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Benthic Acidification

Scaling-up impacts to predict changes in ecosystem function

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Monitoring changes in benthic communities…

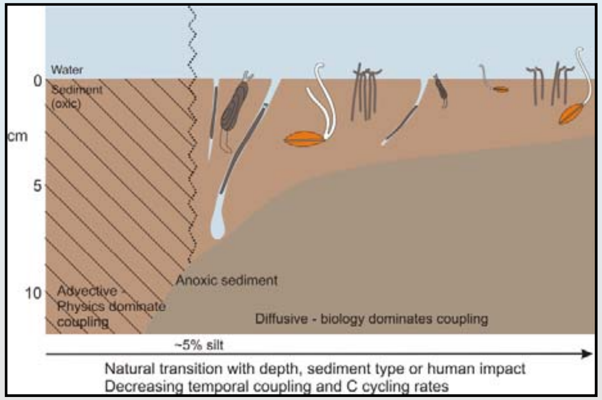
- Aim: to determine the effects of ocean acidification on the overall function of key benthic habitats

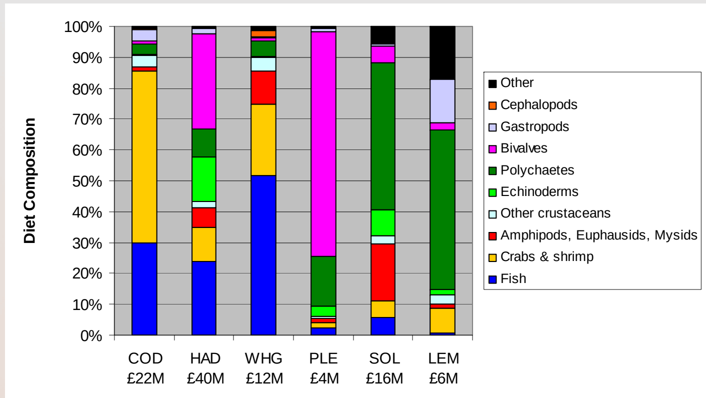
- To develop and test a conceptual framework to assess the broad-scale effects of OA in benthic communities (to 'scale-up' from experiments ➡ assemblage ➡ ecosystems

- Results from high CO_2 environments, field and lab experiments will be used to inform the effect of OA on sediment functions

- Baseline assessment of species distribution and abundance (functional trait information)

- Functions: bioturbation, bioirrigation, production, provisioning for higher trophic levels





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Ocean Acidification

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Experiments

Predictions

End users

Organisms physiology

Behaviour

Communities

Populations

Ecosystem Function

Biodiversity

Ecosystem value

Modelling

Policy

Society

Amphiura filiformis , *Cerastodesma edule* and *Nereis virens*

380 ppm T=ambient

380 ppm T=+4oC

1000 ppm ambient

1000 ppm T=+4oC

Control

Widdecombe, S., Dupont, S., Thorndyke. Laboratory experiments and benthic mesocosms studies. 2011. Guide to best practice for ocean acidification research and data reporting. Edited by U. Riebesell, Fabry, V.J., Hansson, L. Gattuso, J-P. Luxemburg, EU.

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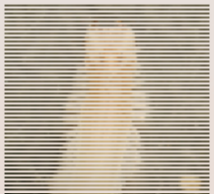
HYPOTHESIS

H_0: future high CO_2 scenarios will have no significant impact on the functioning of sediment habitats

Task: Map baseline species/assemblages=> functions and sediment biogeochemistry within the North Sea

- Benthic faunal work (abundance and BTA)
- Biogeochemical work (direct and indirect methods)
- Provisioning services – ‘bottom up’ effects on higher trophic levels (Fish)



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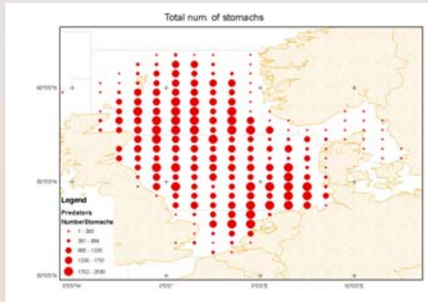
Data sources

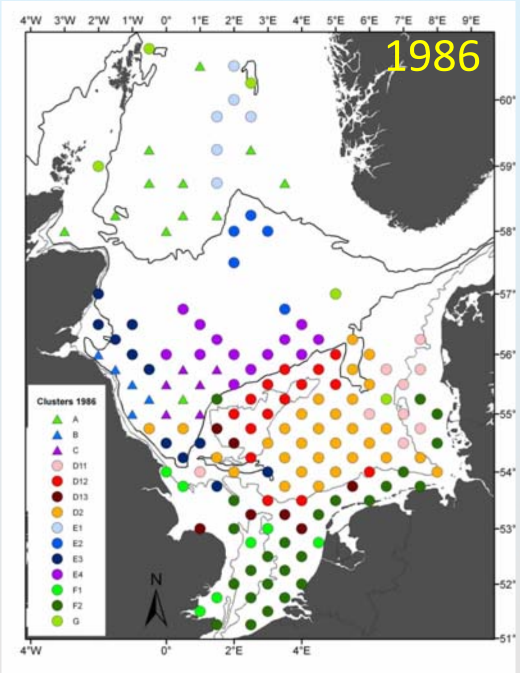
- Identification of existing data sets (1950-1955, Kirkegaard, 1969), ICES North Sea Benthos (1986 and 2000), project surveys with information on species and their physical variables.
- Selection of traits to classify species /biological traits Analysis (BTA)
- Biogeochemical work (Defra funded projects E3205, E5301)
- Key functions based on key mediated biologically mediated ecosystem processes (bioturbation, bioirrigation, production)
- ICES and Cefas' DAPSTOM database for fish consumption=> in relation to the 3 benthic species (OA benthic consortium)

