Integrating marine mammal populations and rates of prey consumption in models and forecasts of CC-ecosystem change in the N Atlantic

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ICES Science Plan

- The Science Plan identifies research on climate change processes and predictions of impacts as a High Priority Research Topic for 2009-2013.

- Role of top predators in marine ecosystems has also been identified as a HPRT.

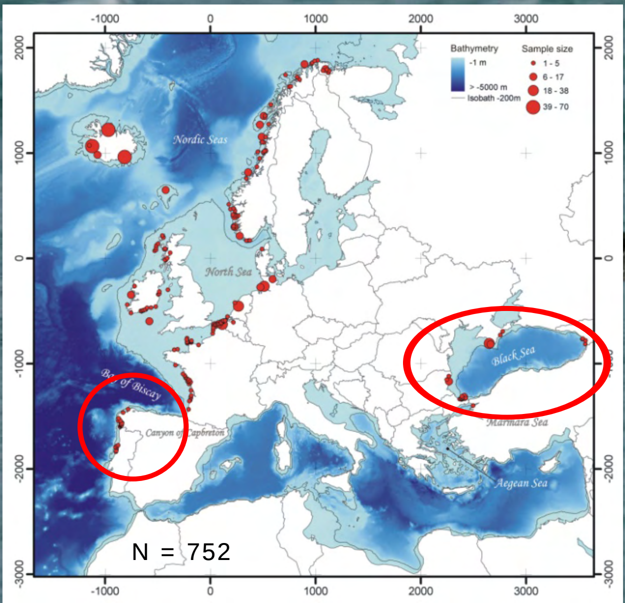
www.ices.dk/assets/ssi/text/WhatsnewScience/ICES_Science_Plan__2009-2013.pdf

Rationale

- Adoption of EAFM requires assessment of impacts on the ecosystem of changes in abundances of key components
- Marine mammals, as top predators, play an important role in marine ecosystem functioning by controlling prey populations (top down control)
- Changes in distribution and abundance are expected as a result of climate/global change

Population definition

Harbour porpoise



Analyses of highly polymorphic microsatellite loci revealed 'continuous' NE Atlantic population (isolation by distance)

Separate Iberian and Black Sea populations

Retreated from Mediterranean during postglacial warming. Isolation of Iberian porpoises since 'Little Ice Age' (≈ 300 yrs) and retreat of cold water spp.

Fontaine et al., 2007

Integrating marine mammals

Data requirements for modelling

Population parameters: distribution and movements, abundance, energy needs, diet

Values needed: current values, long-term trends

How determined: modelled dynamics *or* measured time series *or* indicators of trends

Generic issues: accuracy, precision, variability, sensitivity to external drivers

Population parameters may respond to external drivers such as CC → marine mammals can also provide direct indicators of climate change

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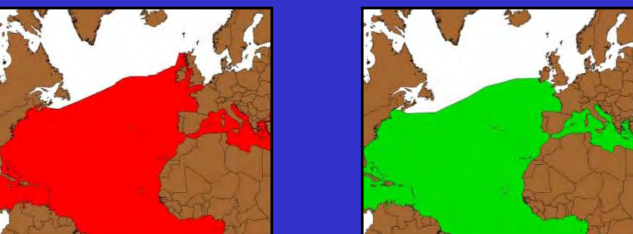
Integrating marine mammals

Parameter	Measures	Indicators	Models
Distribution	Surveys, tagging	Strandings	Habitat models (niche envelopes)
Abundance	Visual surveys (aerial, boat)	Acoustic surveys, Strandings	Population dynamics models
Energy intake	Food intake, respirometry	Body size	Dynamic energy budgets
Diet	Stomach contents	Stable isotopes	Functional responses

