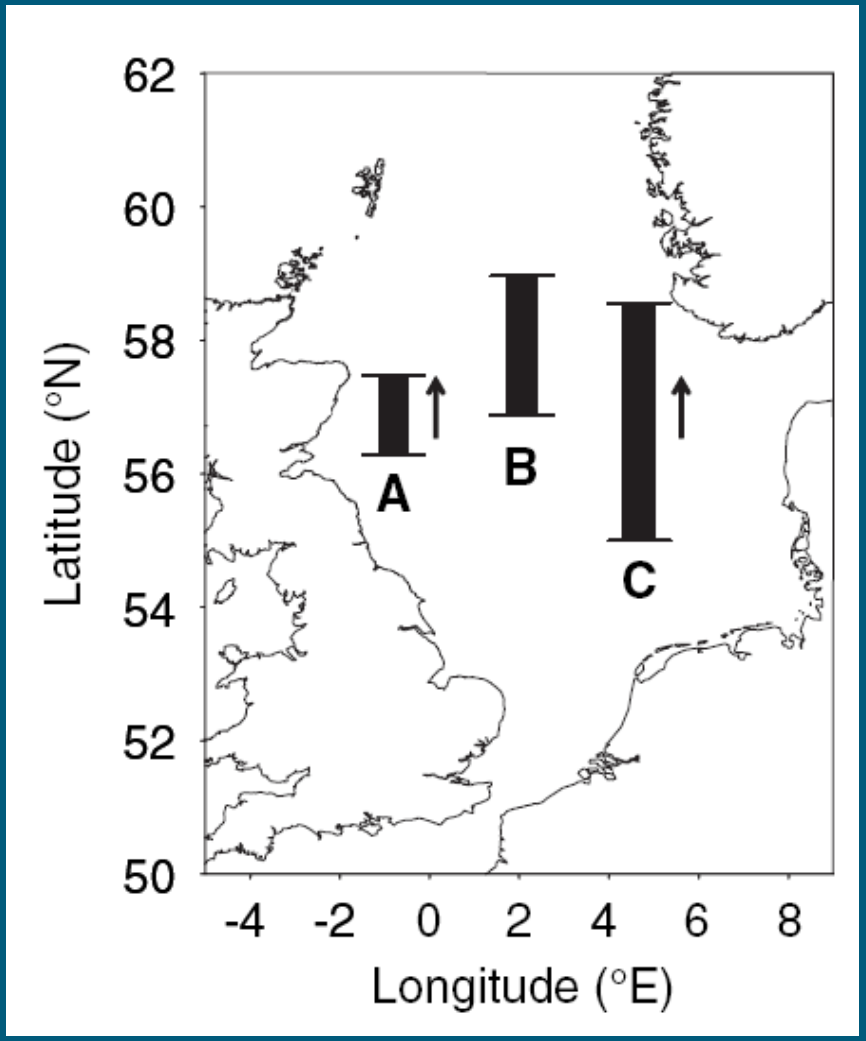


From Freitas et al. (2007)

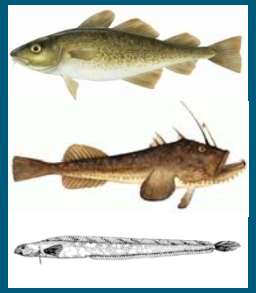
Temperature is one of the primary factors, together with food availability and suitable spawning grounds that determine the large-scale distribution patterns of fish.

Because most fish species prefer a specific temperature range, an expansion or contraction of the distribution range often coincides with long-term changes in temperature and/or climate.

The recent warming trend in the northeast Atlantic has coincided with an apparent northward shift in the distribution of fish species from southerly latitudes



A = cod
B = monkfish
C = snake blenny



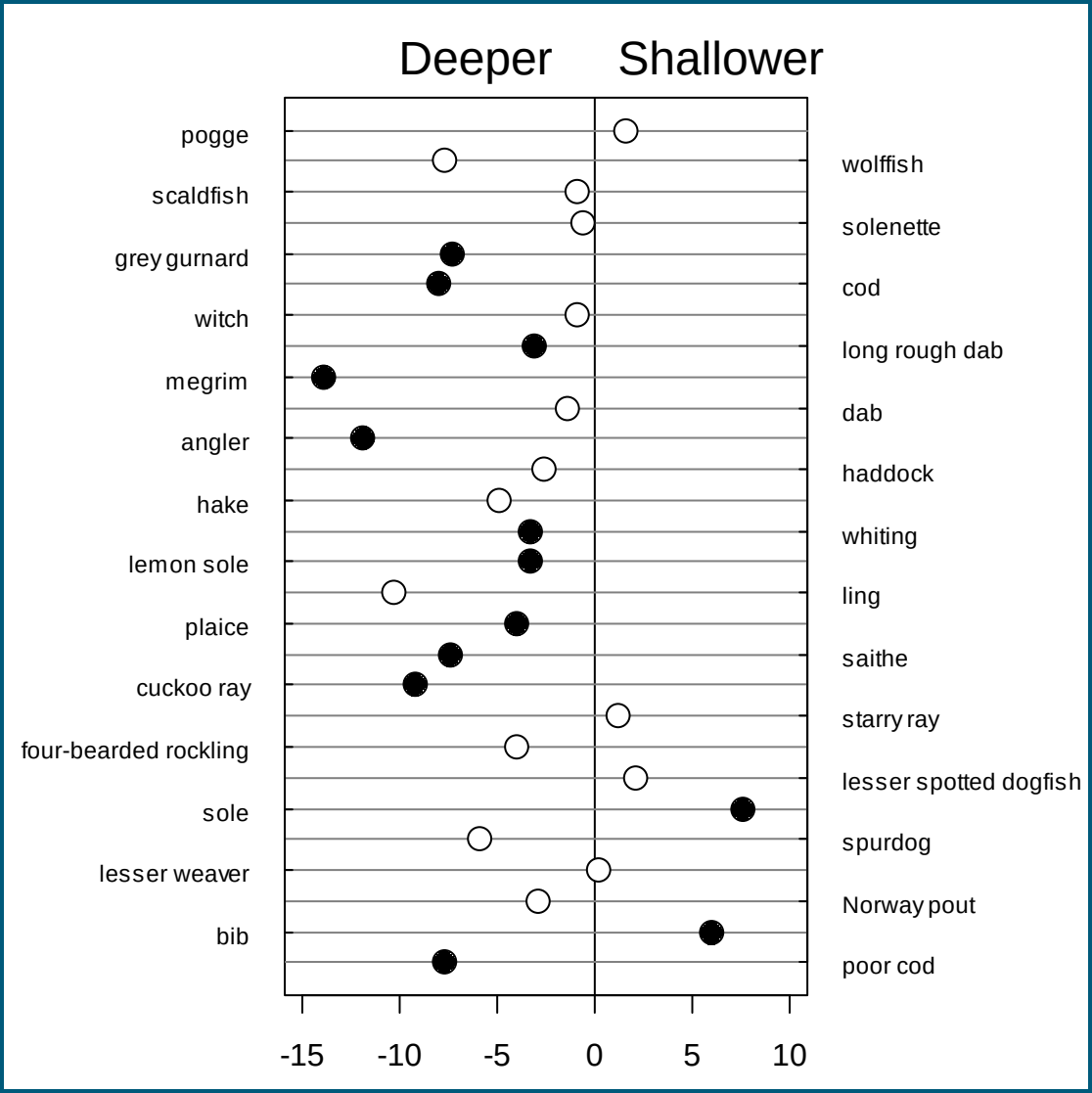
Perry et al. (2005) demonstrated that distributions of both exploited and non-exploited North Sea fishes have changed markedly over the last 25 years.

Centres of distribution generally shifted by distances ranging from 48 to 403 km during the period 1977 – 2001.

These authors concluded that further temperature rises are likely to have a profound impact on commercial fisheries.

[see *Science* 308: 1912-1915]

Fish have also moved to deep waters.....



From 1980-2004, the North Sea fish assemblage 'deepened' by ~3.6 m per decade

The deepening response was more dramatic in comparison with the latitudinal response that had previously been reported

Coldwater species, like megrim and anglerfish, are deepening fastest with warm-water species (e.g. sole and bib) shallowing over time.