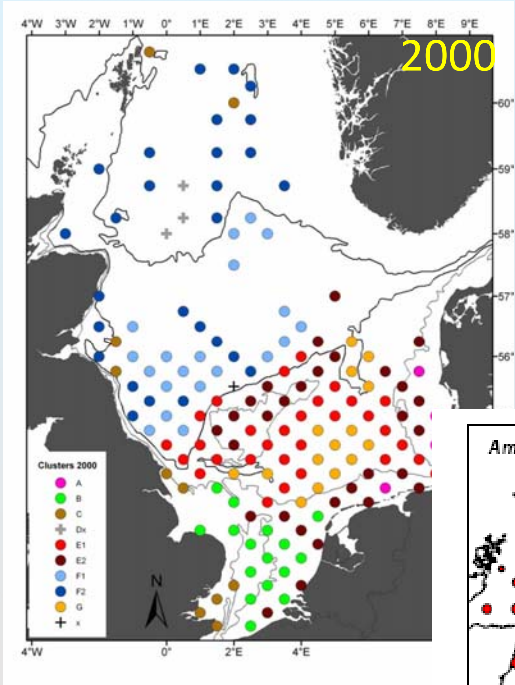
  *The ICES dataset of fish stomach contents for 10 commercial species (good spatial coverage but limited number of predators)

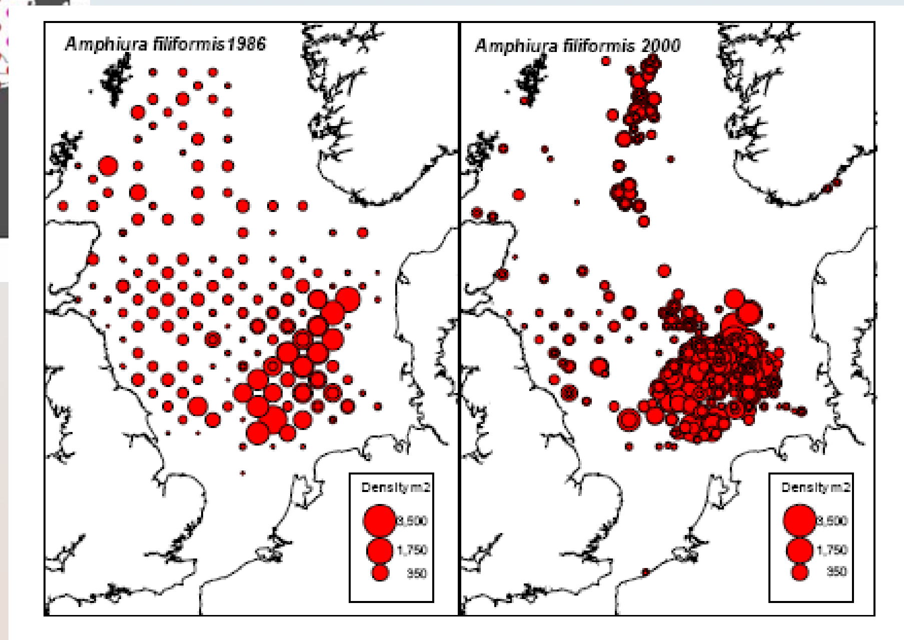
  *The Cefas 'DAPSTOM' database that covers 149 different fish species, spanning the past 100 years (1893-2010) but limited spatial coverage



Benthic assemblages







*Rees, H. L., et al , 2007, Kunitzer et al., 1992

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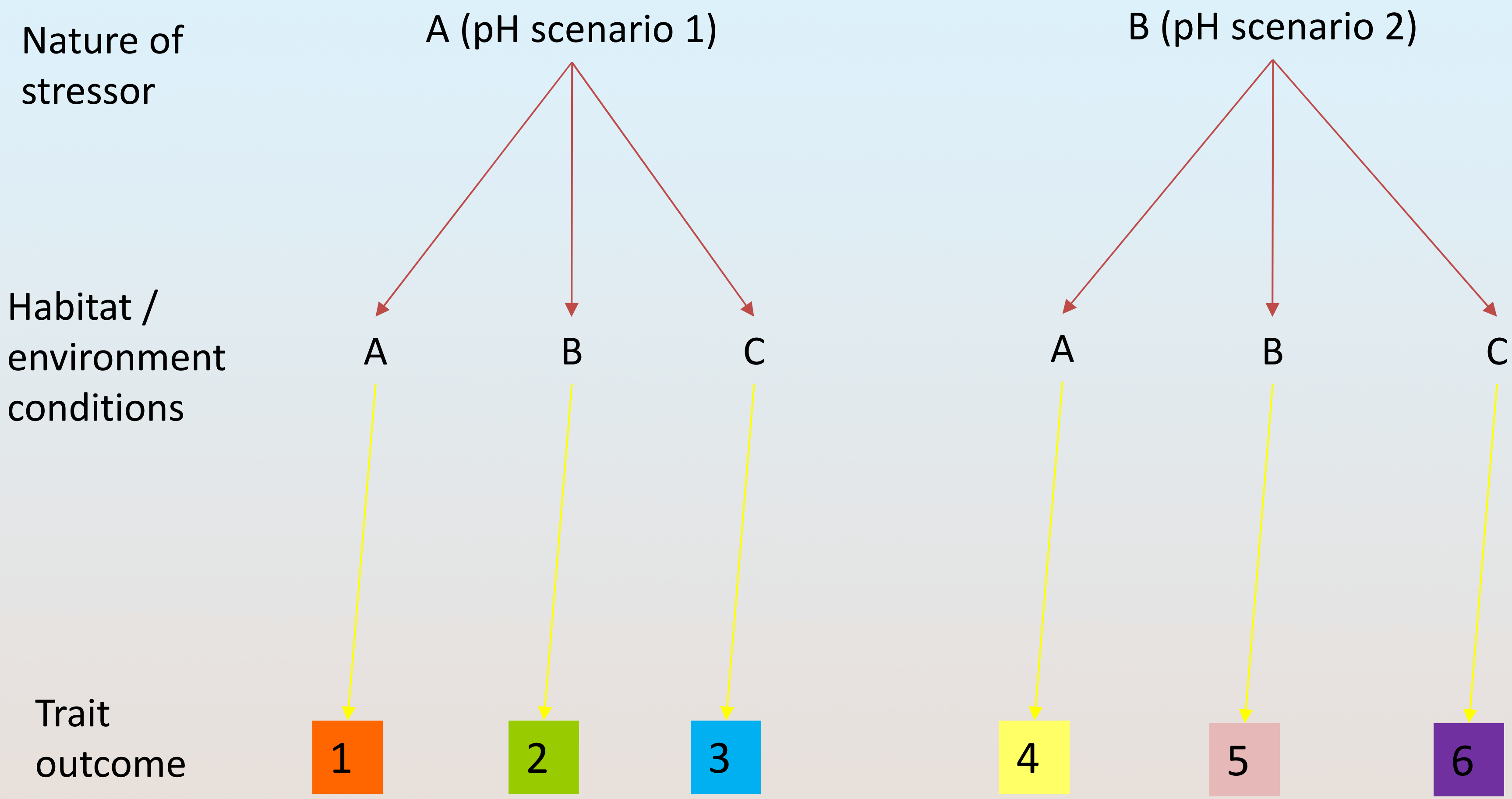
Fauna