Cetacean distribution

Cooler water dolphins
***Lagenorhynchus* spp.**



Warmer water dolphins
common, striped dolphins

MacLeod et al., 2007

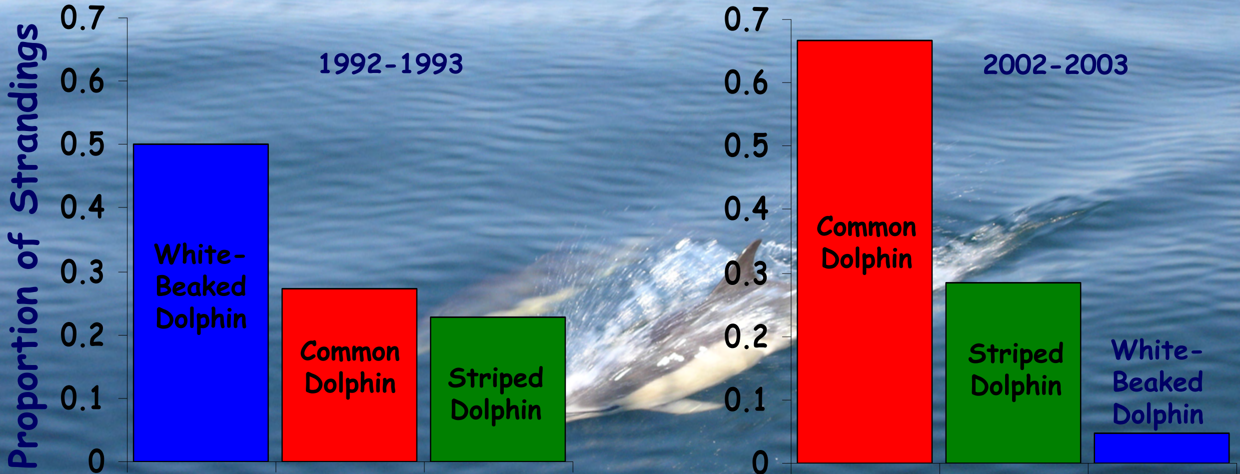
White-beaked dolphin is endemic to the colder waters of the N Atlantic

Common + striped dolphins are more widespread, occurring in warmer shelf and oceanic waters

Strandings data avaliable since 1913 in UK

Routinely collected now in Scotland since 1992 as part of a government funded stranding scheme

Cetacean distribution



Once the most commonly stranded dolphin species in NW Scotland, white-beaked dolphin now ranks third, behind striped dolphin - a species first recorded in this region in 1988

MacLeod 2005

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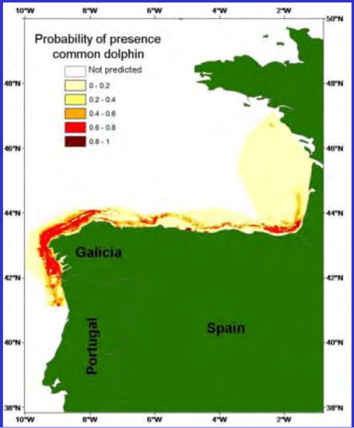
Modelling distribution

Habitat models aim to predict distribution by capturing habitat requirements. Issues include:

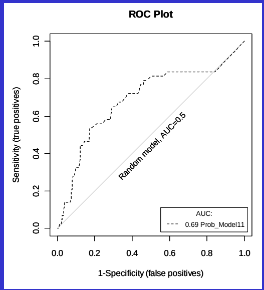
- data quality (e.g. reliability of absence records)
- non-linear relationships
- choice of explanatory variables (relevance, availability, collinearity)
- difficulty of including complex oceanography
- model evaluation (compare to “random”, test in other areas)



Common dolphin in Galicia: Maxent (presence only) model:

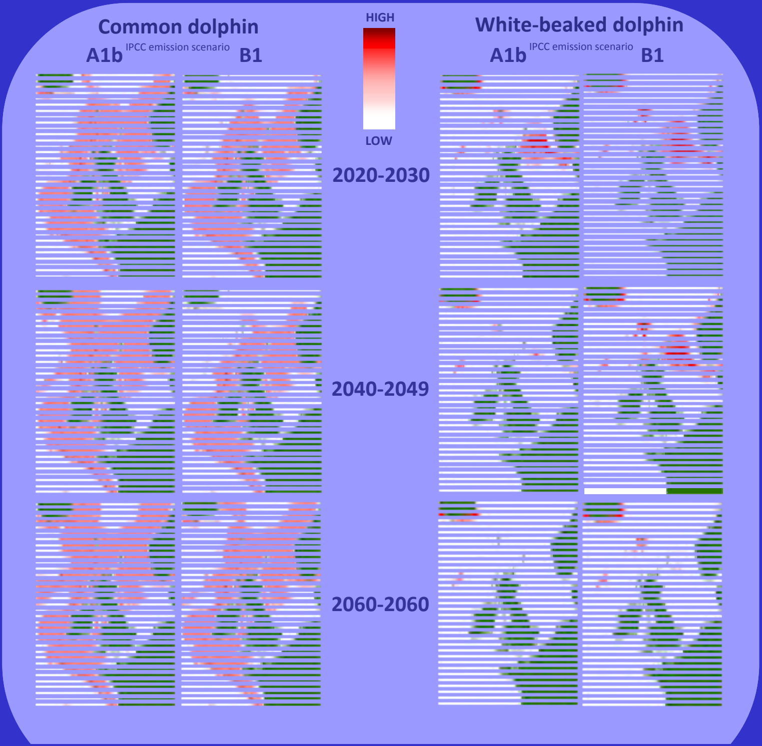
Presence related to distance to coast, depth, seabed slope & standard deviation of slope

Model significantly “better than random”