[see *Dulvy et al. 2008*] [See presentation B2-6054]

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

RECLAIM

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 cod, haddock, sole and plaice distribution data were analysed

1913-2008: 'Statistical Charts' with cod, haddock, sole & plaice cpue by rectangle, for British steam and motor otter trawlers

Analyses of Scottish and English commercial catch data spanning the period 1913-2007, by Engelhard et al. (Cefas, Lowestoft) has revealed that the peak catches of target species such as cod, haddock, plaice and sole, have all shifted

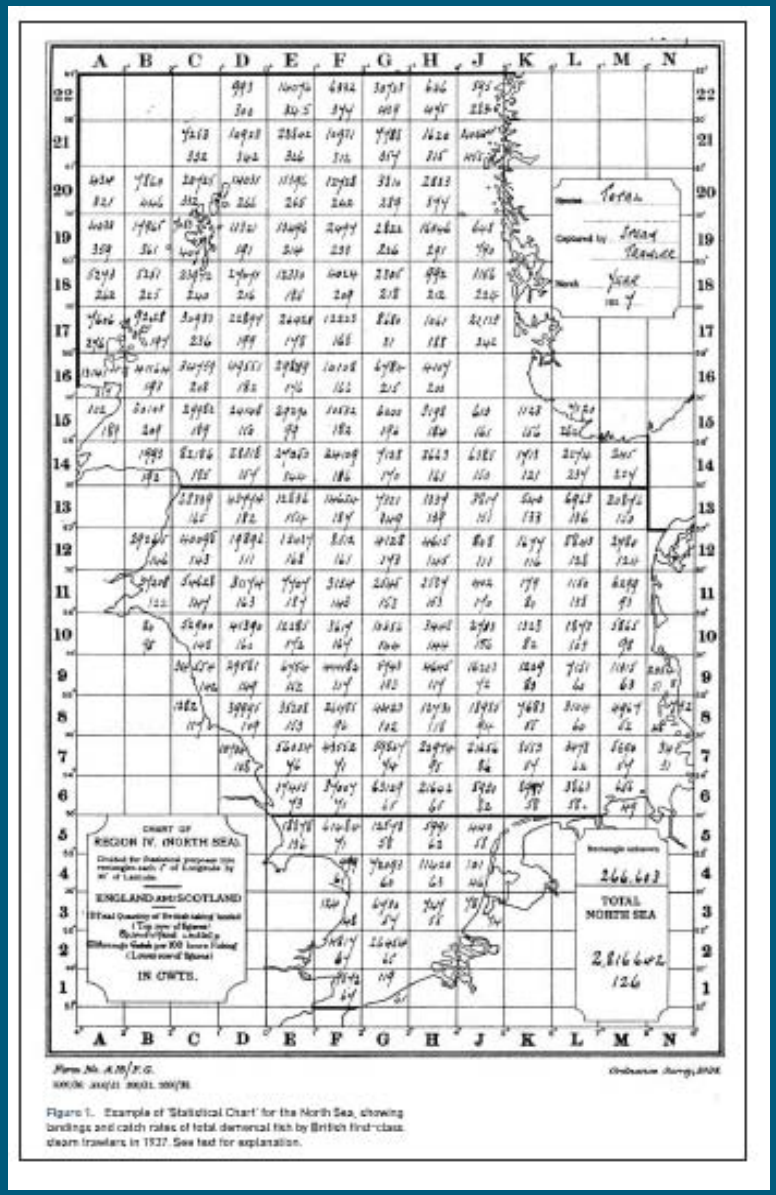
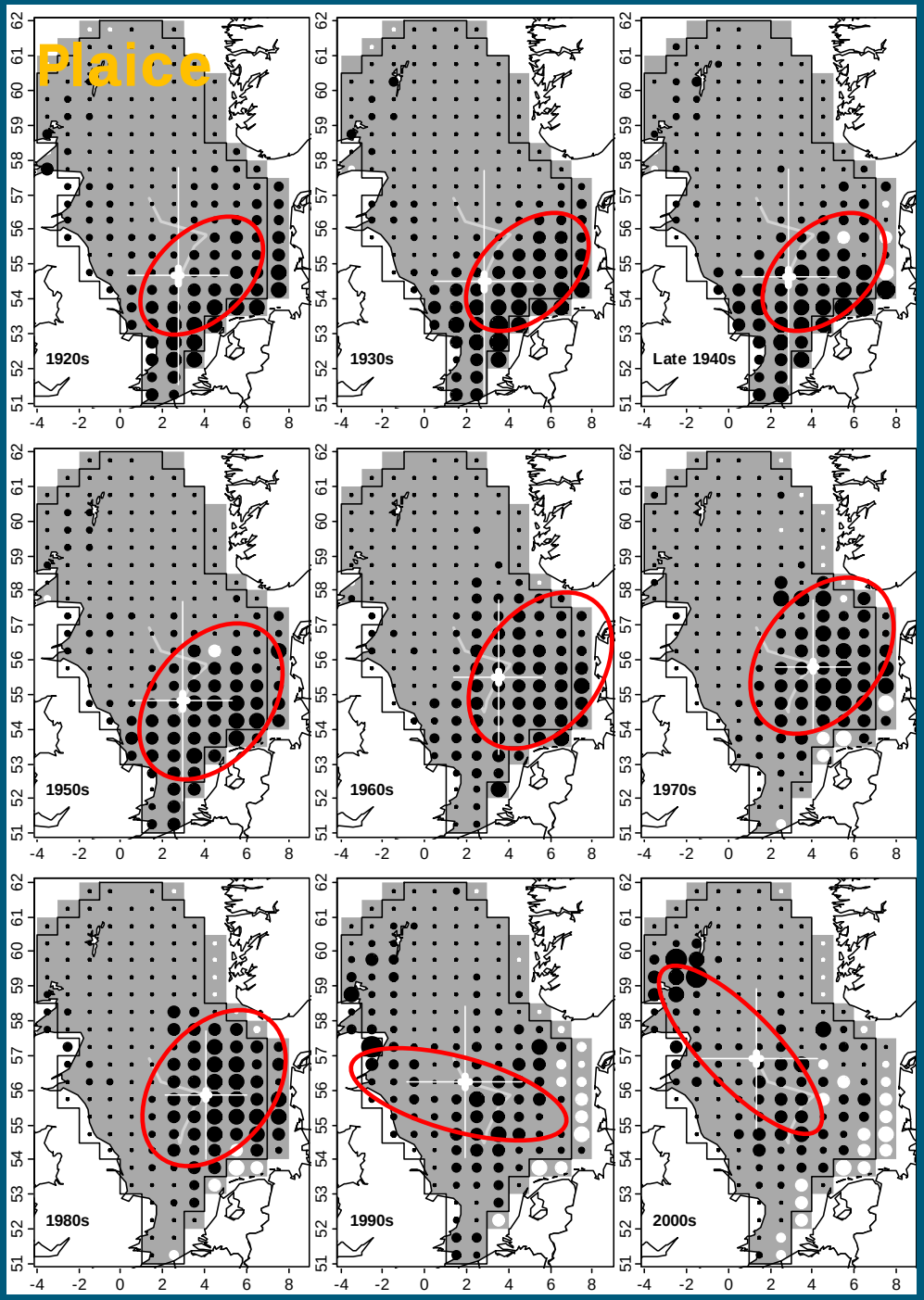


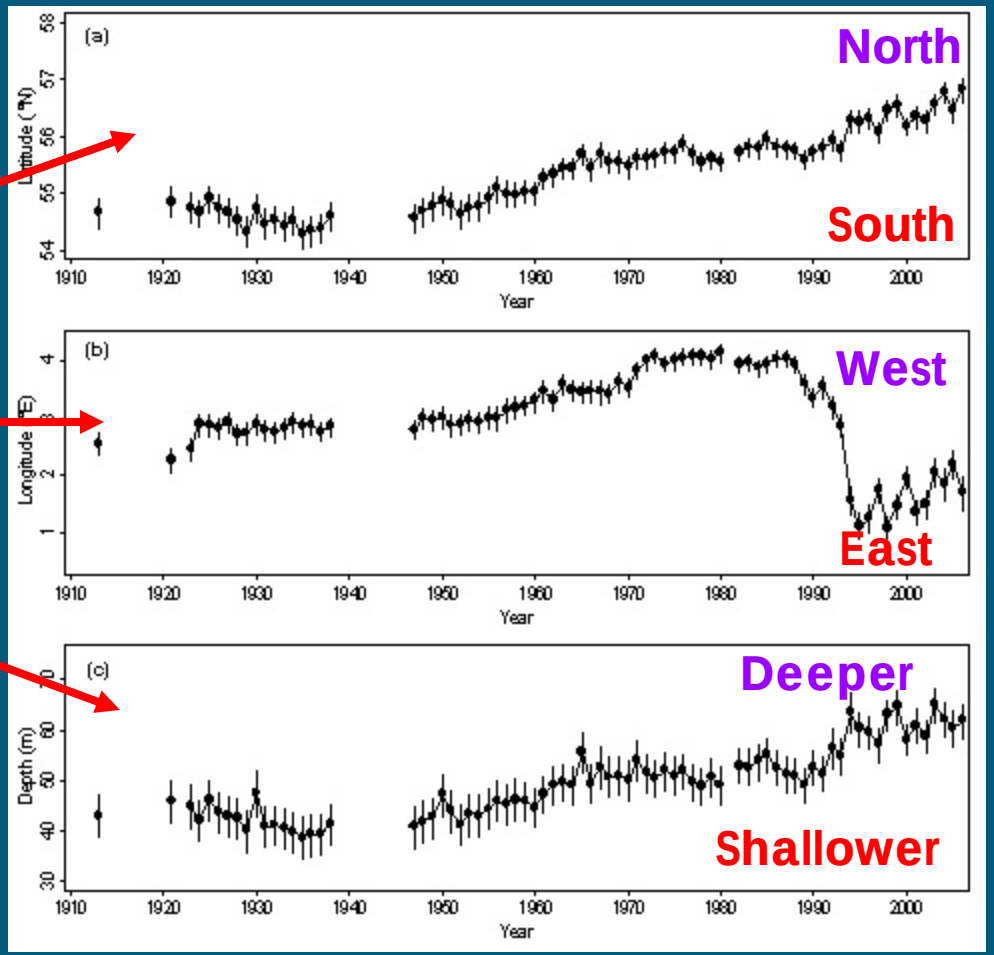
Figure 1. Example of 'Statistical Chart' for the North Sea, showing landings and catch rates of total demersal fish by British first-class steam trawlers in 1937. See text for explanation.

