BioSpace25 - Biodiversity insight from Space
10 - 14 February 2025 | ESA-ESRIN | Frascati - Italy

Relationships between shelf-sea fronts and biodiversity studied using Earth observation data

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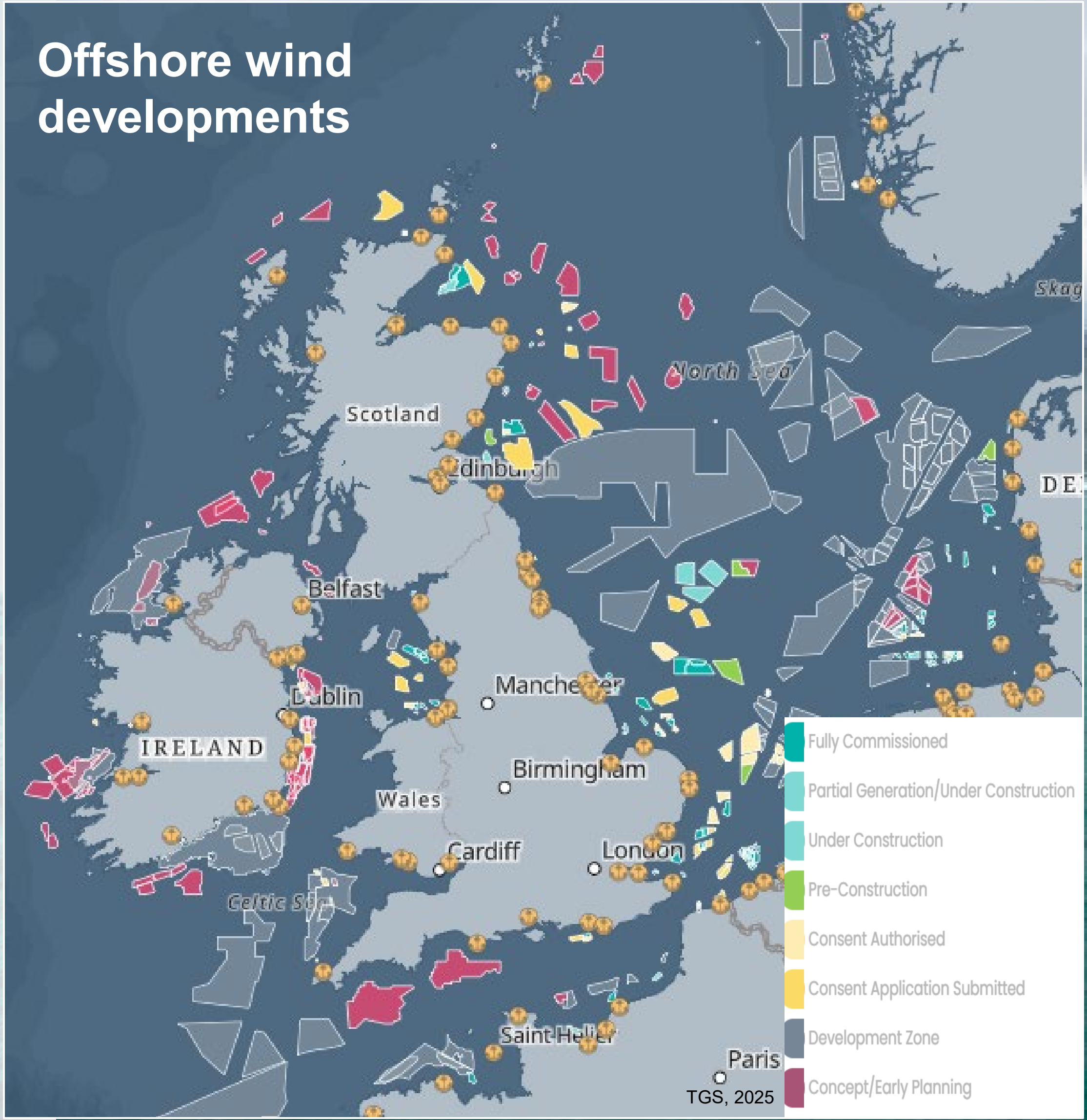
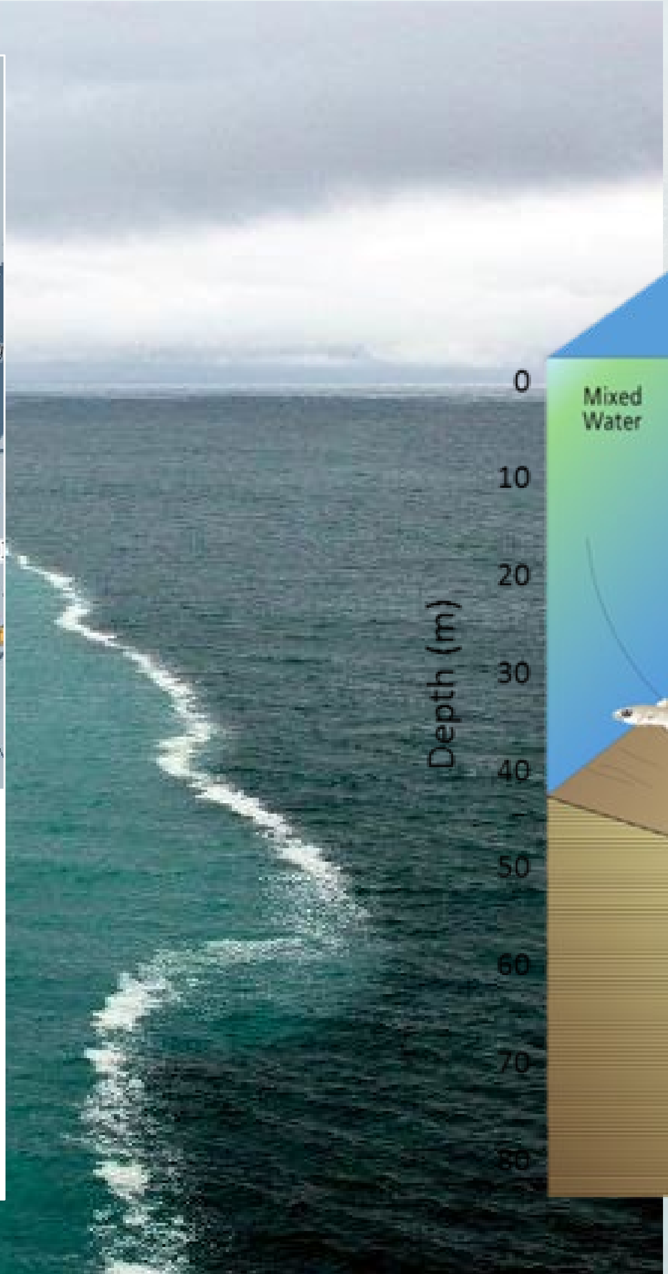
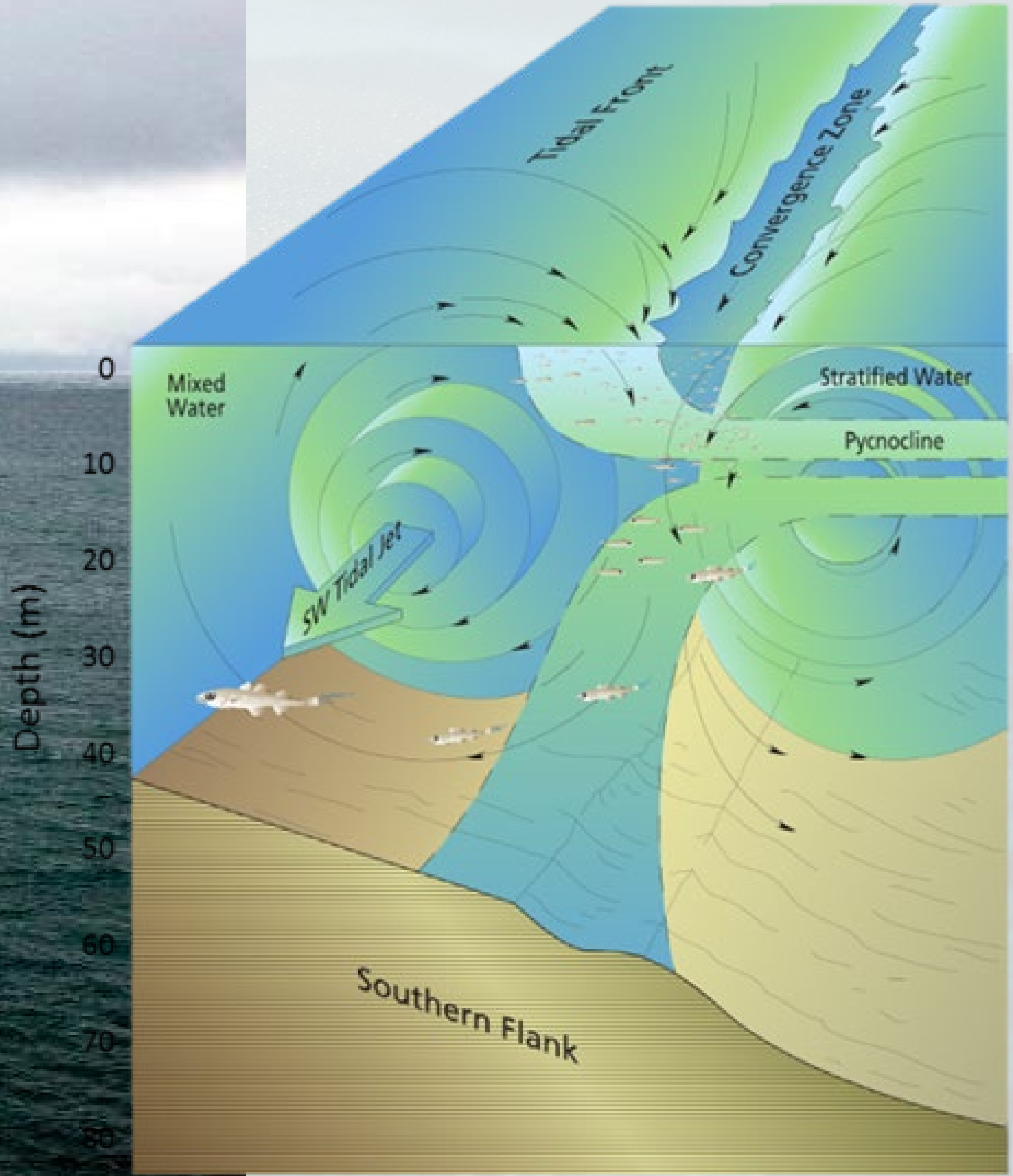
Why are ocean fronts important for biodiversity?