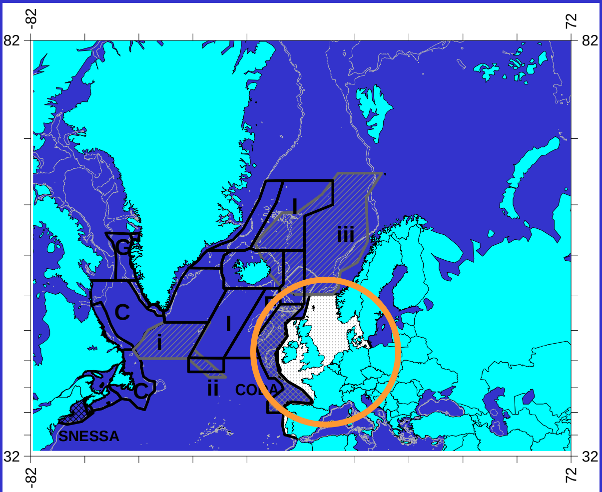
Forecasting distribution changes

- Predicted shifts in response to CC
- Northwards expansion of common dolphin
- Northwards contraction of *Lagenorhynchus* spp. range



Lambert et al 2009

Cetacean abundance



Planned survey area for T-NASS, SNESSA, CODA and SCANS-I & II
Norwegian survey area not shown

Major surveys in ICES area:

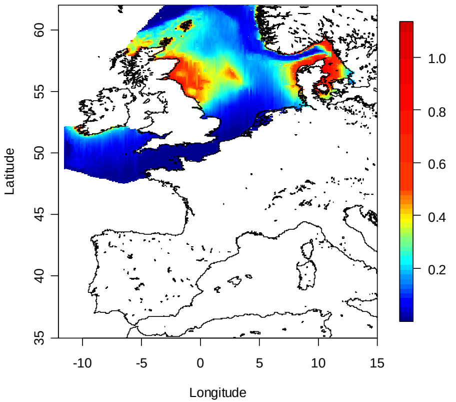
TNASS (Trans N Atlantic Sighting Survey)
SNESSA (S New England to Scotian Shelf Abundance)
CODA (Cetacean Offshore Distribution and Abundance)

Obtained the first pan-Atlantic estimation of distribution and abundance for several species, in summer - autumn 2007

SCANS-I (1994) + SCANS-II (2005)

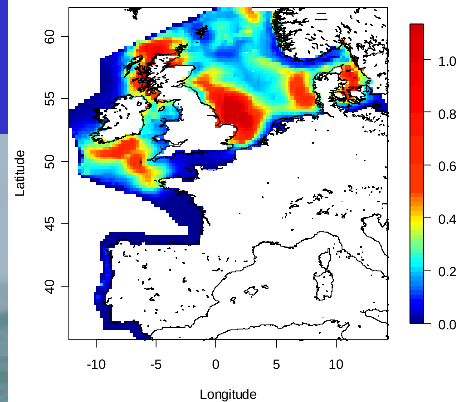
Harbour porpoise abundance

SCANS-I (1994)



Estimated density surface (animals/km^2)

SCANS-II (2005)



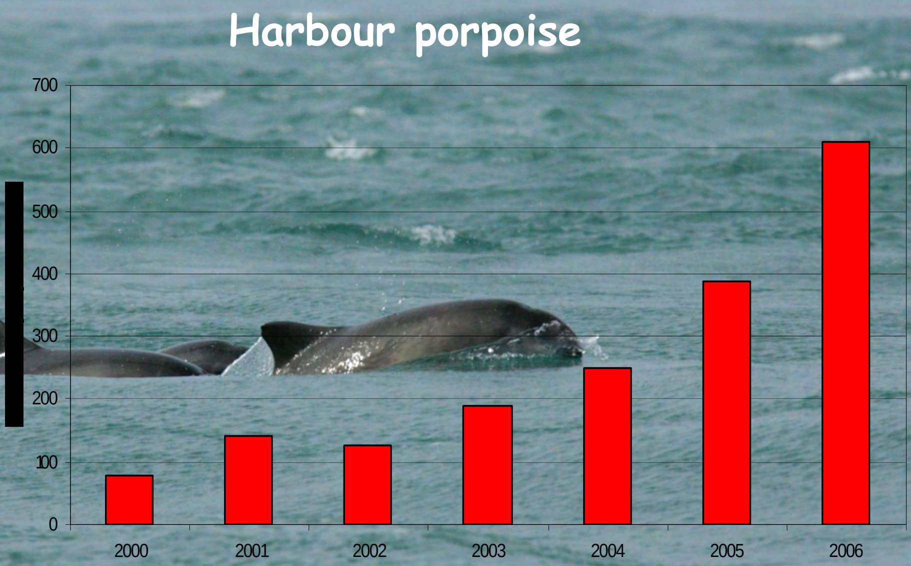
SCANS-I (1994)	<u>Area surveyed</u>	SCANS-II (2005)
239 000	N Sea, northern strata	120 000
102 000	N Sea, southern strata	215 000
341 400 (CV=0.14)	Total area	385 600 (CV=0.20)
341 400 (CV=0.14)	SCANS-94	335 000 (CV=0.21)