- Cod distribution seems to have shifted steadily north-eastward, towards deeper water
- Haddock catches have moved very little in terms of centre of distribution, but their southern boundary has shifted northwards by approximately 130 km
- Plaice have moved offshore towards the central North Sea (i.e. north-westwards)



Changes in the centre of gravity of plaice distribution

- Latitudinal
- Longitudinal
- Depth

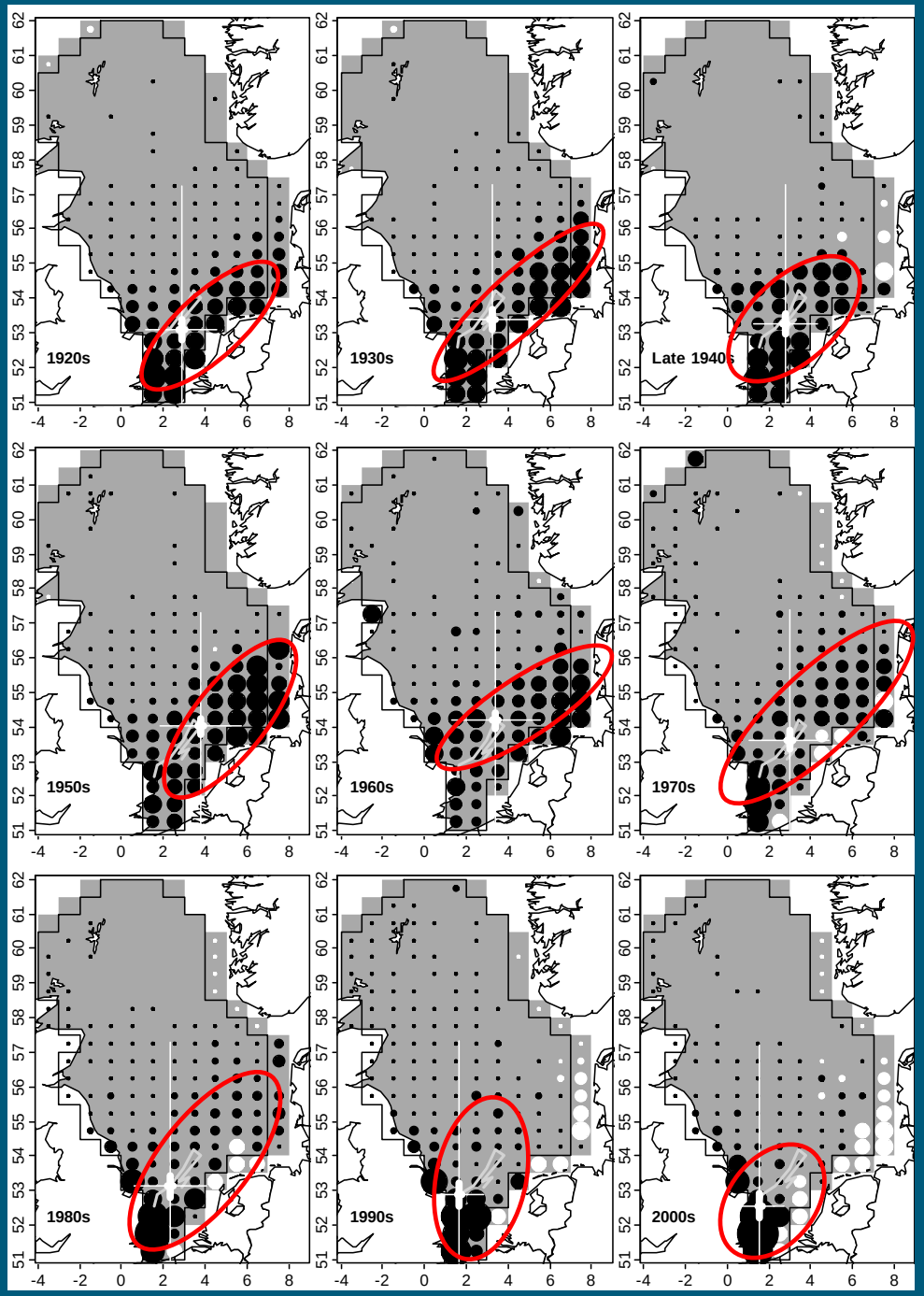


- Since WWII, ***near-continuous northward shift*** (and eastward up to 1990s), depth shift mimics N-S depth gradient

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

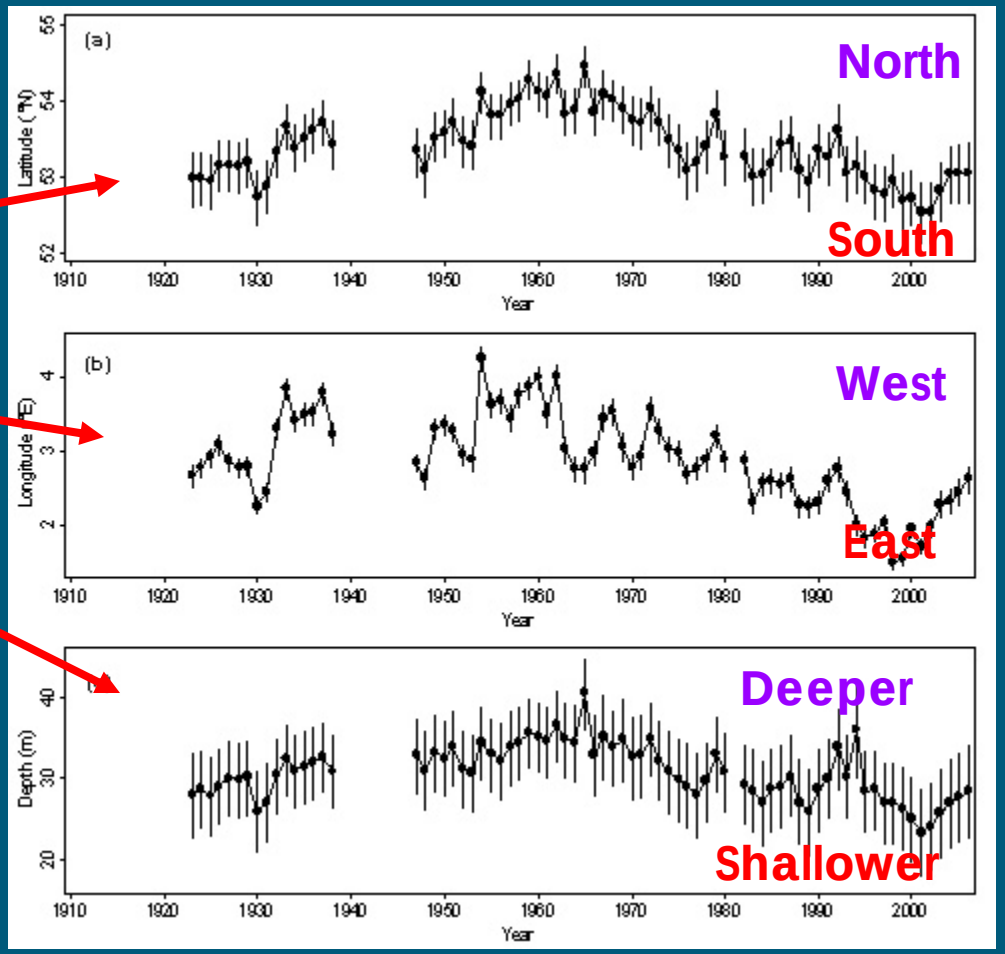
(cpue normalised by year)