Shelf-sea fronts vs. biodiversity using EO data

- Ocean front metrics
- Biodiversity index
- Linking fronts and biodiversity
- What drives front locations and characteristics?

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Shelf-sea fronts vs. biodiversity using EO data

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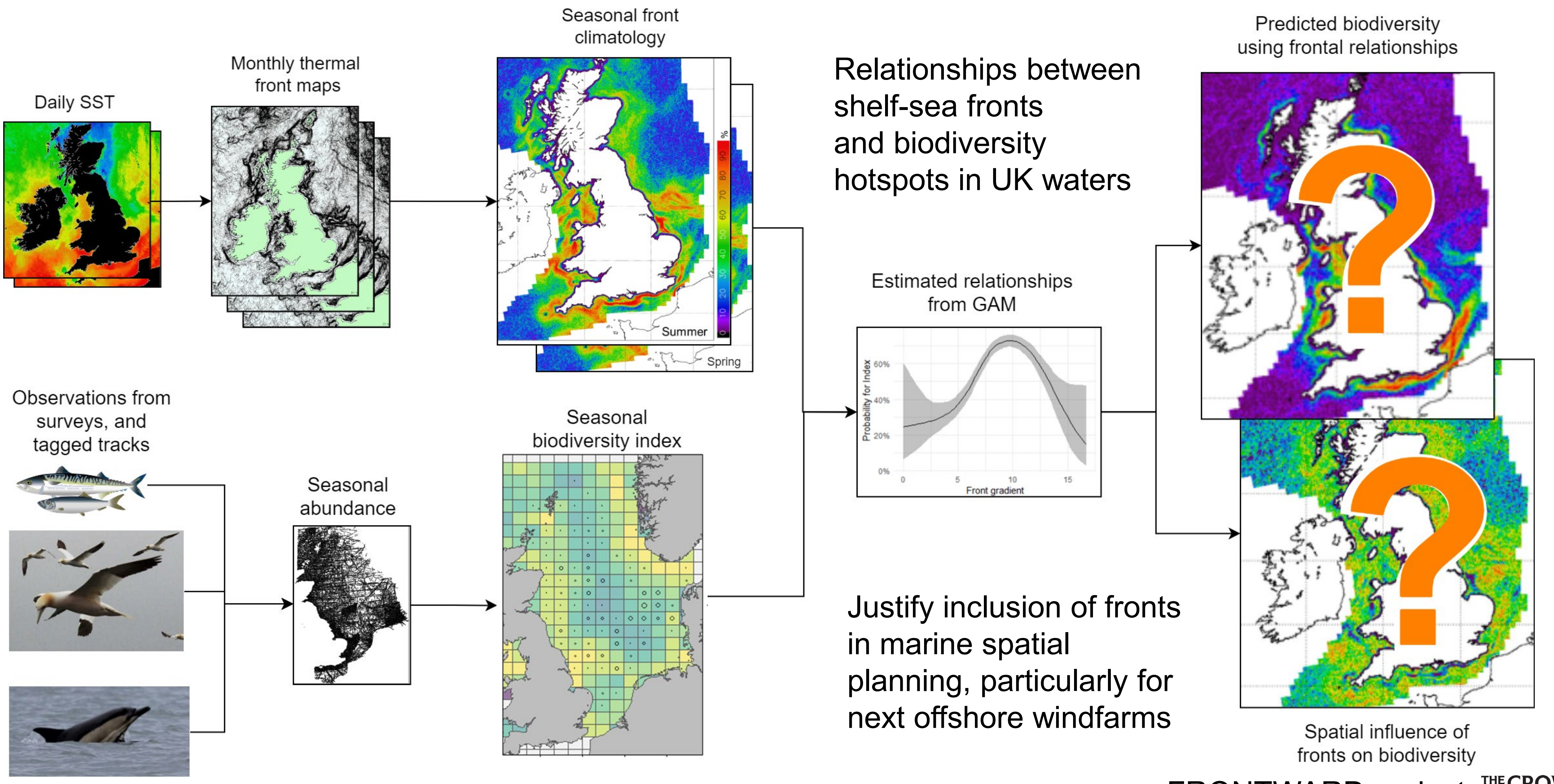
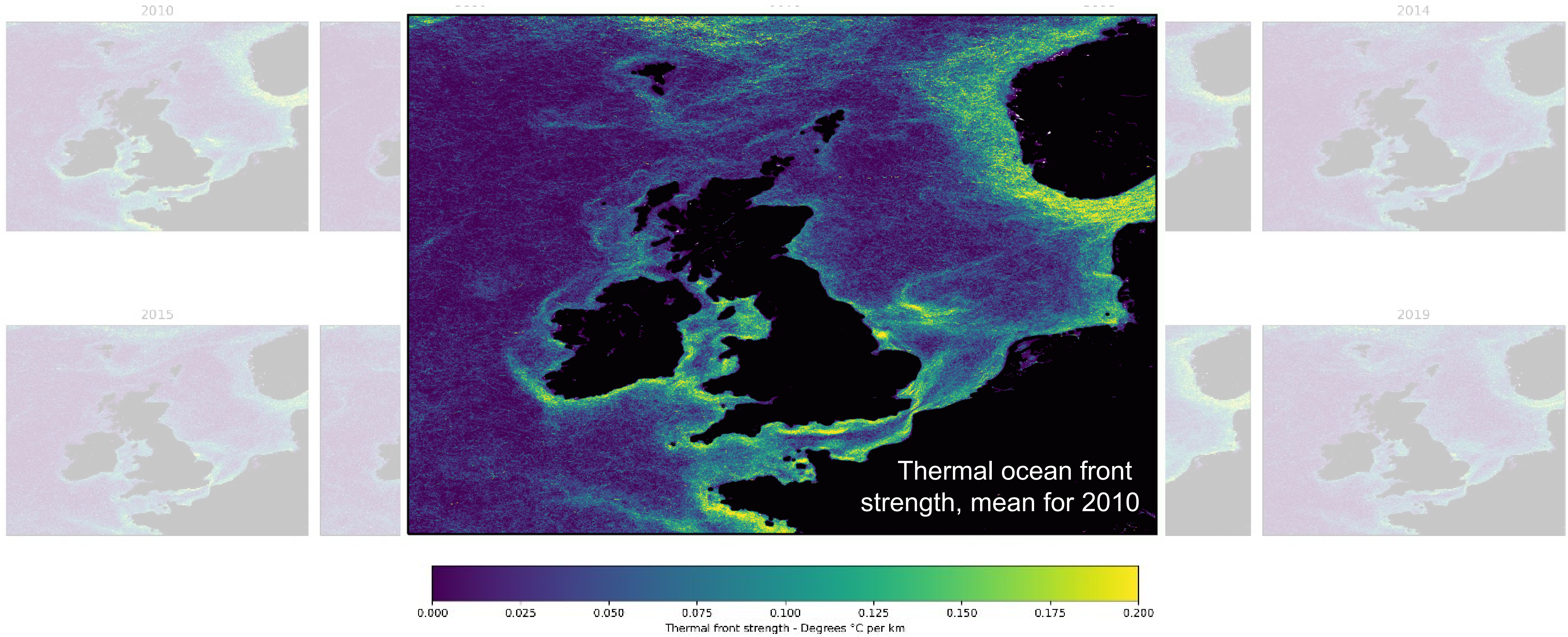