Shift towards the southern N Sea

LIFE04NAT/GB/000245, FINAL REPORT, SCANS-II

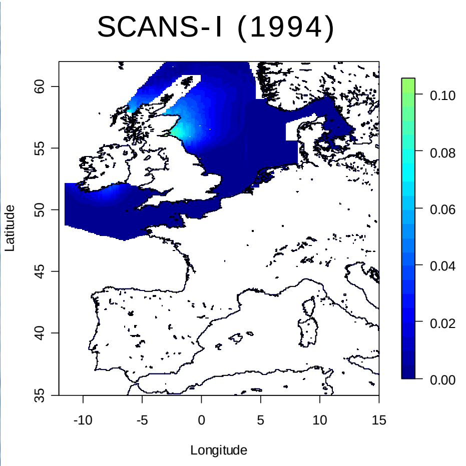
Cetacean distribution

Strandings on the coasts of Belgium, northern France and the Netherlands

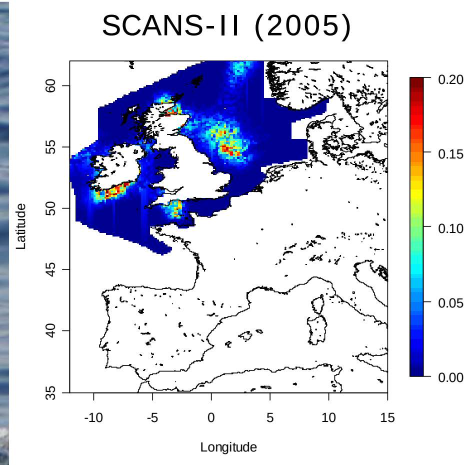


Increase in strandings & sightings in Southern N Sea

Minke whale abundance



Estimated density surface (animals/km²)



SCANS-I (1994)	Area surveyed	SCANS-II (2005)
8 400 (CV=0.24)	Total area	18 600 (CV=0.30)
8 400 (CV=0.24)	SCANS-94	10 500 (CV=0.32)

Changes in the areas of max. density

LIFE04NAT/GB/000245, FINAL REPORT, SCANS-II

But…

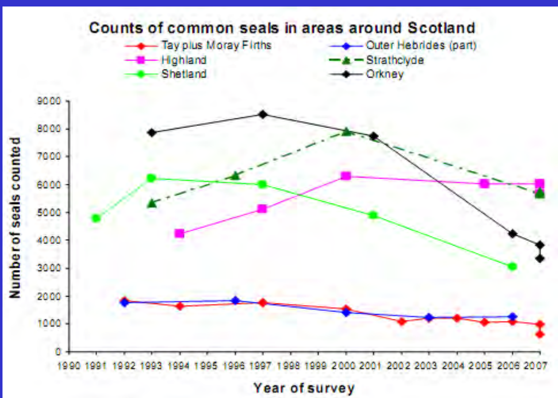
Large-scale cetacean abundance surveys expensive → low frequency (~10 ys)

Alternative: small-scale surveys

Sensitivity analyses highlighted that only rather large changes in abundance are detectable

Best option: combination of 10-yearly large-scale surveys and local surveys with a higher (e.g. annual) frequency. Need to adopt a standard protocol for the local surveys (e.g. JCP)

Harbour seal abundance



~33% of European sub-species lives in UK (85% in Scotland)

Large-scale mortality due to epizootics (1980s, 2000s)

Recent decline in Scotland (by ≤50% since 2000)

Scottish population:

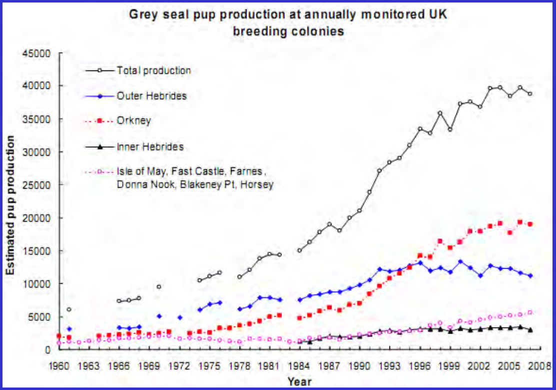
(40 000 – 46 000)

SCOS Main Advice 2008

Grey seal abundance

~45% of world population in Britain (90% live in Scotland)

UK population is increasing (pop growth seems to be slowing)



UK population:

182 000 (96 200 – 346 000)

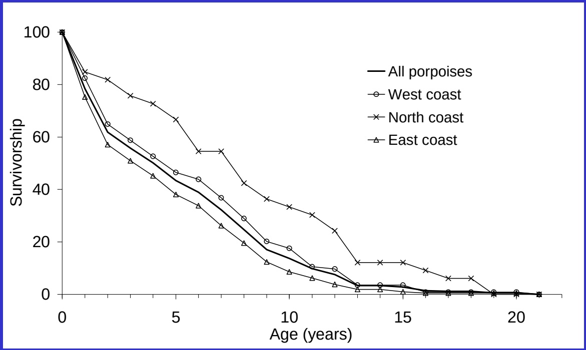
SCOS Main Advice 2008

Modelling abundance trends

Population dynamics models need data on:

- Population age structure, sex ratio
- Birth and mortality rates, immigration, emigration
- Growth rates, age at sexual maturity
- Influence of external drivers, e.g. food availability, CC, pollutants, disturbance (via effects on energy budget, immunocometence and reproduction)

Porpoise survivorship, from strandings in Scotland, 1992-2005



Energy requirements

Relevant empirical data are rarely available

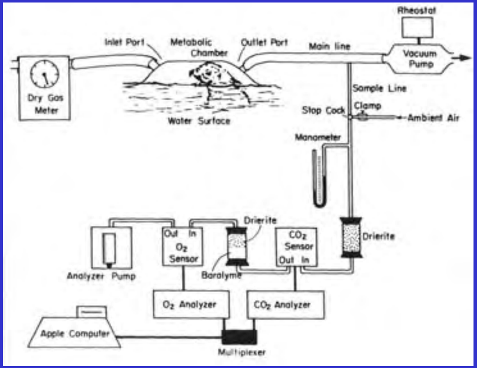
- Validity of applying captive data to free living animals
- Need to consider population age structure, reproduction costs, seasonal variation, etc

Measurement?

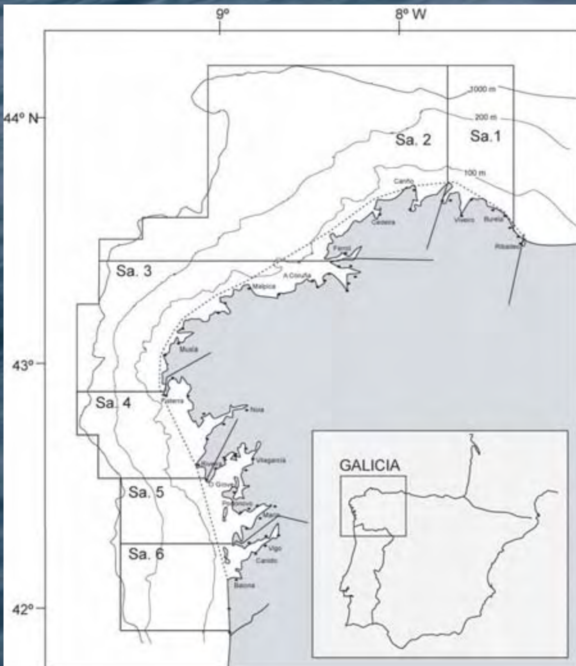
- Food intake, respirometry
- Doubly labelled water

Modelled?

- From standard metabolic rate equations
- Mass balance approach
- Dynamic energy budget models



Diet of common dolphin



Sample size: 504 stomachs from stranded + by-caught dolphins, 1991 - 2008

Main prey: blue whiting, sardine, hake, scad

Diet variability analysed in relation to:

Sex, length, area, month, year, cause of death, prey abundance

Santos et al., 2004; in prep.

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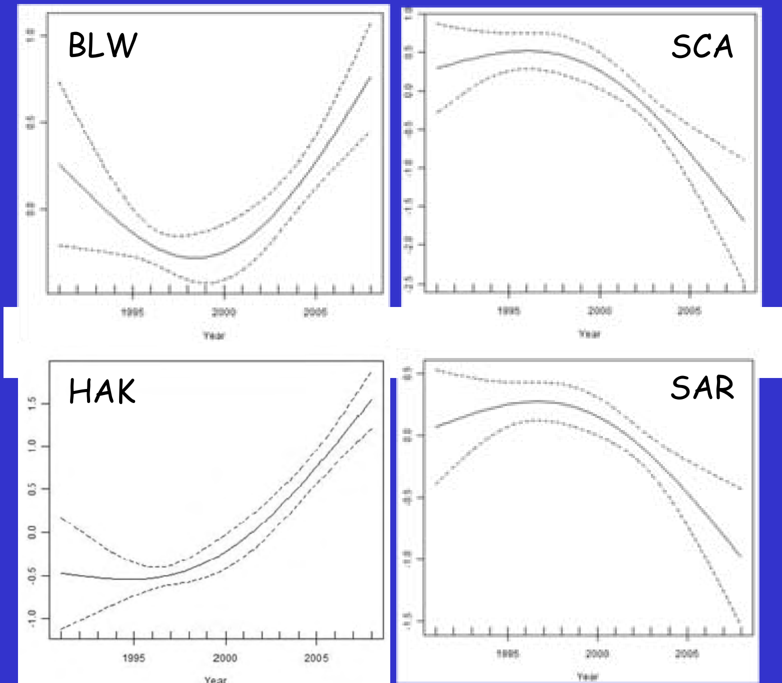
Changes in diet: DDE