- 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



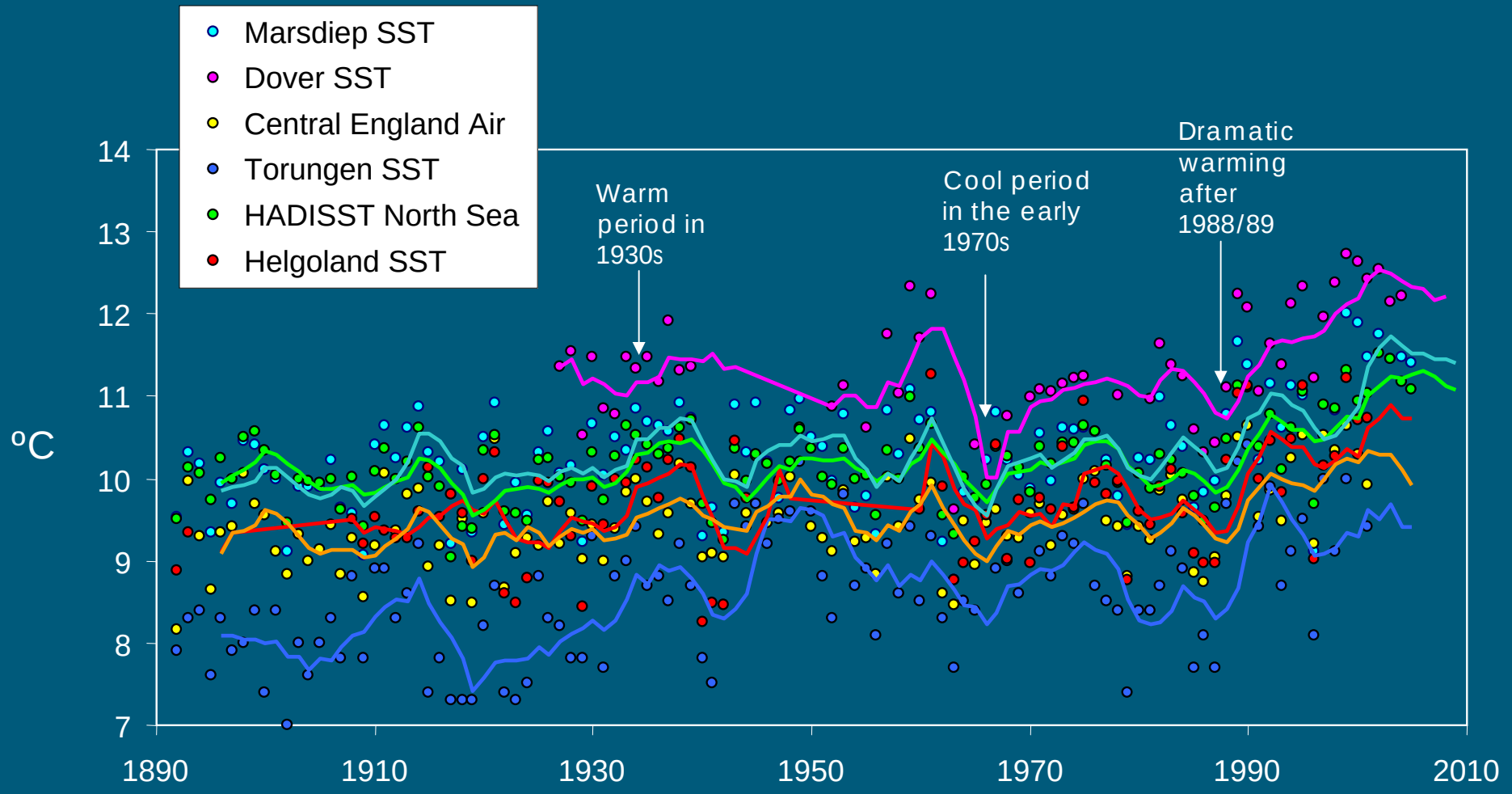
- Pre-1980s, **shifts in CoG of sole appear linked to warmer and cooler climate regimes**

- 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

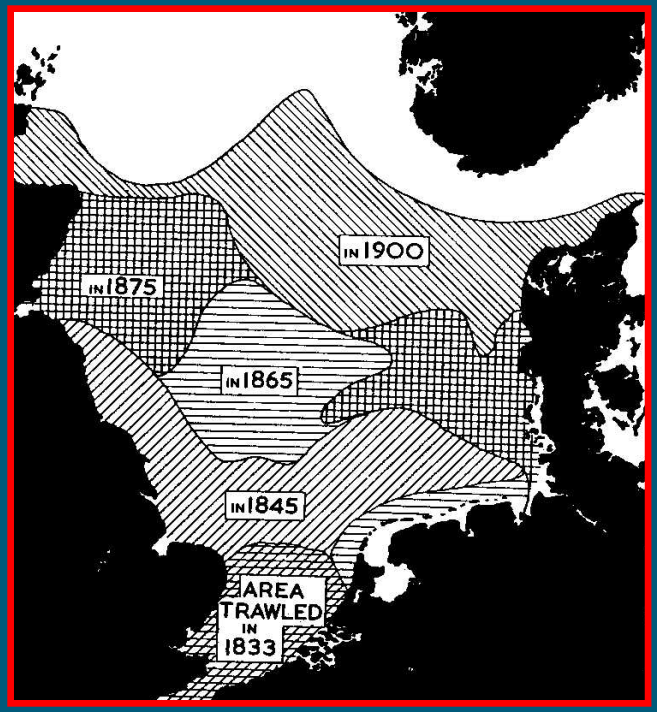
[Also see presentation A2-6080, ter Hofstede & Rijnsdorp]

There have been big changes in sea surface temperature (SST)

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

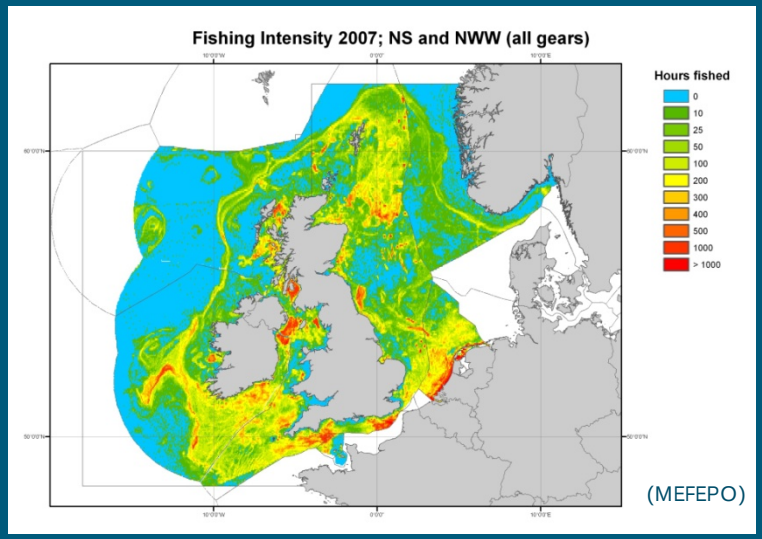


However there have also been big changes fishing pressure……..

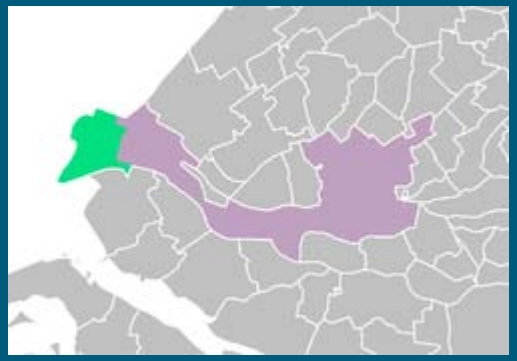


Fishing mortality rates have been higher in the southern North Sea than in the north (Heath et al., 2003, Heath et al., 2007).

Apparent changes in distribution (as indicated by Perry et al. 2005) could simply be a consequence of **local patterns of fishing pressure and different rates of depletion** in spatially segregated sub-stocks.



….. and significant modification of habitats.



e.g. Maasvlakte is part of the harbour and industrial area of Rotterdam, the Netherlands.

It was created in the 1960s by reclaiming land from the North Sea. Maasvlakte 2 in the next few years will cover 1000 hectares.

There has been considerable public concern that this development will impact the transport and retention of flatfish and herring larvae.

Erftemeijer et al (2009) attempted real-time modelling of hydrodynamic forcing (with wind, air pressure and river discharge) and larval behaviour to establish whether this development is likely to have an effect.

In this case – the impact *"will be negligible"*

[See presentation A2-6258]

What will distribution shifts mean for fisheries?

- Populations may move away from (or towards) the area where fishing fleets operate.

- Distribution changes may have significant consequences for the distance that must be travelled by fishing boats to reach the target resources with implications for fuel usage and time at sea.

- Also species distributions may migrate across the boundaries where quotas belong to different nations.

- Species may move outside the boundaries of marine protected areas / fishery closure areas

- Incoming species may be commercially exploitable and therefore offer new opportunities for fisheries.