Species	Species traits	Assemblage traits
Species A	Deposit feeder No migration Burrower	Scavenger Deposit feeder No migration Horizontal migration Vertical migration Burrower Crawler
Species B	Scavenger Horizontal migration Vertical migration Burrower Crawler	

(Bremner et al., 2003; Bremner et al., 2006)


Nature of stressor
A (pH scenario 1)
B (pH scenario 2)
Habitat / environment conditions
A
B
C
A
B
C
Trait outcome
1
2
3
4
5
6

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Biological traits

Trait	Function
Size	Carbon storage
Feeding	Energy transfer
Bioturbation	Nutrient cycling
Habit	Energy transfer
Reproduction	Connectivity Energy export
Larval life	connectivity

- Example of traits/attributes for benthic fauna
- Add traits to inform OA effects (e.g. shell, other responses)
- Species' sensitivities to OA
- A total of 935 taxa coded (fuzzy coding)
- Information available for most species / 'expert judgement'
- BTA analysis (Birchenough et al., 2011; Bremner et al., 2003a, Bremner et al., 2003b, 2006)

Traits	Attributes
Size (mm)	<20
	20-50
	50-100
	>100
Feeding	Carnivore (C)
	Scavenger (S)
	Selective deposit-feeder (sDF)
	Non-selective deposit-feeder (nsDF)
	Suspension-feeder (S)
Living habit	Tube
	Permanent burrow
	Free living
Bioturbation	Surface deposition (surf)
	Diffusive mixing (diff)
	Conveyor belt transport (convey)
	Reverse conveyorbelt (reverse)
	No bioturbation (No)
Reproduction type	Asexual (asex)
	Sexual-A
	Sexual-B

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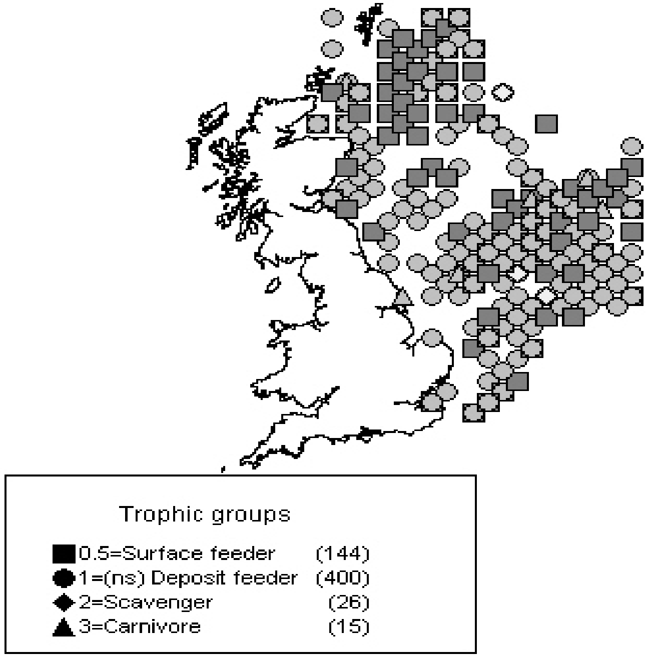
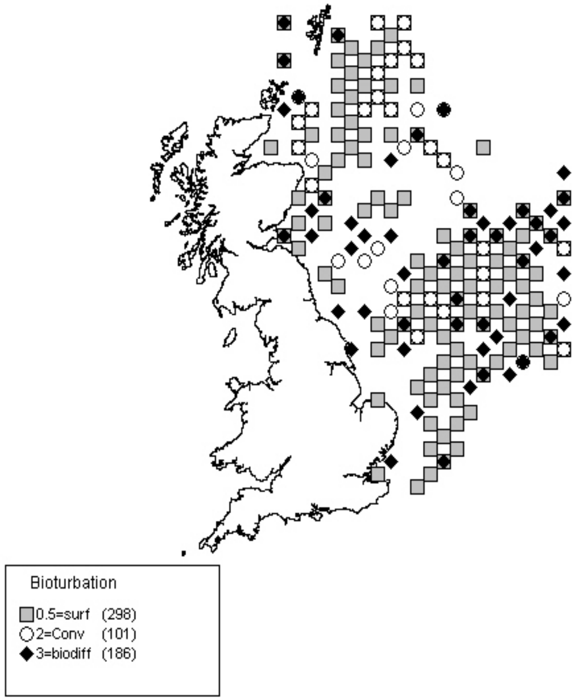
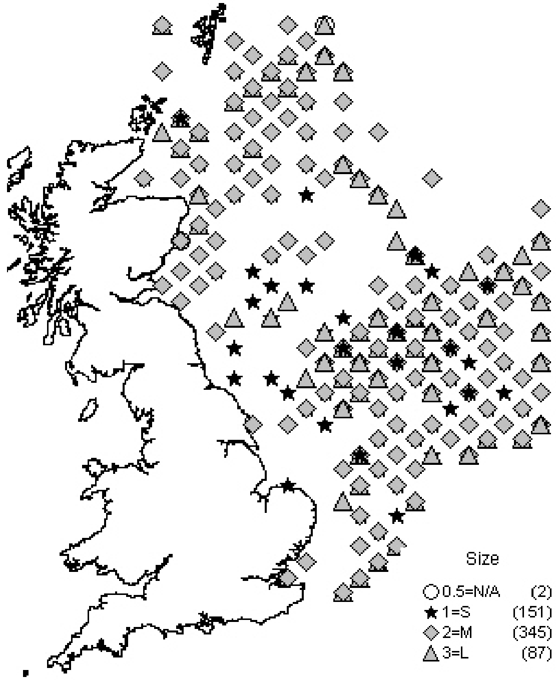
Patterns