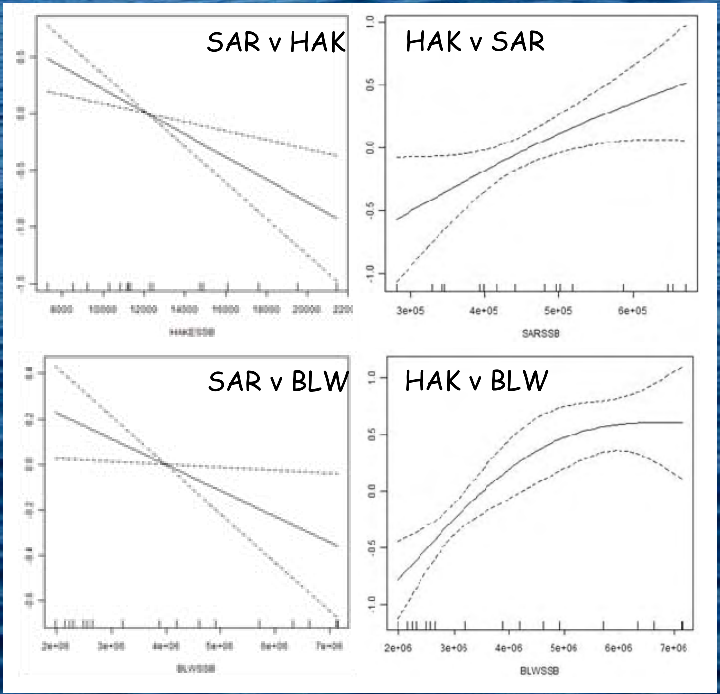
Generalised Additive Models (GAMs) for numbers of prey eaten versus year

Changes are seen in consumption of main prey over the time series

Prey consumption affected by prey availability

Santos et al. in prep.

Changes in diet: DDE



BUT: consumption of each prey species affected by abundance of other prey species

Multispecies functional response: amount eaten F_i of species i depends on its abundance N_i, and abundances N_j of other species j.

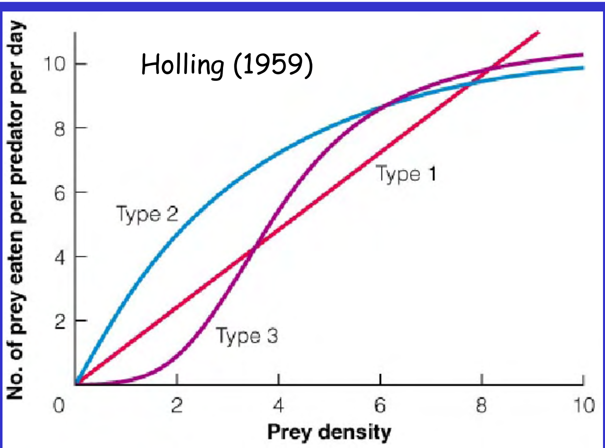
$$F_i = \frac{a_i N_i^{m_i}}{1 + \sum_{j=1 \ldots N} a_j t_j N_j^{m_j}}$$

Santos et al. in prep.

Functional responses

How predators respond to changing availability of different prey

Prey availability difficult to measure at appropriate scale



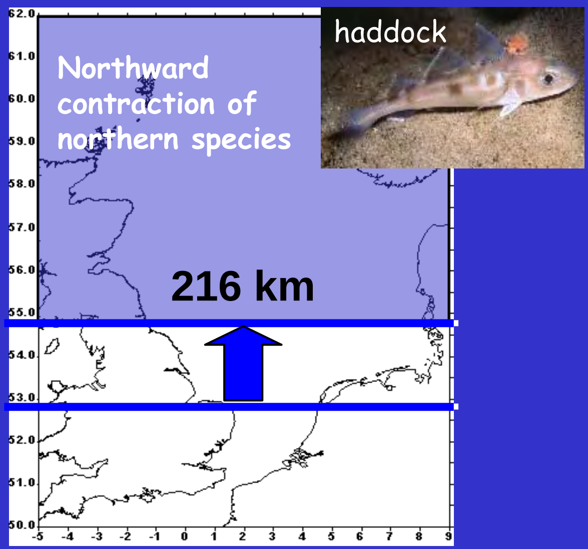
Forecasting impacts of CC requires us to take into account not just changes in the shape of the functional responses but also changes in the species involved, as prey species distributions shift