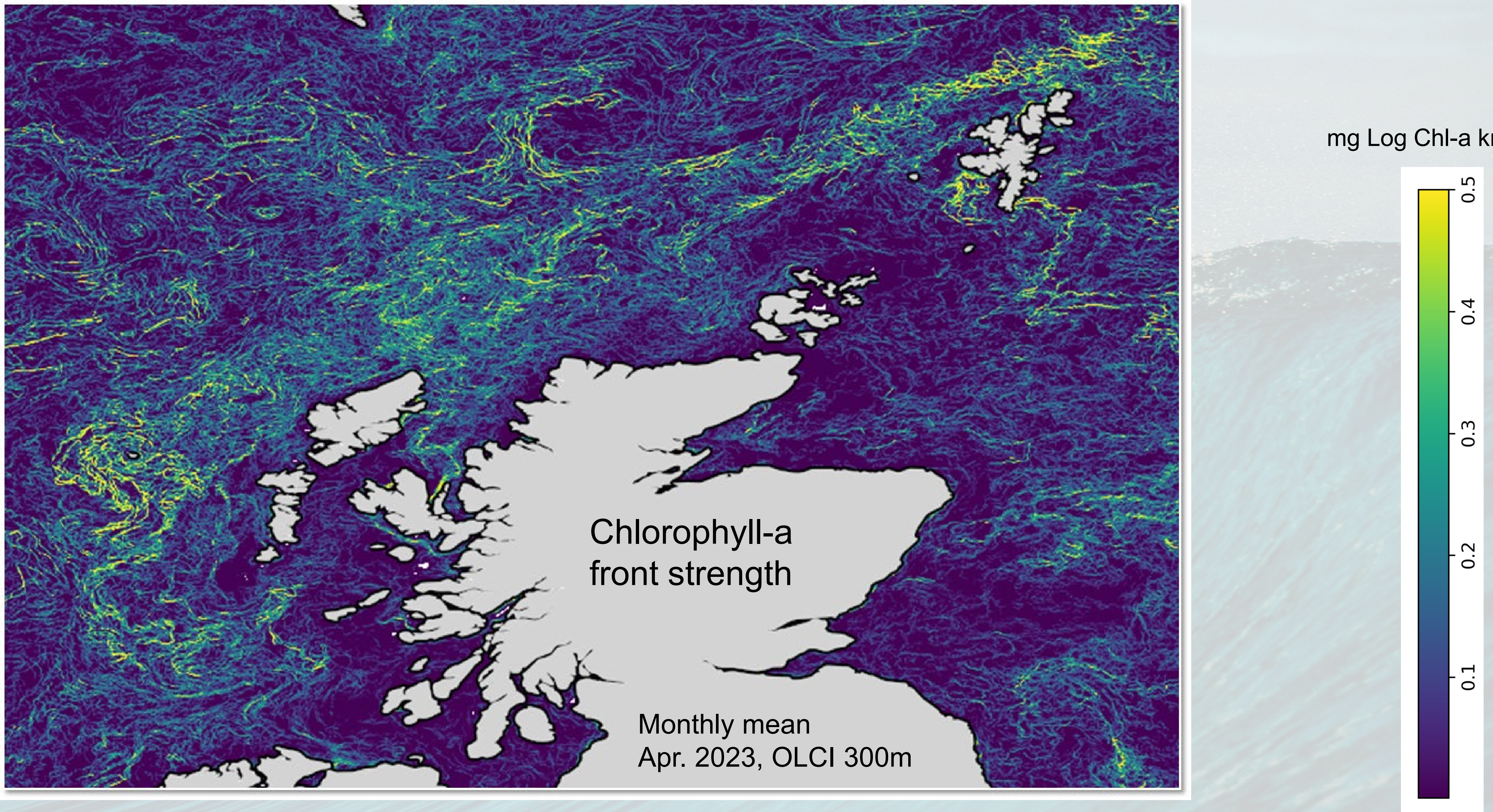
FRONTWARD project THE CROWN ESTATE

Ocean front metric: Thermal front strength



Annual mean strength (gradient magnitude) of sea-surface temperature fronts, 2010-2019

Ocean front metric: Chlorophyll-a front strength



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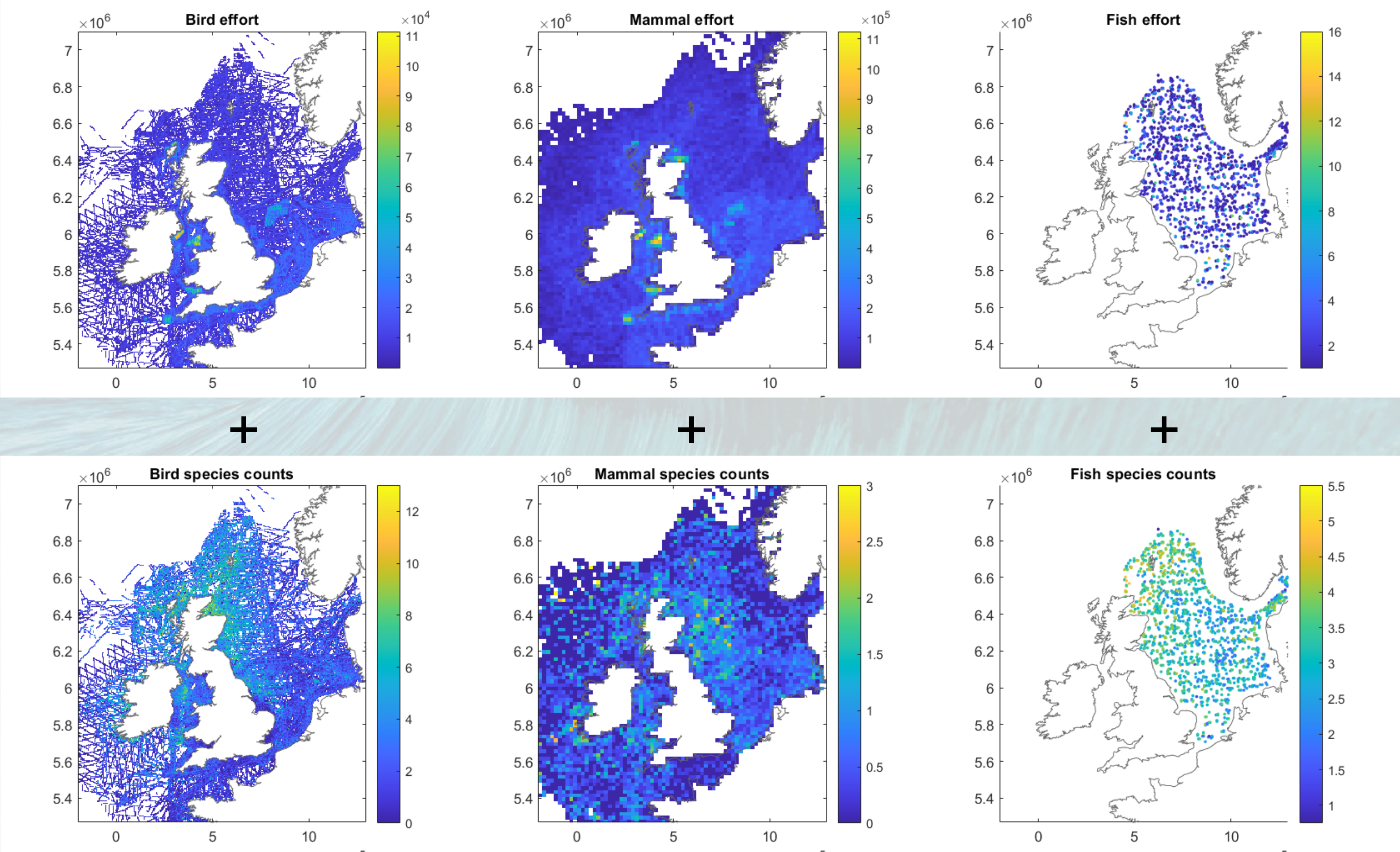
Effort and species counts

Effort and species counts are combined in the modelling for each group (bird/mammal/fish) along with survey type and method, to produce the biodiversity estimates

Sampling effort

Species counts



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Biodiversity index multi year