Feeding
Carbon Storage



Bioturbation
Nutrient cycling



Size
Energy transfer

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Sensitivity review

Taxa	Species	Description	CO_2 system parameters	Sensitivity	Reference
Mollusca	*Haliotis laevigata*	Greenlip abalone	pH 7.78; pH 7.39	5% and 50% growth reductions	Harris *et al.* (1999)
	Haliotis rubra	Blacklip abalone	pH 7.93; pH 7.37	5% and 50% growth reductions	Harris *et al.* (1999)
	Mytilus edulis	Blue Mussel	pH 7.1 / 10 000 ppmv	Shell dissolution	Lindinger *et al.* (1984)
			pCO_2 740 ppmv	25% decrease in calcification rate	Gazeau *et al.* (2007)
			pH 6.6	100% mortality within 30 days	Bamber (1990)
	Mytilus galloprovincialis	Mediterranean	pH 7.3, ~ 5000 ppmv	Reduced metabolism, growth rate	Michaelidis *et al.* (2005)
	Crassostrea gigas	Pacific Oyster	pCO_2 740 ppmv	10% decrease in calcification rate	Gazeau *et al.* (2007)
			pH 6.0	100% mortality within 30 days	Bamber (1990)
	Placopecten magellanicus	Giant scallop	pH < 8.0	Decrease in fertilization and embryo development	Desrosiers *et al.* (1996)
	Tivela stultorum	Pismo clam	pH < 8.5	Decrease in fertilization rates	Alvarado-Alvarez *et al.* (1996)
	Pinctada fucada martensii	Japanese pearl oyster	pH 7.7	Shell dissolution, reduced growth	Reviewed in Knutzen (1981)
			pH .7.4	Increasing mortality	
	Mercenaria mercenaria	Clam	Ωarag =0.3	juv. shell dissolution, leading to increased mortality	Green *et al*. (2004)
	Strombus lohuanus	Gastropod	pH 7.9	Survival rate significantly lower	Shirayama and Thornton (2005)
Arthropoda	*Cancer pagurus*	Edible crab	1% CO_2 ~10 000 ppmv	Reduced thermal tolerance, aerobic scope	Metzger *et al.* (2007)
	Porcelana platycheles	Porcelain crab	pH 7.4	after 40 days no effect detected	Calosi *et al.* (2009)
	Callianassa sp.	Mud shrinp	pH 6.3	tolerant	Torres *et al.* (1977)
	Necora puber	Swimming crab	pH 6.16	100% mortality after 5 days	
	Amphibalanus amphitrite	barnacle	pH 7.4 – pH 8.2	Weakening of shell	McDonald *et al.* (2009)
Echinodermataa	*Strongylocentrotus pupuratus*	Sea urchin	pH ~6.2–7.3	High sensitivity inferred from lacking of pH regulation and	cf. Burnett *et al.* (2002)
	Psammechinus miliaris	Sea urchin		passive buffering via test dissolution during emersion	Spicer (1995); Miles *et al.* (2007)
	Hemicentrotus pulcherrimus	Sea urchin	~500–10 000 ppmv	Decreased fertilization rates, impacts larval developments	Kurihara and Shirayama (2004)
	Echinometra mathaei	Sea urchin			
	Cystechinus sp.	Deep-sea urchin	pH 7.8	80% mortality under simulated CO2 sequestration	Barry *et al.* (2002)
	Amphiura filiformis	brittlestar			Wood *et al.* (2008)
Sipuncula	*Sipunculus nudus*	Peanut worm	1% CO_2, 10 000 ppmv	Metabolic suppression	Pörtner and Reipschläger (1996)
				Pronounced mortality in 7 week exposure	Langenbuch and Pörtner (2004)
Polychaeta	*Nereis virens*		pH 6.5	tolerant	Batten and Bamber (1996)
	Nereis virens				Widdecombe *et al.* (2007)
Nematoda	*Procephalotrix simulus*		pH < 5.0	tolerant	Yanfang and Shichum (2005)
Foraminifera	*Marginoptera kudakajimensis*		pH 7.7 – pH 8.3	Decline in calcification rate, possibly precluding survival	Kuroyanagi *et al.* (2009)

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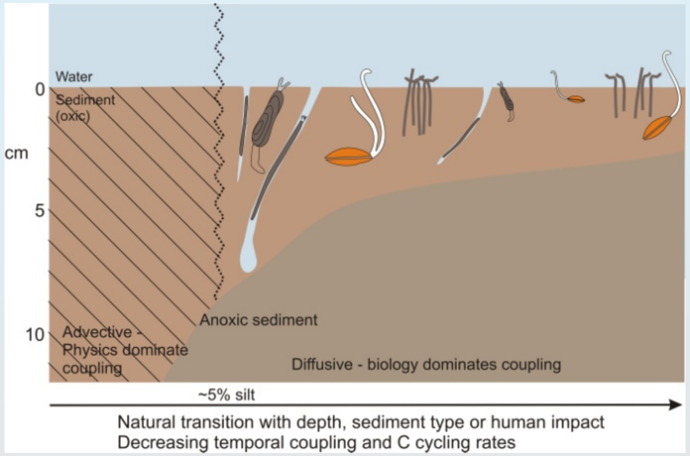
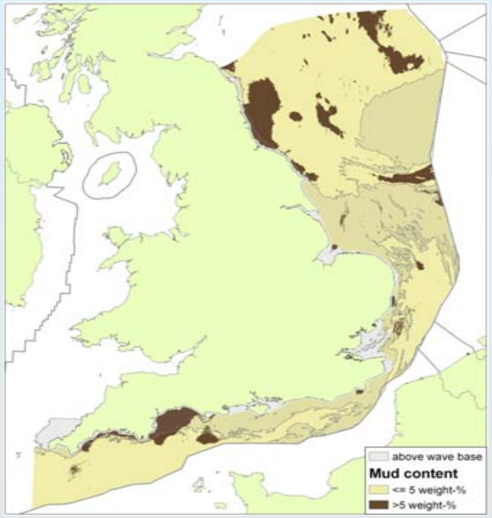
Modelling effects of OA on regional biogeochemical functioning: Methods