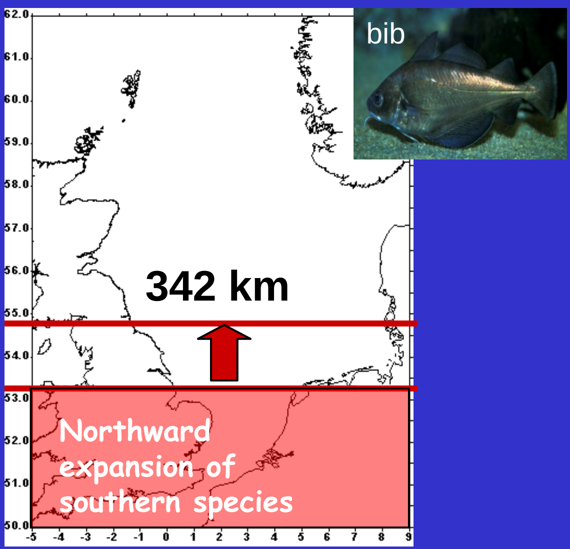
Fish distribution

Biogeographic shifts reflect warming Ts

changes in temperature

changing range boundaries of North Sea fishes

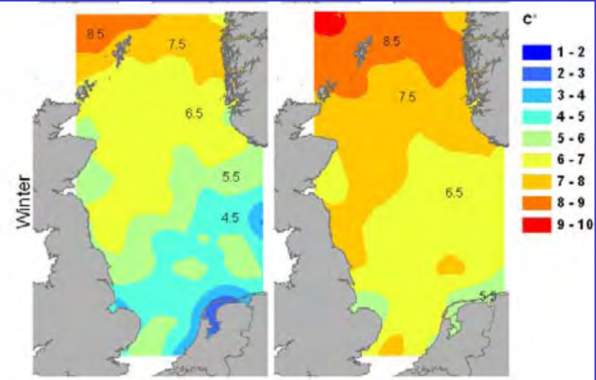




Perry et al. 2005 *Science*

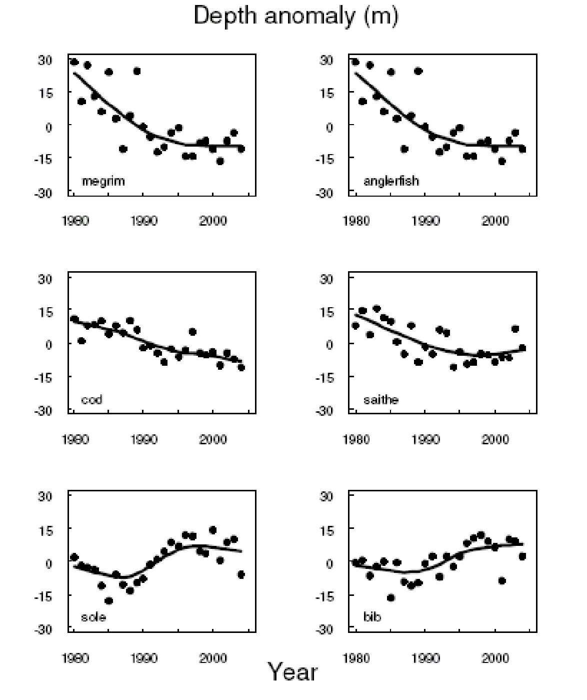
Mean depth of fish assemblages

Deepening of fish assemblages reflects warming and deepening of isotherms



cold period (1983-1987)

warm period (1990-2003)



Dulvy et al. 2008

Changes in diet: seals

Samples: opportunistic collection of seal scats on haul-out sites

Time period: 1986 - 2006

Diet: very consistent, numerical p% of sandeel in the summer diet (93-100%).