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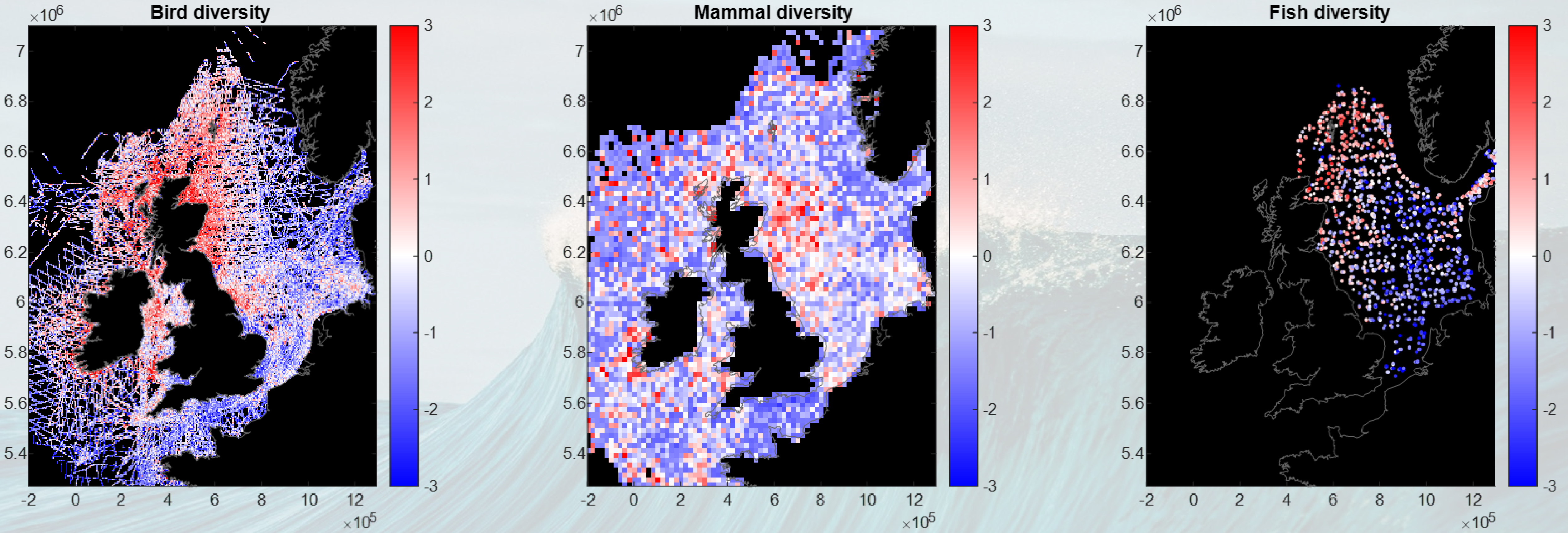

- Combined all animal datasets over sampling season (Apr.–Sep.) and 20 years.
- Modelled predicted species richness given the survey type, method, and amount of survey effort.
- Separately for the bird, mammal, and fish datasets.

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Biodiversity model: Generalised additive modeling (GAM)

$$y_i \sim Binomial(p_i, k_i)$$

$$\text{logit}(p_i) = \beta_0 + f_1(\text{Cell}_i) + f_2(\text{F}_i) + f_3(\text{IW}_i) + f_4(\text{CM}_i) + f_5(\text{CP}_i) + f_6(\text{MA}_i) + f_7(\text{MV}_i) + f_8(\text{BA}_i) + f_9(\text{BV}_i + f_{10}(\text{F}_i)$$

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where:

- y_i is the number of species detected in cell i
- p_i is the probability to detect species
- k_i is the assumed total number of species which could be detected given survey methods
- β_0 is the intercept
- f_1 is a Markov Random Field smooth with K knots
- $f_2, \ldots, 5$ are cubic regression splines with 5 knots
- $f_6, \ldots, 10$ are cubic regression splines with 3 knots

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Linking biodiversity to ocean fronts

- Predicted detection probability of selected species, incorporating effect of front metrics.
- Ten-year average of EO data and biodiversity index.

$$y_i \sim Binomial(p_i, k_i)$$
$$\text{logit}(p_i) = \beta_0 + f_1(\text{Cell}_i) + f_2(\text{F}_i) + f_3(\text{IW}_i) + f_4(\text{CM}_i) + f_5(\text{CP}_i) + f_6(\text{MA}_i) + f_7(\text{MV}_i) + f_8(\text{BA}_i) + f_9(\text{BV}_i + f_{10}(\text{F}_i)$$