Regional distribution of biogeochemical status and controls



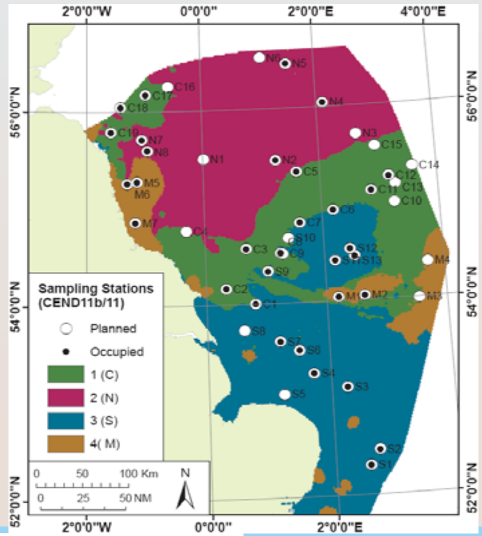


Areas where biogeochemical cycling processes are physically or biologically mediated. Permeable and not ~ wave base and % fines.

From Diesing and Parker, 2011 – Defra E5301

Direct: pH changes in water column propagation into the sediment – different sediment types (carbonate, quartz, shell ratios). Early stages – regional survey.
Indirect: Changes in macrofaunal assemblage (existing method)

Spatial and site specific modelling of existing datasets
Links statistical and ERSEM modelling



2011 Sampling of pH profiling and Sediments (seabed integrity)

*Greenwood et al. 2012

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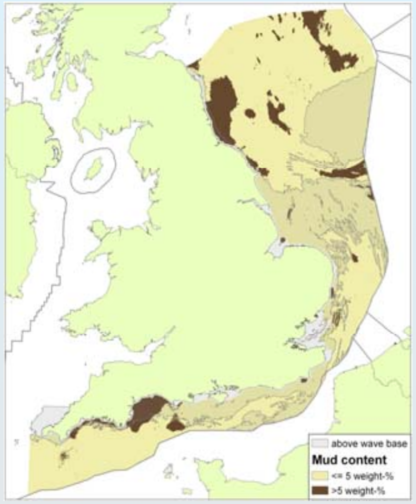
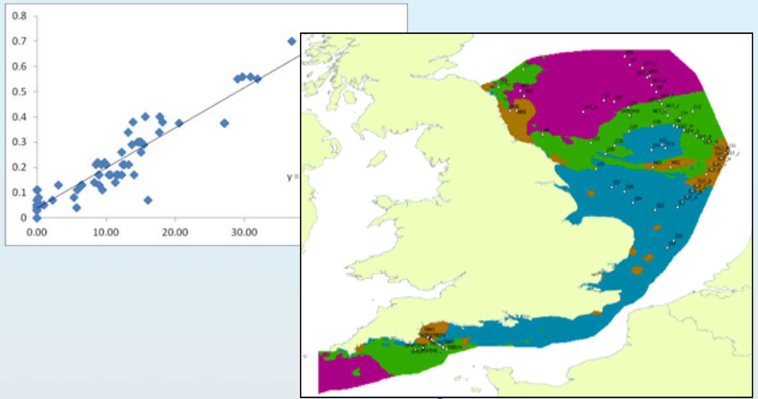
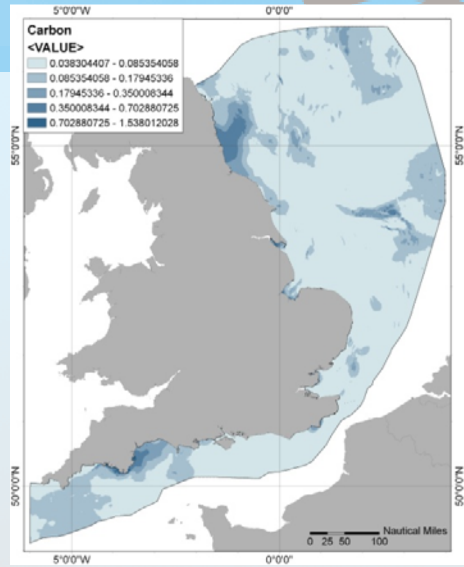
Biogeochemical Baselines



% silt/clay



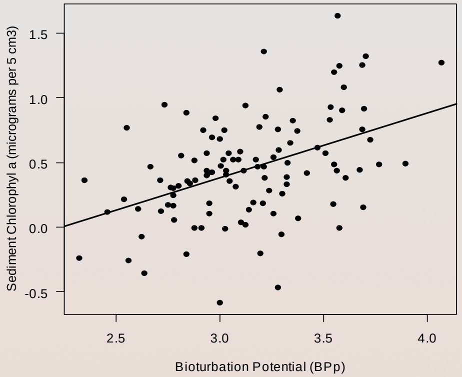


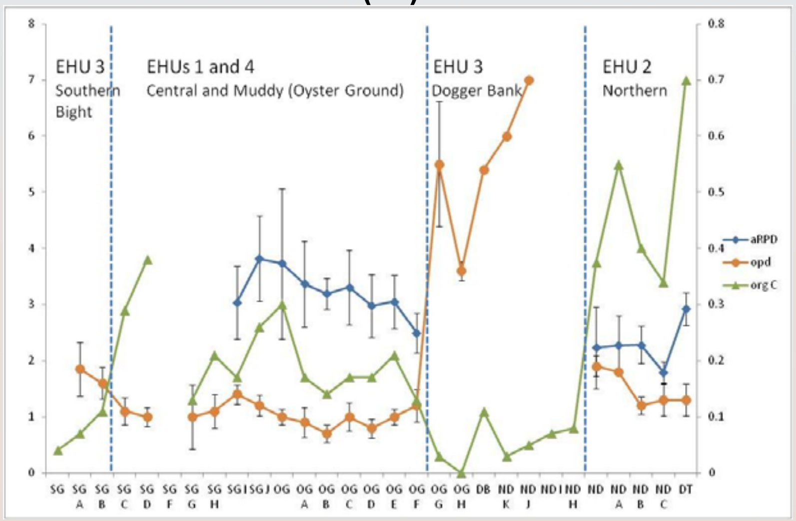
Carbon (%)