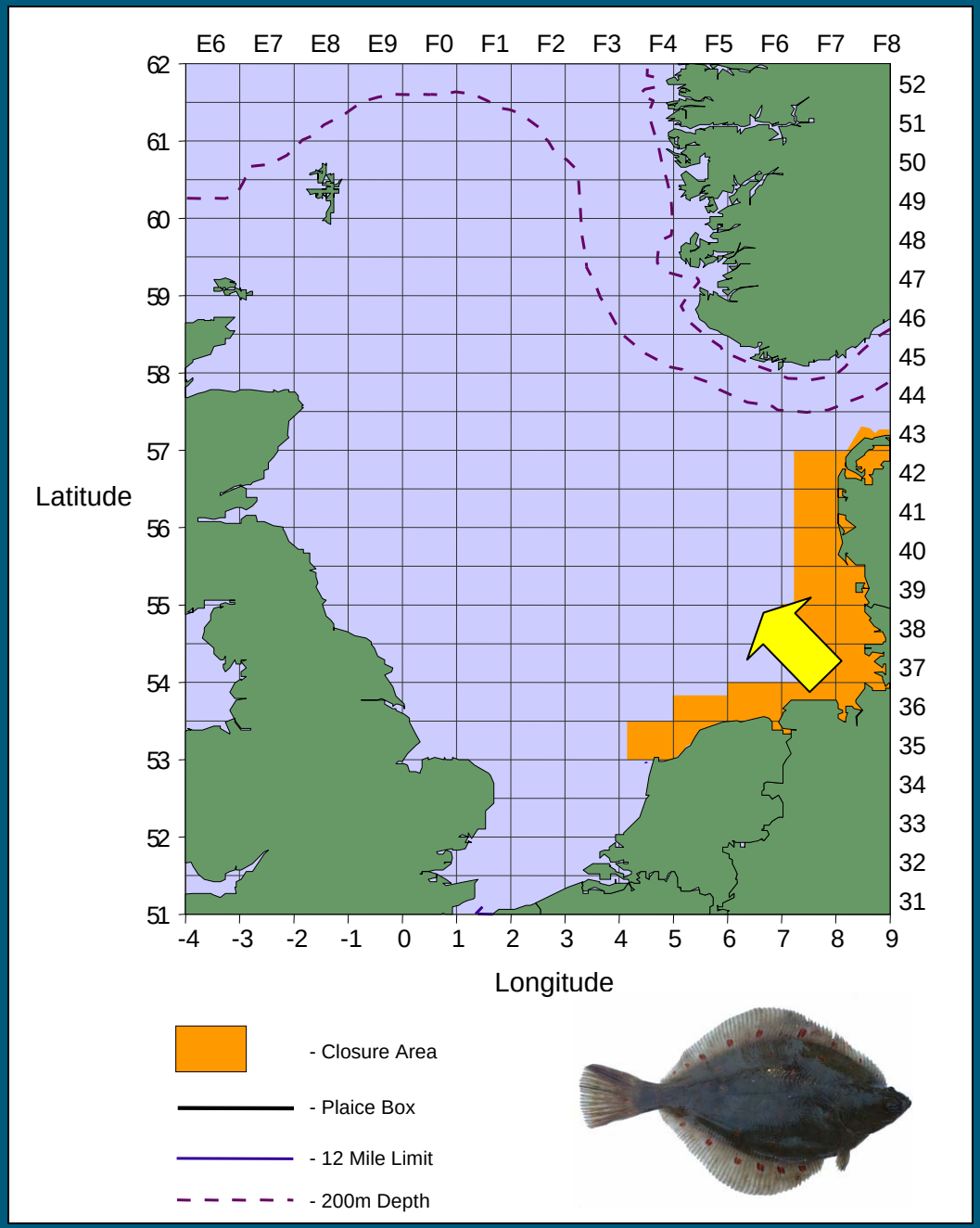
Species may move outside MPA boundaries

The Plaice Box was first established in 1989 to reduce discards of juvenile plaice (i.e. to protect nursery grounds).

Recent surveys in the Wadden Sea have shown that 1-group plaice is almost absent from the area where it once was very abundant.

The 'Plaice Box' is now much less effective as a management measure in comparison with the situation 10 or 15 years ago.

MPA boundaries may need to be 'adaptive' in the future.



[see van Keeken et al., 2007; and presentation A2-6258]

The current debate about North Atlantic Mackerel……

In 2009 mackerel appeared to have moved away from the Norwegian Sector, resulting in disagreements over permissible catches by Norwegian boats in EU waters.

Norwegian vessels were forcibly evicted from Scottish waters by UK fishery patrol vessels once they had caught their allotted quota

Both Iceland and the Faroe Islands unilaterally claimed additional quota, because mackerel had moved into their waters

Such disagreements may become more common place in the future

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9 October 2009 £1.85

Jubilee Quest launched at Whitby

The new single/twin-rig whitefish trawler Jubilee Quest GY 900, at 21.67m the biggest new vessel built for Grimsby for 25 years and only the port's third new build in 20 years, was lifted into the River Esk at Whitby on Sunday lunchtime after severe gales had caused the launch to be delayed for 21 hours, reports David Linkie.

Designed by S C McAllister and built by Parkol Marine Engineering, Jubilee Quest is owned by the Olbek Fishing Company which is a partnership between skippers Graham Hall and Ross Crooks and Jubilee Fishing Ltd of Grimsby.

Jubilee Quest was named by Mrs Vera Allard, whose late husband Derek Allard founded Jubilee Fishing in 1977 with the long-term vision of building a larger class of steel-hulled trawler, the first of which, the 21.2m Jubilee Quest GY 900 (recently renamed Jubilee Spirit GY 25) entered service in 1997, a week before Derek Allard passed away.

The launch and celebratory reception of Jubilee Quest was a particularly

Turn to page 2

Weighing 169t Jubilee Quest, swung round by a Sarens heavy lift crane, hangs suspended above Whitby's historic skyline

EU CLOSES MACKEREL FISHERY TO NORWEGIANS

Norway's pelagic fleet exceeds its quota so stopped from fishing western mackerel in North Sea – report page 3

9 October 2009 www.fishingnews.co.uk NEWS 3

Mackerel closure for Norwegian vessels in EU waters

THE EU stopped Norwegian pelagic vessels from fishing western mackerel in the North Sea from midnight on Thursday 1 October as a result of exceeding their agreed allocation of 53,000t taken in EU waters, reports David Linkie.

In the last three weeks of September a large fleet of Norwegian vessels had fished well inside the UK sector, often less than 20 miles east of Shetland on some days with catches of more than 10,000t. In highlighting the degree to which the migratory pattern of mackerel appears to be changing, this situation is in marked contrast to that of previous years when at this time of year, the main run of mackerel has usually been lying some 140 miles further east in the Norwegian sector (FN 25 September).

Earlier this year a new set of control and reporting measures, similar to the rules already in force for Scottish vessels fishing in Norwegian waters, were imposed on the Norwegian and Faroese fleets working in EU waters. Marine Scotland subsequently monitored the uptake of mackerel quota in EU waters as declared by the Norwegian vessels before exiting these waters and alerted the commission to the fact that the reports indicated the quota had been taken.

FPV *Jura* deployed

On Thursday afternoon Marine Scotland received the official communication from the commission to Norway informing them the fishery would be closed to vessels at 24.00hrs ber. Marine Scotland PV *Jura* to the area, mber of Norwegian re operating, to n to leave because a was exhausted. egian vessels on de left EU waters, hat no fishing took

FPV Jura was employed by Marine Scotland to advise Norwegian pelagic vessels to stop fishing mackerel in EU waters east of Shetland from Thursday midnight on receipt of official communication from the EU to Norway

place after midnight.

Derek Duthie, chief executive of the Scottish Pelagic Fishermen's Association said: "At a time when reform of the CFP is on the agenda it is important to remember that for fisheries management to succeed fair and equitable regulatory frameworks need to apply. This includes third country fishermen who wish to take advantage of fishing opportunities in our waters.

Review needed

Mackerel is only one of the stocks in this category and there is a need for the EU to review the systems they have in place for other stocks to ensure that they are up to the standard of the new mackerel provisions.

"Effective control and enforcement systems are a vital part of securing this sustainable future and it is with this in mind that the closure of community waters to Norwegian vessels fishing for mackerel is a hugely significant event. The reporting arrangements for third country vessels fishing in EC waters were reviewed by the European Commission and member states this year. These rules are a vital component in the overall management of mackerel fisheries and have been implemented efficiently and effectively by Marine Scotland Compliance in the past few weeks. They are not however unique. Community vessels fishing in the Norwegian zone have had to comply with strict and rigorously enforced reporting and control regimes for decades.

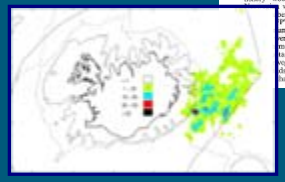
"The Scottish pelagic fleet has no access to fish mackerel in Norwegian waters and this makes the 53,000t available to the Norwegian fleet in our waters this year look exceedingly generous. Scottish pelagic fishermen have painful memories of having to wait patiently for the mackerel to enter the EU zone in the past while the quota year ran down.

"The Scottish pelagic industry seized the initiative in 2007 when it entered its mackerel fishery for assessment into the Marine Stewardship Council (MSC) standard. The fishery was certified at the start of this year, the first large-scale mackerel fishery to achieve this. This is a statement of intent of the importance placed by the industry on this key stock and the approach is keenly supported by Marine Scotland. At a time when the actions of some fishing nations are threatening to undermine mackerel management, the Scottish pelagic industry will continue to work with Marine Scotland, the European Commission and its colleagues in the Northern Pelagic Working Group to secure stability.