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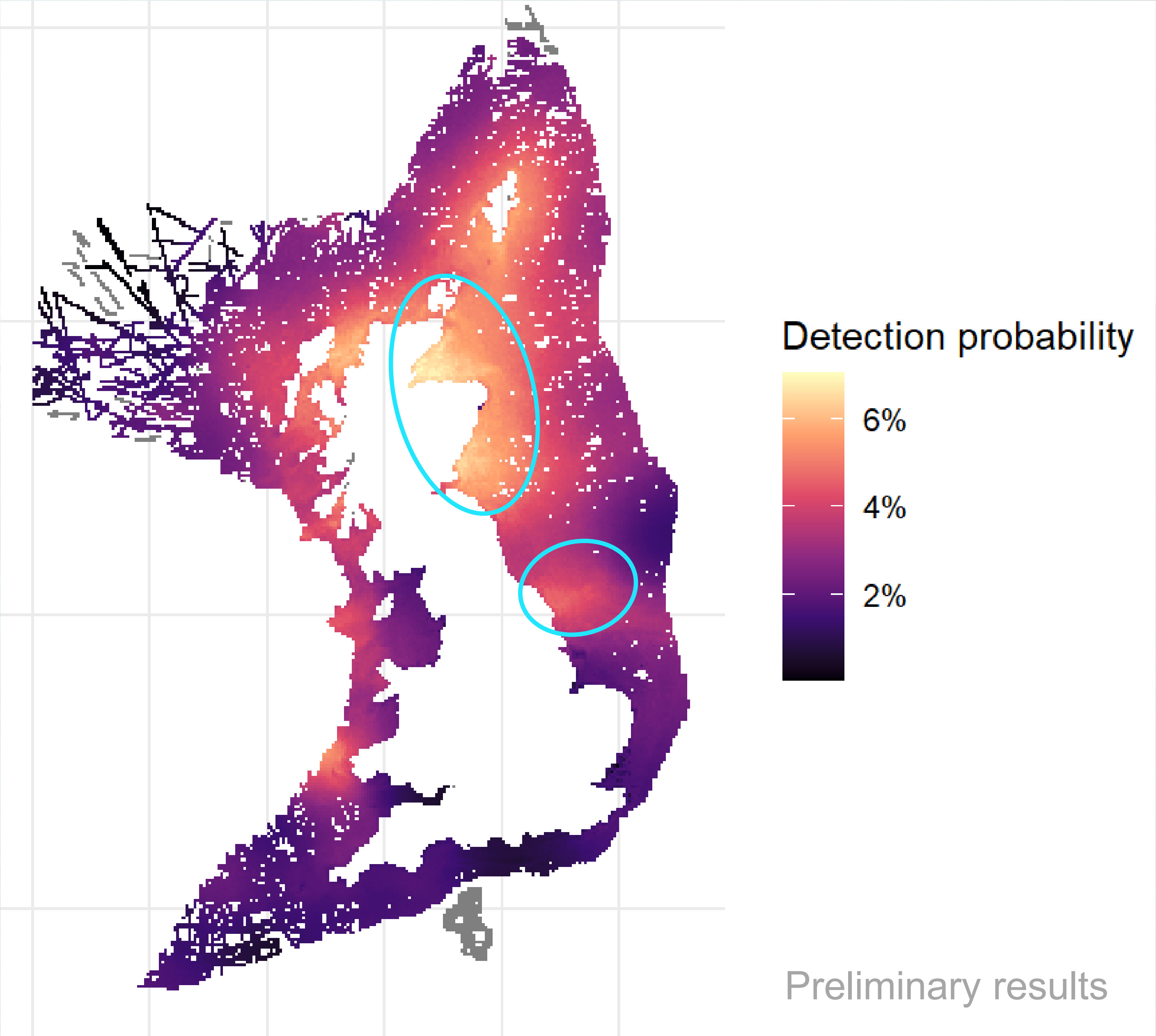
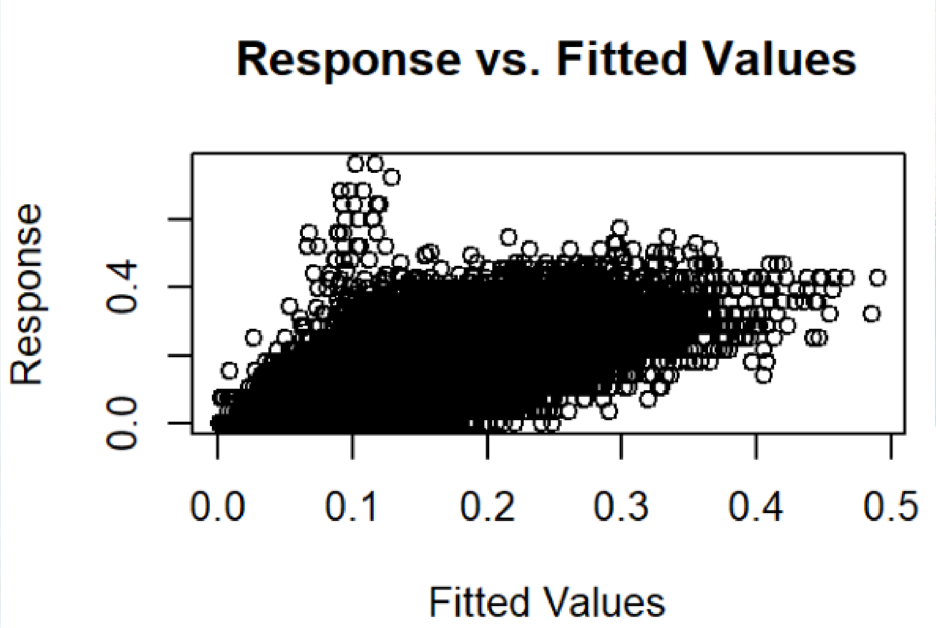


How much do fronts influence biodiversity?

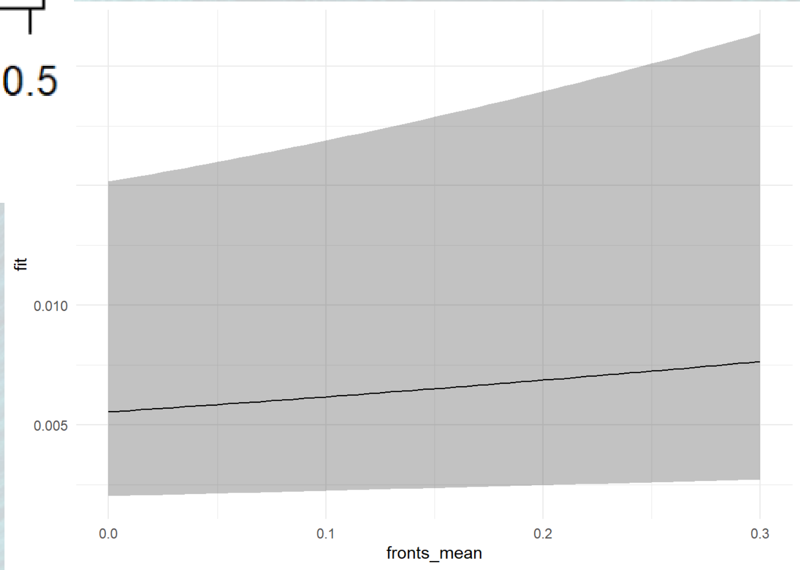
- $R^2 = 0.432$
- Deviance explained = 41.8%

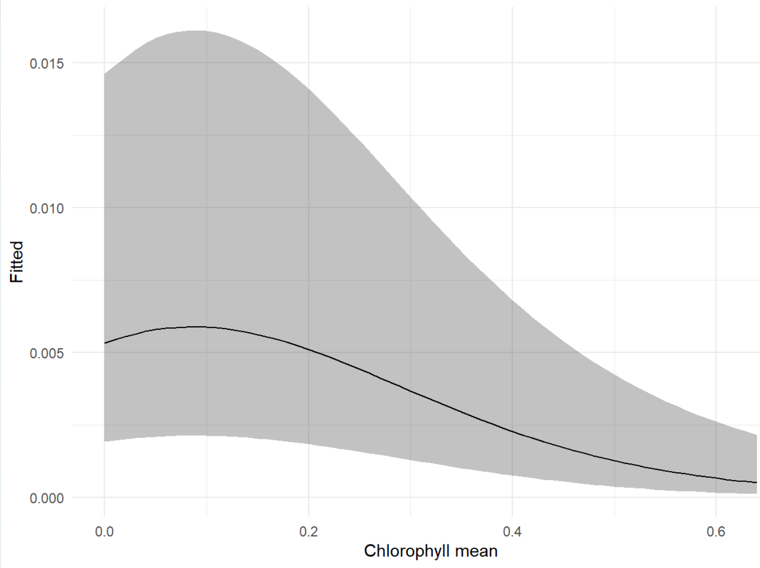


How important is each frontal metric?