Biogeochemical status – North Sea
OPD
Carbon and Pigments
Nutrients
Redox (aRPD)

Linking to

Biological metrics
Production / P:B
Bioturbation (BPc)





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Provisioning services – 'bottom up' effects on higher trophic levels

•Assessing the consumption by fish on specific benthic invertebrate species that are thought to be vulnerable to ocean acidification

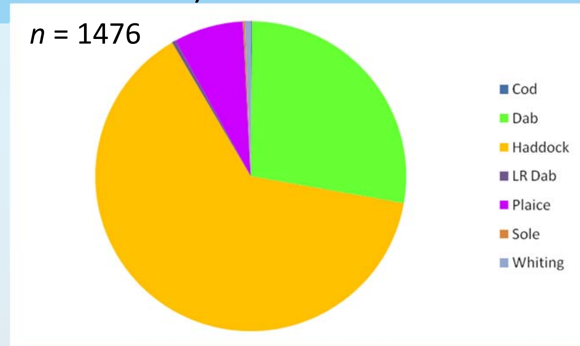
The 'DAPSTOM' dataset

The DAPSTOM database now contains 177,827 records from 157,159 individual predator stomachs and 149 fish species.

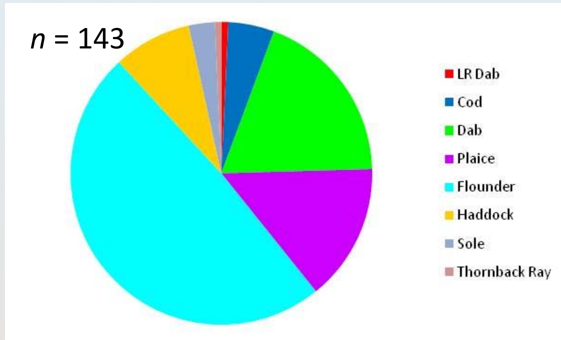
The full dataset is searchable via an online data portal (www.cefas.defra.gov.uk)

The dataset can be searched by "predator" species (e.g. haddock) or "prey " species (e.g. *Amphiura*).

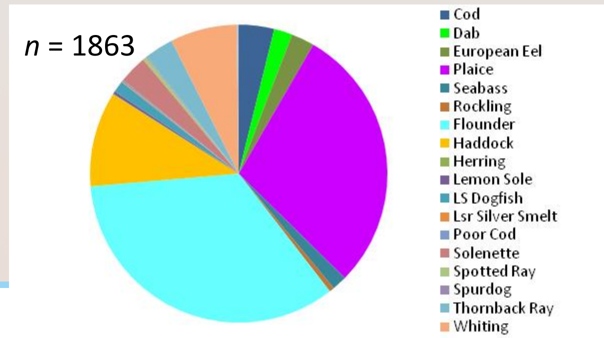
Predators feeding on *Amphiura filiformis* (% of records in database)