Mackerel the mainstay

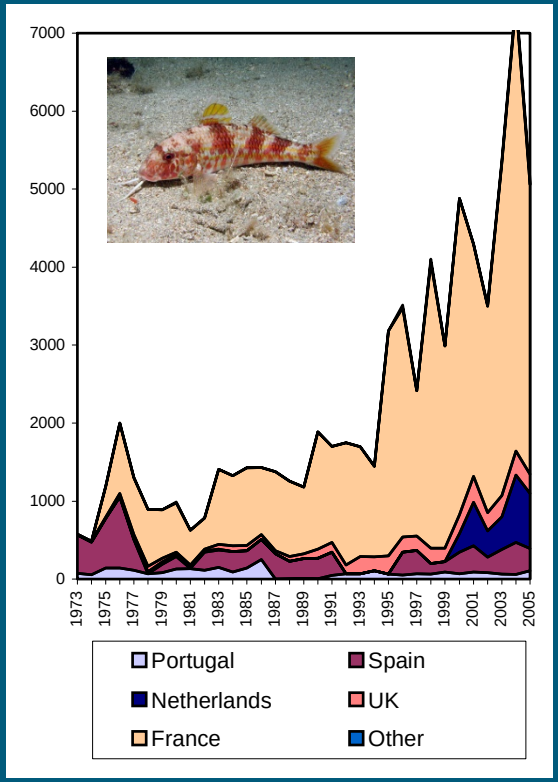
"North East Atlantic mackerel has been the mainstay of the Scottish pelagic fleet for many years now. As well as keeping the fleet viable, it is also responsible for providing employment to a large number of primary and secondary processing workers in Scotland's most fishing dependent communities. It is widely acknowledged that the stock is in a very healthy condition and there is a determination within the country to maintain a well-managed fishery for future generations.

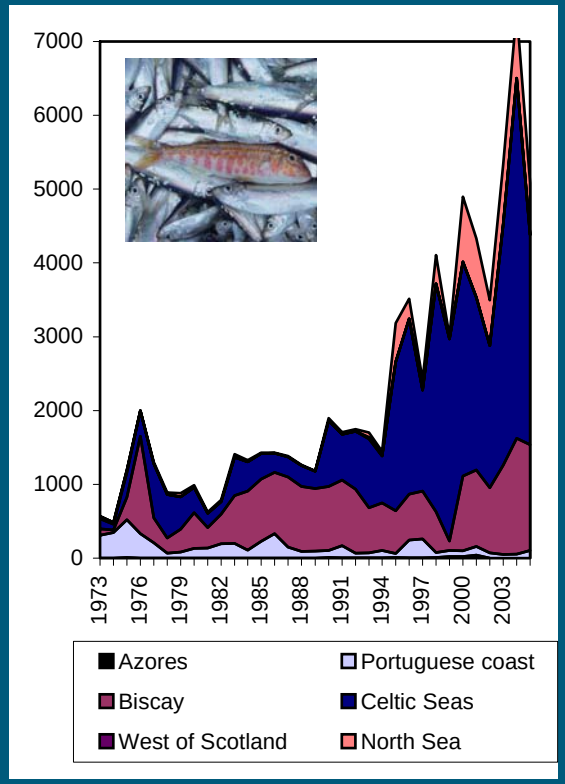
"The quick utilisation of the Norwegian access tonnage in 2009 is not surprising. For a number of years now a western movement in the distribution of the mackerel stock has been observed. This year is merely a continuation of a trend whereby mackerel is spending a greater amount of its time in community waters evidenced by the early migration of the stock from the Norwegian to the community zone and the widespread abundance of mackerel observed by inshore and offshore fishermen throughout the year."



9th October, 2009

Incoming species & new fisheries.....





International fishery landings of red mullet *Mullus surmuletus* between 1973 and 2005.

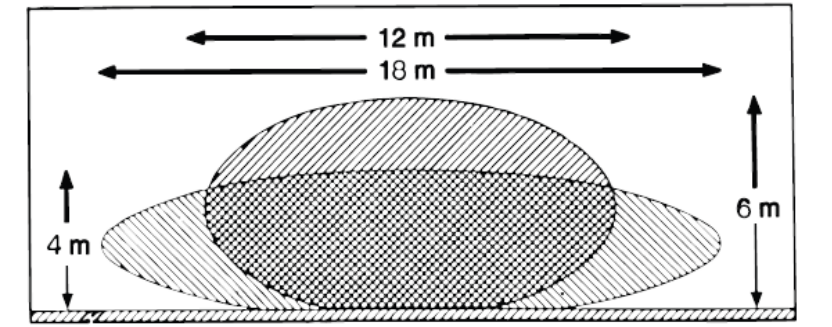
European fishermen have witnessed and responded to a number of new opportunities in recent years, as warm-water species have moved further North and/or their exploitation has become commercially viable for the first time.

Notable examples include new and/or expanding fisheries for seabass, red mullet, john dory, anchovy and squid in the Channel and southern North Sea

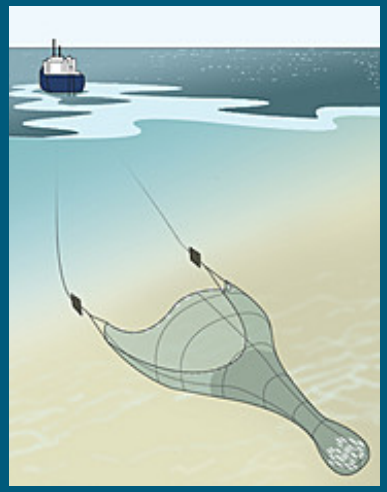
Anchovy in the Channel ……

31st October 2009

Will fish become harder to catch?



Difference in trawl geometry of the Campelen 1800 shrimp trawl used in Norwegian bottom trawl surveys of the Barents Sea at depths of 50 m and 450 m. (Adopted from Godø and Engås 1989).



Perhaps – yes!

- It is known that gear geometry and hence 'catchability' of certain fish species can be greatly influenced by water depth (Godø and Engås 1989).

- Given that Dulvy et al. (2008) found that the whole North Sea fish assemblage has deepened by ~3.6 m per decade since 1981, we might anticipate that traditional target fish will become more difficult to catch.

Consequences for food-webs?

Considerable effort has been dedicated to the digitization of fish stomach content data spanning the period 1884-2010 to look for major changes in food-webs over the past 100 years

The DAPSTOM database (www.cefas.co.uk/dapstom) now contains 175,000 records for 135 fish species and is searchable online.

Using this data it has been possible to compare stomach contents of fish (of similar size) in the Dogger Bank region in 1902-1909, with those in 1950-1959 and 2004-2010

Have North Sea food webs changed????

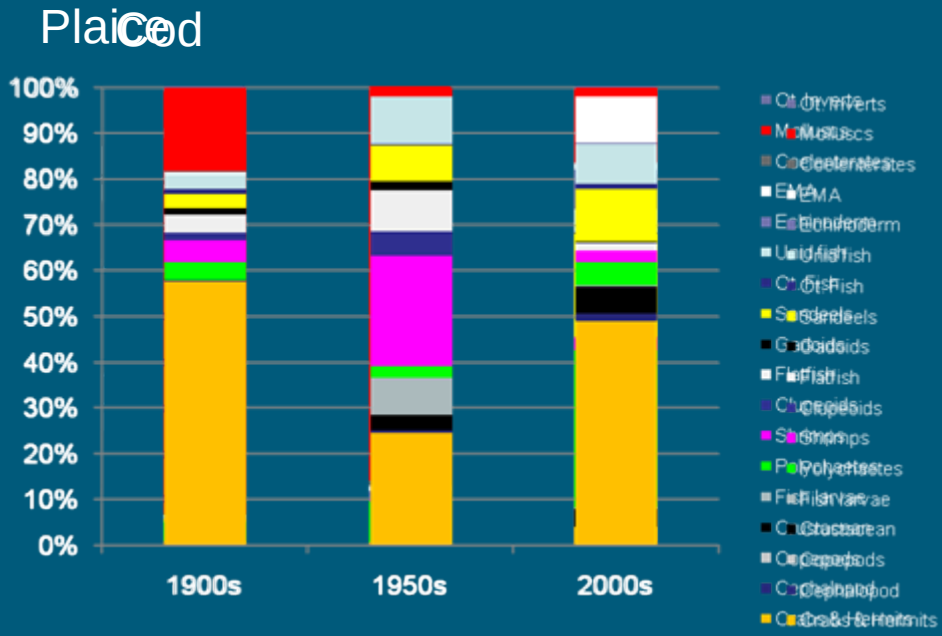
Sandeels represent a greater proportion of the diet now compared to 100 years ago