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value	
s(ROWID)	93.496	99.000	10839.540	< 2e-16	***
s(fronts_mean)	1.000	1.001	6.093	0.013583	*
s(fronts_pers)	2.828	3.211	17.921	0.000469	***
s(internal_wa)	3.495	3.832	12.971	0.034707	*
s(chl_mean)	2.926	3.373	31.373	1.8e-06	***
s(chl_persist)	1.001	1.001	0.338	0.561269	





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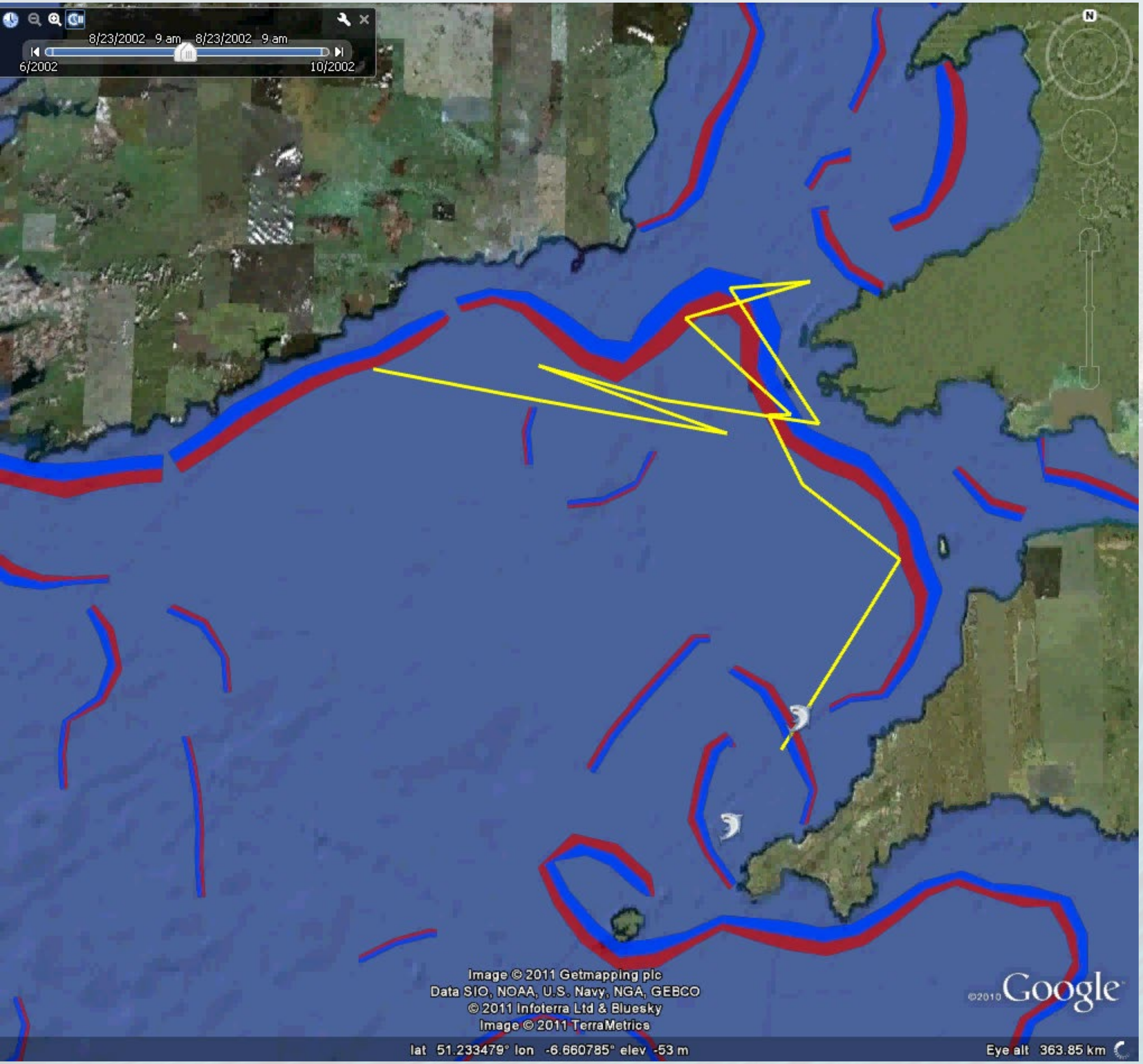
Dynamic fronts influence dynamic biodiversity