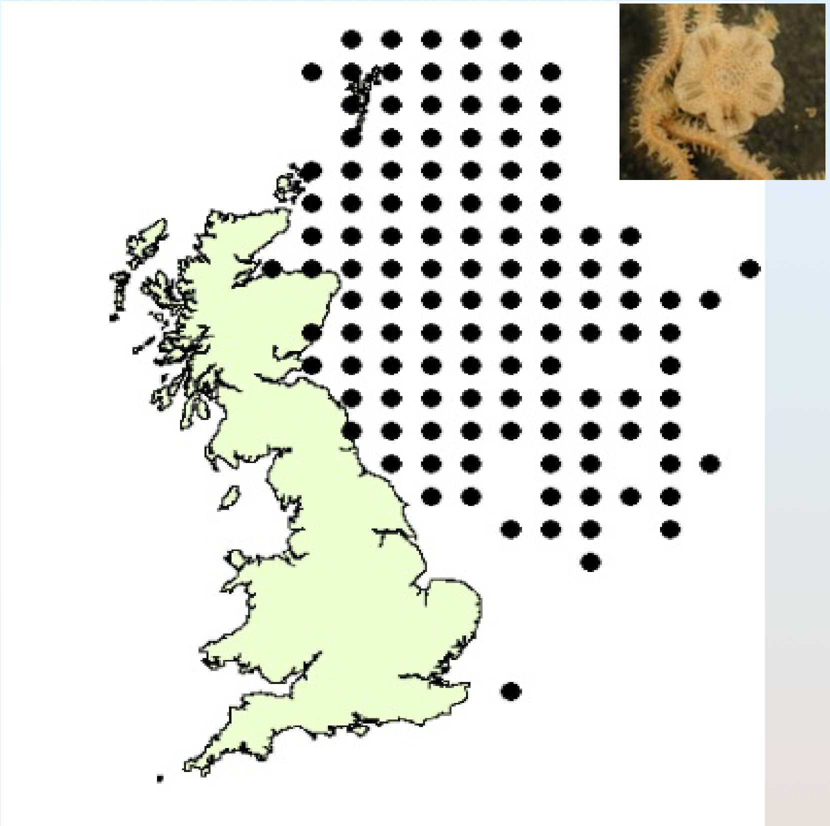


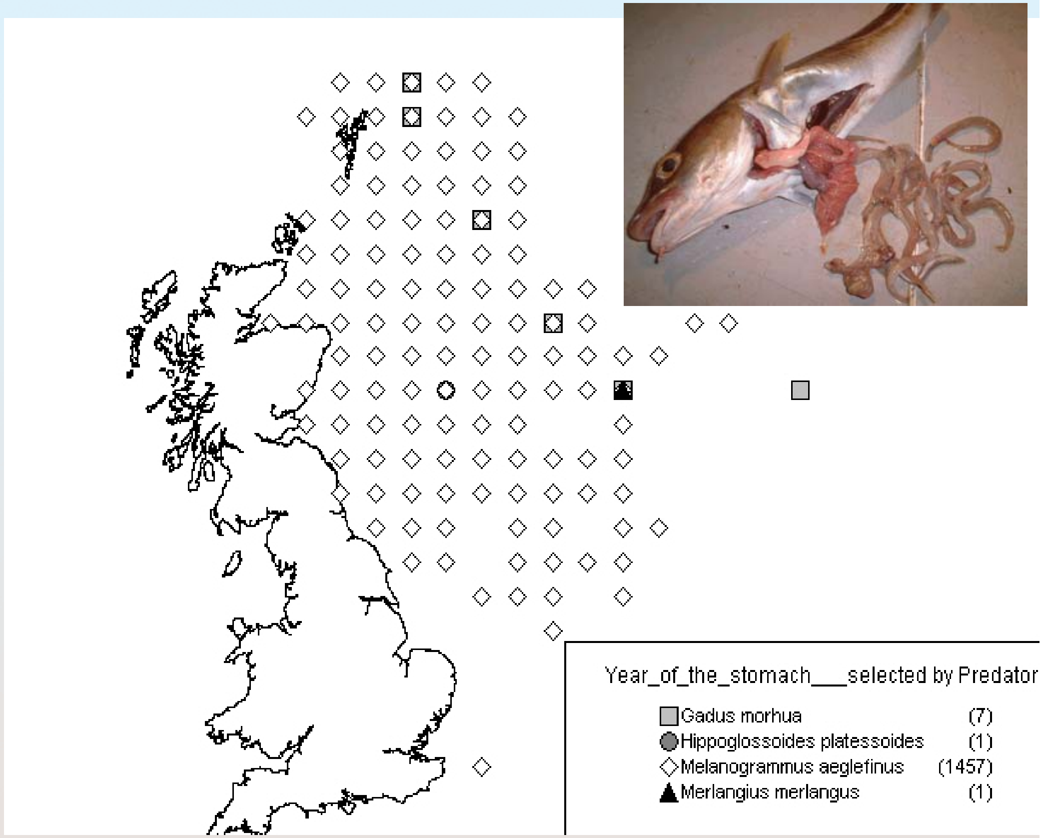
Predators feeding on *Cerastodesma edule*



Predators feeding on *Nereis/Nephtys* spp.







- Main predators (Haddock, Cod, Plaice, Whiting)
- Physiological effects on fish (need more information)
- How different fish predators might respond in the future to the changing patterns of prey availability (Kaplan et al., 2010)

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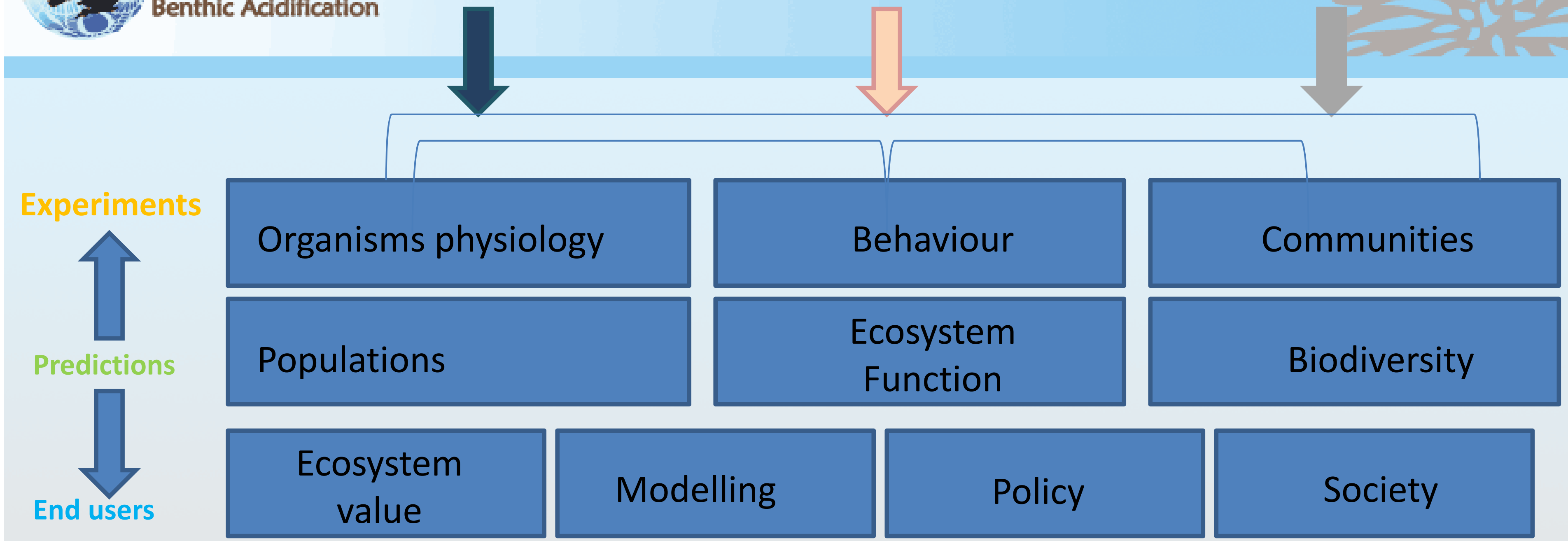
Ocean Acidification



- This approach is a direct method to assess functional responses to ‘OA’ covering a number of benthic assemblages/sediment types in the NS.
- This information is complementary to experimental evidence and will help us to identify possible OA impact/areas
- This work will be used to ‘scale up’ from to possible impacts on ecosystem function (e.g. bioturbation, bioirrigation, production, nutrient cycling, provisioning for higher trophic levels)

Questions?