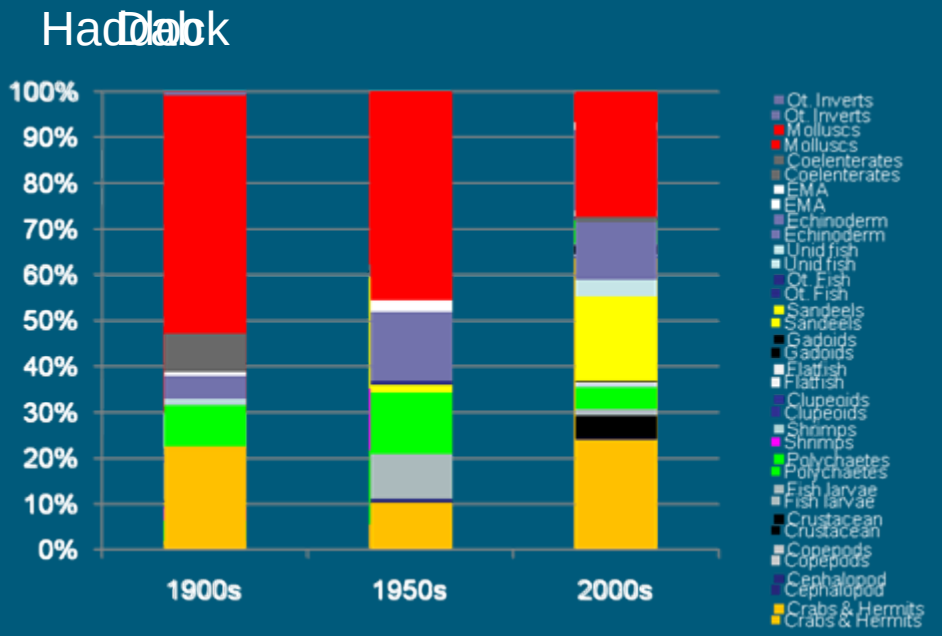
Mobile prey (e.g. crabs, hermit crabs) are now more important prey items

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????





Predicting the future…….

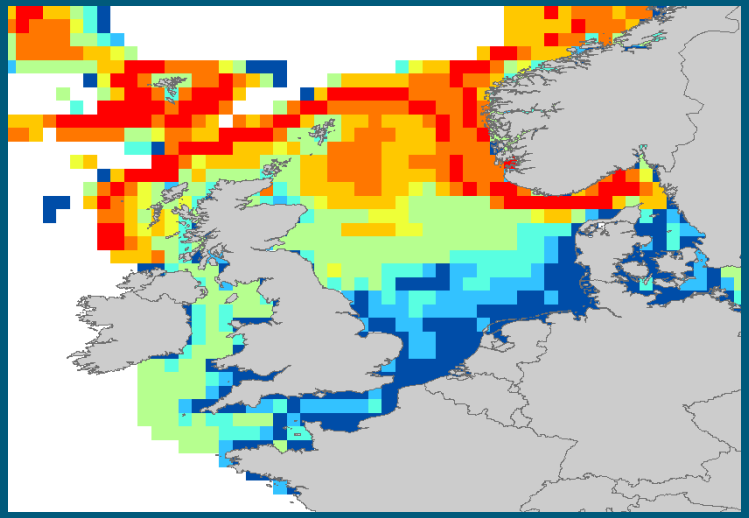
Modelling strategies for predicting the potential impacts of climate change on the distribution of species have often focused on the characterization of a species' **'bioclimate envelope'.**

In other words, by looking at the current range of temperatures tolerated by a species, it is possible to predict future distribution, if we know how the physical environment in an area will likely change in the future.

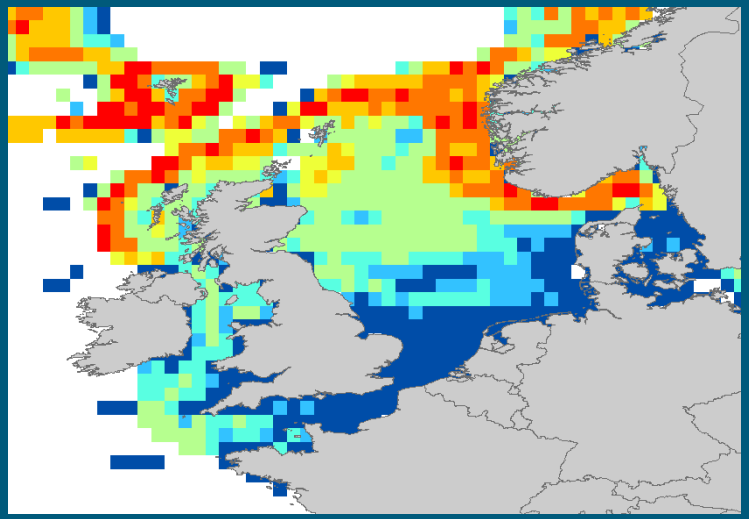
A world-wide analysis has been carried out (Cheung et al. 2009) using this technique, based on 1066 commercial fish and invertebrate species.

[See presentation P1-D1-6105]

Original (static) cod distribution



Cod distribution after 50 years
(Climate projection from NOAA/GFDL CM 2.1)



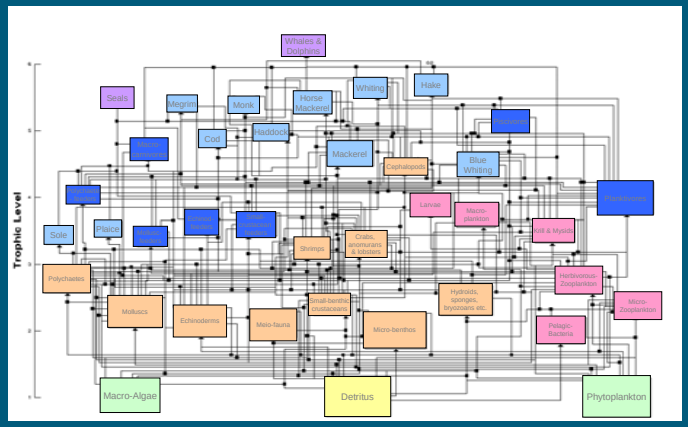
Predicting how food-webs might look in the future….

‘Ecopath with Ecosim’ (EwE) has emerged as one of the most popular and widely applied ecosystem modelling approaches in the marine environment.

At it’s core Ecopath is essentially a food-web model, and includes all fluxes between biological components of the system, from detritus and bacteria up to whales.

Ecosim is a time-dynamic version of Ecopath and can be used simulate the long-term or historic impacts of different fishing practices.

Ecosim can be **‘tuned’** to fit real time-series data or **‘forced’** using assumptions about fishing and long-term (and seasonal) climate or plankton productivity.