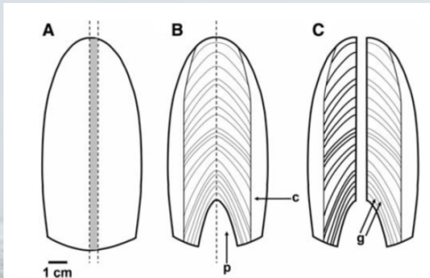
Increase in size of sandeel eaten

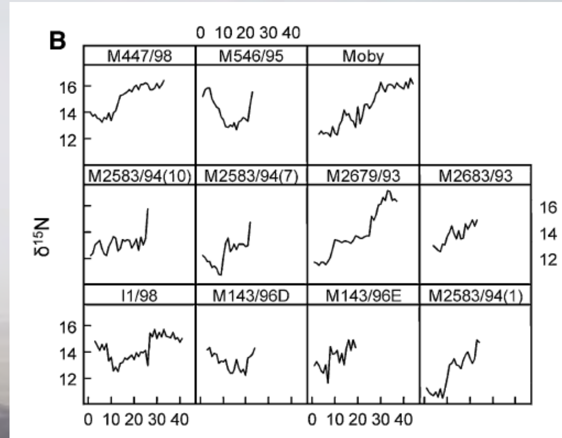
... against a background of declining sandeel and seal populations since the late 1990s

Ieno et al., poster 5777

Indicators of diet trends: stable isotopes in teeth

Sperm whales





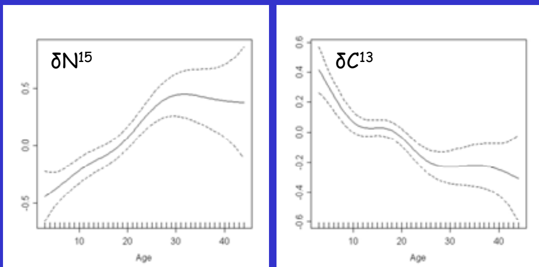
Teeth sectioned and isotope ratios measured in each Growth Layer Group

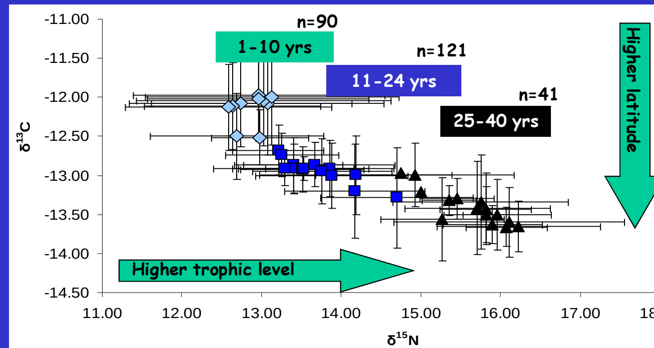
In most whales, δN^{15} increases with age, indicating increased trophic level

Mendes et al. 2007

Indicators of diet trends: stable isotopes in teeth

Sperm whales





GAM used to detect ontogenetic (0-40 yr) and calendar-year related (1950s-1990s) variation

For both C and N, significant ontogenetic trends but calendar year differences not significant

Mendes et al. 2007

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Ecosystem models

Ecosystem models simplify nature to relatively few components linked by mathematical functions

Complexity

- **Extensions of single-species assessment models**: with few additional inter-specific interactions
- **Dynamic System Models (Biophysical)**: represent both bottom-up (physical) and top-down (biological) forces interacting in an ecosystem
- **Minimum Realistic Models (MRM)**: limited number of species most likely to have important interactions with target species of interest
- **Whole ecosystem models**: try to model all trophic links

Plagányi 2007. Models for an Ecosystem Approach to Fisheries. FAO Fisheries Technical paper 477

Some examples with ECOPATH

Area	With marine mammals?	Data used?	Are they important?	Reference
Baltic Sea	Seals	Counts, literature data	Historically, seals exerted top-down control; currently minor component	Harvey et al 2003; Osterblom et al 2007; Sandberg 2007
Bay of Biscay	Not included			Sanchez & Olaso 2004
Faeroes	Baleen whales, toothed mammals	Diet from Pauly review	Pilot whale significant for Hg transfer	Zeller & Reinert 2004; Booth & Zeller 2005
Gulf of Maine, USA	toothed whales, baleen whales, seals		Minor component. Declined if fisheries increased	Link et al 2009
Gulf of St Lawrence, Canada	Cetacean, 3 seal species		Major role as consumers	Morissette et al 2006, 2009
Sørfjord, northern Norway	Mammals	Measured biomass	Less important than large cod	Pedersen et al 2008

Incorporating marine mammal population data

into models, predictions and advice

Complexity ↓

Unspecified component of *M* in fisheries models

In ecosystem models, marine mammals usually included as component with fixed energy needs and diet, sometimes with abundance series

In the future we could add…

+ modelled abundance trends
+ population structure (age, sex, etc)
+ diet & energy needs dependent on sex, age, etc
+ modelled diet (multispecies functional responses)
+ external drivers (pollution, fishing, CC)

Conclusions

- Wealth of marine mammal data (abundance, distribution, diet, etc) available for N Atlantic ecosystem models but time series often lacking
- When marine mammals are included in models, variability in parameters often not considered
- Importance of marine mammals varies between systems
- To forecast impacts of CC and other external drivers we need not only empirical measurements but also dynamic models of population processes


Thank you!