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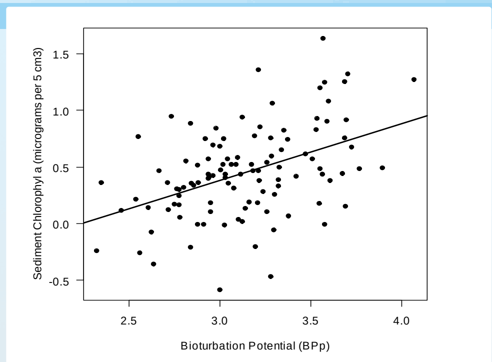
BPc vs sediment biogeochemistry or pH change ~ carbonate/shell etc

Biogeochemical modelling:

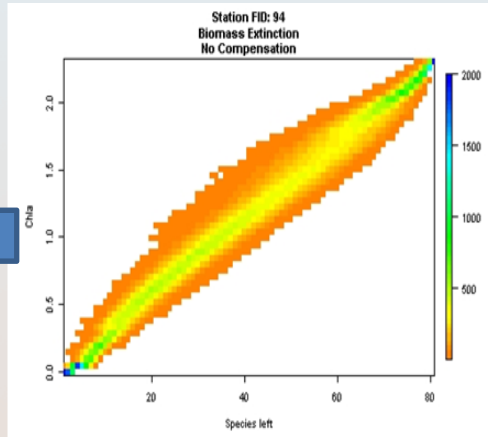
Coincident Biogeochemical & Faunal data
Site specific or regional



Sea region or Sub-region

OA sensitivity matrix of species or substrate type

Assemblage species or substrate altered and BPc/function recalculated



Biogeochemistry and BPc tracked as species removed or under set pH scenarios

Regional futures or rates of change of functions

Parker et al., in prep, Solan et al., in prep, Solan et al., 2004

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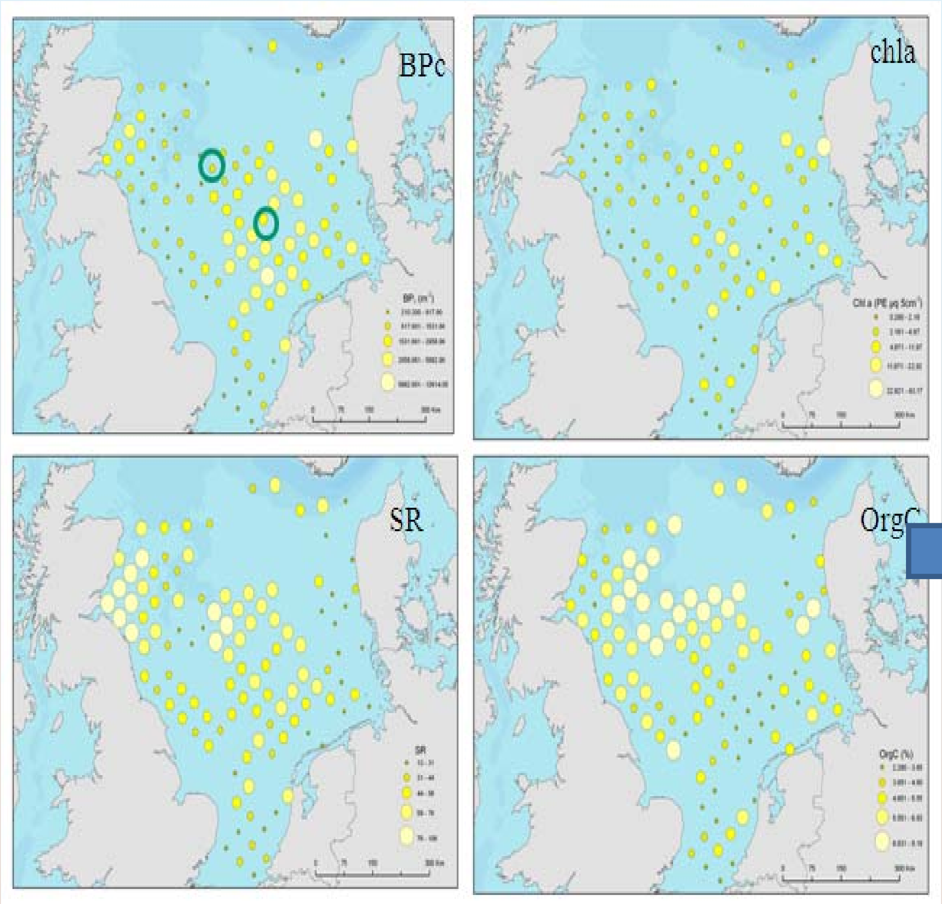
Results: Baseline conditions- NSBS 1986

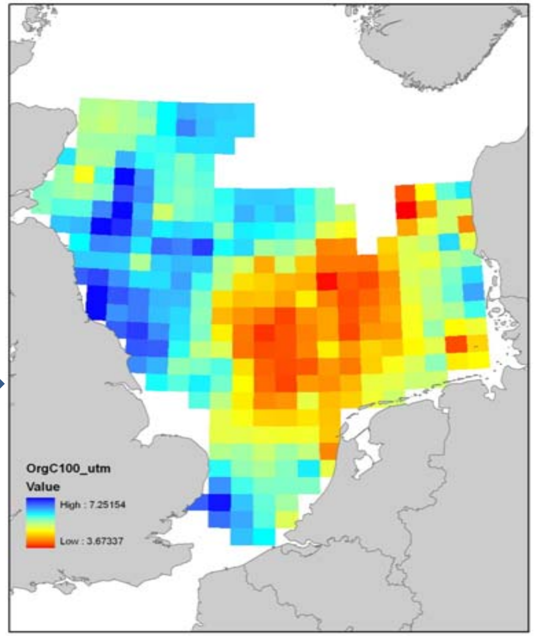


Observations:

Bioturbation (BPc, Solan et al., 2004)

Species richness

Carbon fractions



GIS mapping and volume calculations

Total regional budget as whole or part regions or changes given assemblage change.

ICES NSBS 1986 (from Parker et al., in prep)