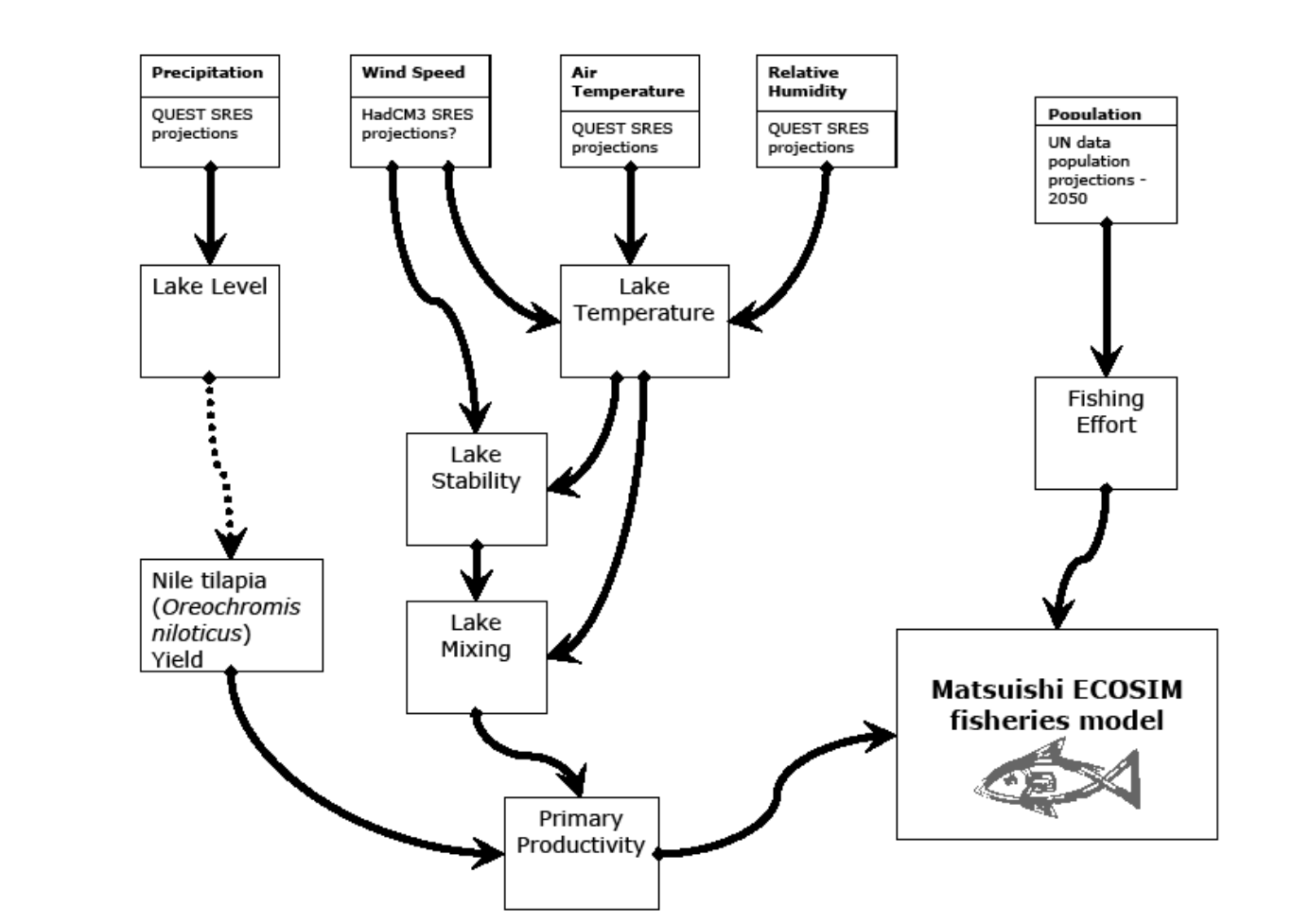


The impact of climate change and fishing on food-webs in Lake Victoria…..

Approaches:

- Ecosystem modelling
- Top down pressure
- Bottom up climate forcing

What data are available to us?



[See poster P1-D1-6199]

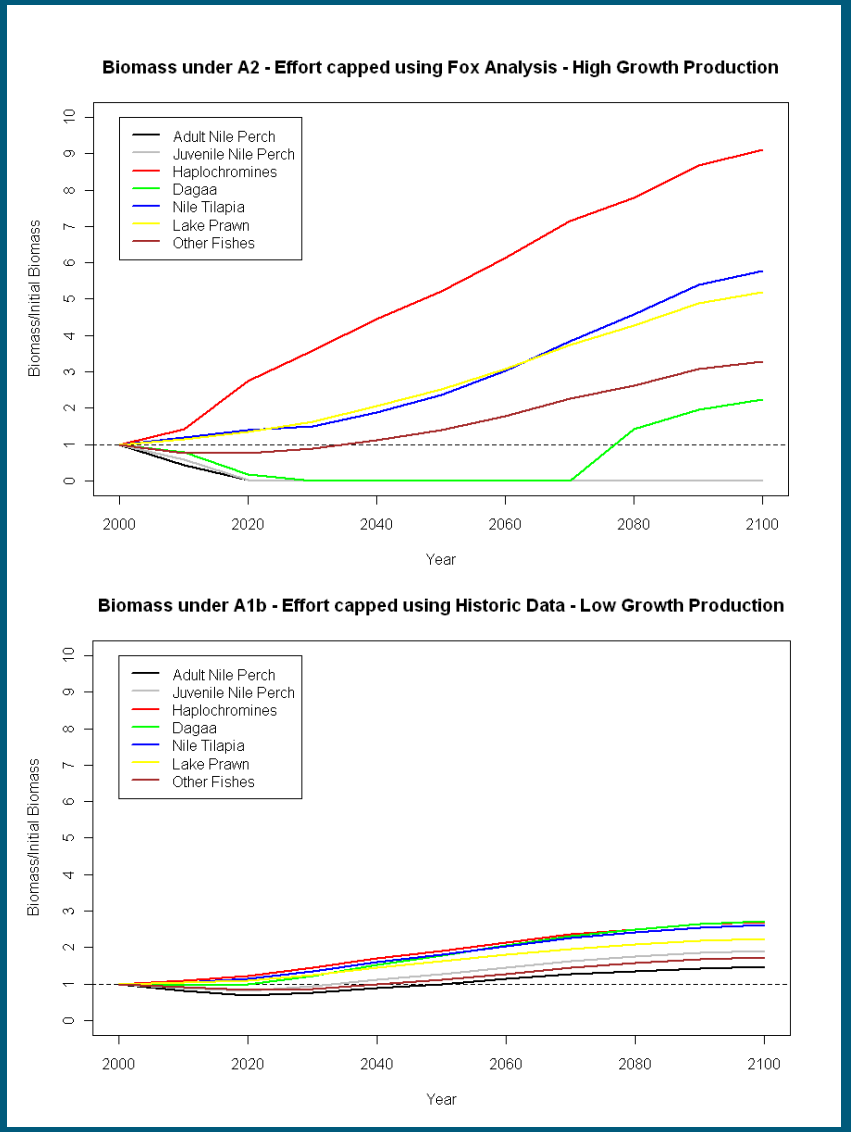
The impact of climate change and fishing on food-webs in Lake Victoria…..

- Results vary dramatically depending on the demographic (human population) and climate scenario selected

- Outcomes were chiefly dependant on future fishing pressure in Lake Victoria

- High fishing effort results in return of Haplochromine sp. biomass

- Greater understanding of the relationship between primary production and climate is needed urgently



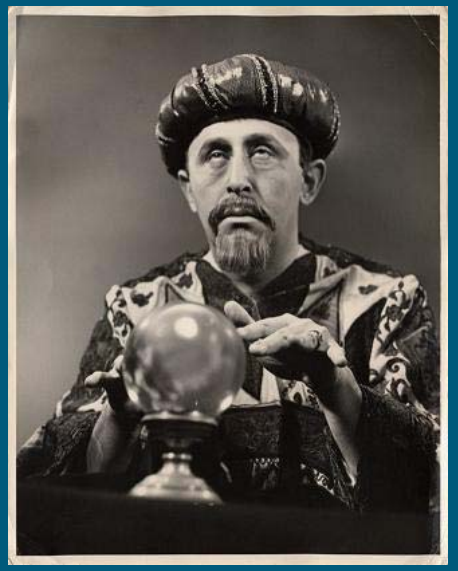
Conclusions & future plans…..

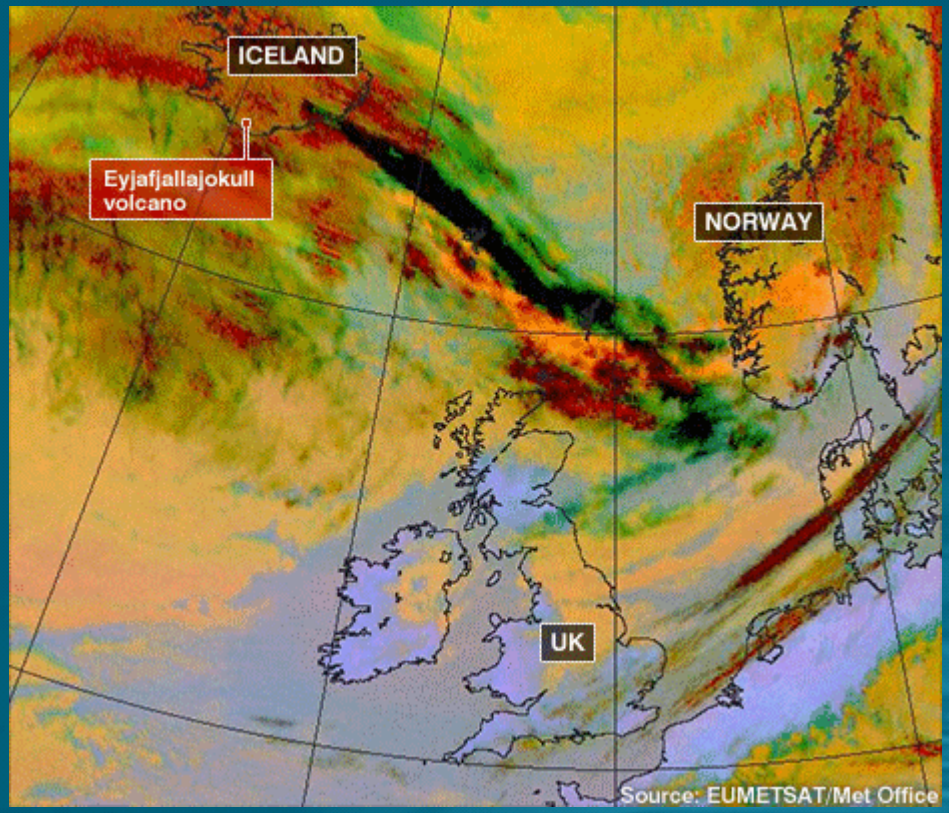
1. There have been major changes in the distribution of North Sea fish species and the prey that they consume

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

3. Fisheries in the North Sea are already being affected by changes in fish distribution (for better or worse)

4. Techniques are being developed to predict what North Sea fish communities might look like in the future and how food-webs might change





Volcanic Ash cloud - 1530GMT 15 April

Acknowledgements

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Cefas