Basking shark tracked with GLS tag

24 Aug. – 15 Oct. 2002

Key

Warm

Cold

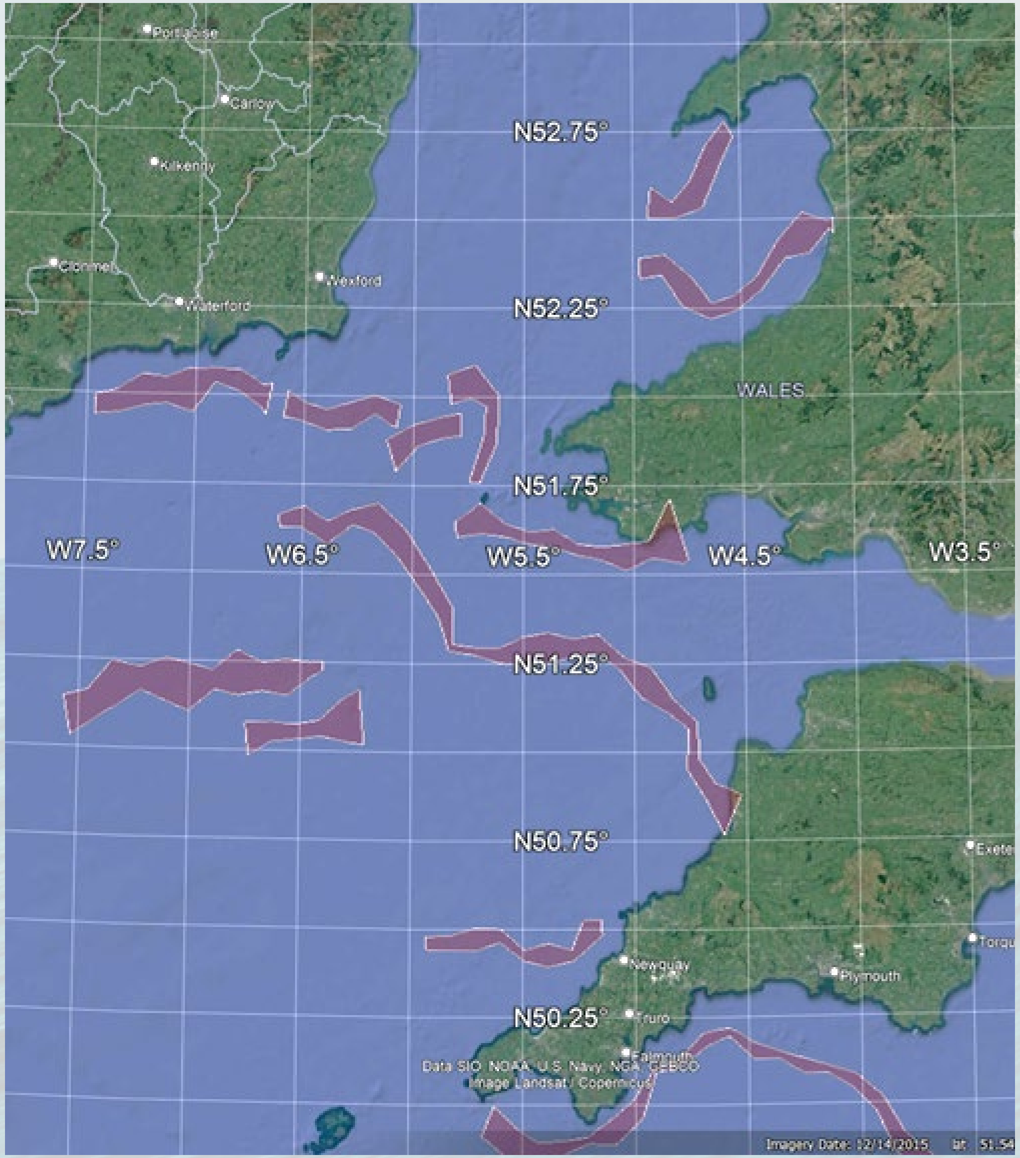
Weak

Strong

Miller, P.I., Scales, et al. (2015) Basking sharks and oceanographic fronts: quantifying associations in the north-east Atlantic. *Functional Ecology*

Characterising dynamic fronts

7-day front dynamic distance



Annual composite of dynamic distance

Drivers of long-term shelf-sea front variability

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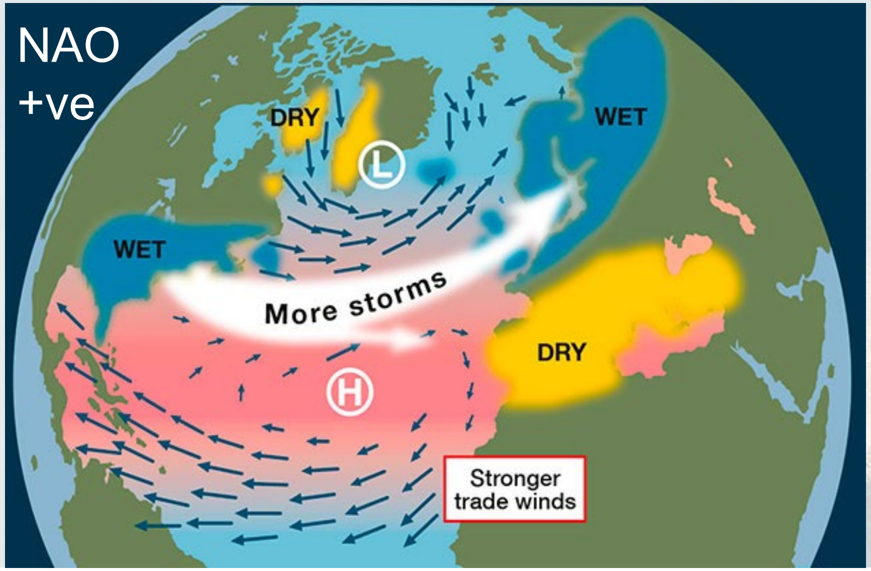
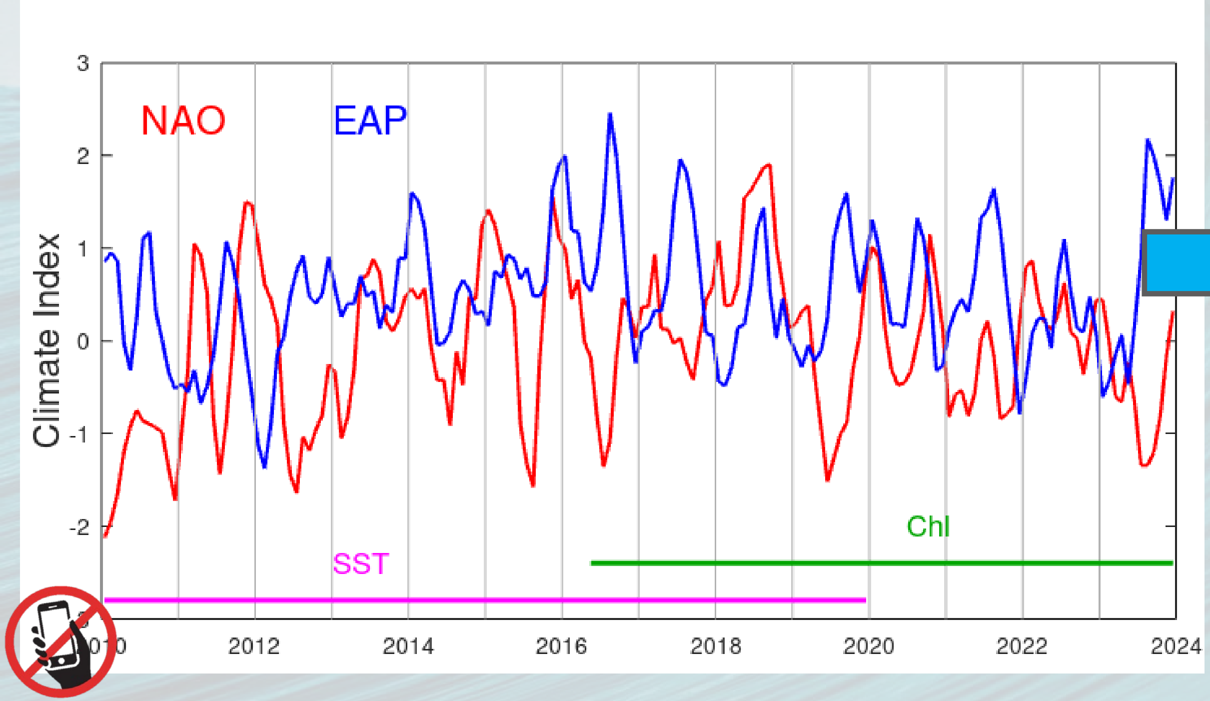
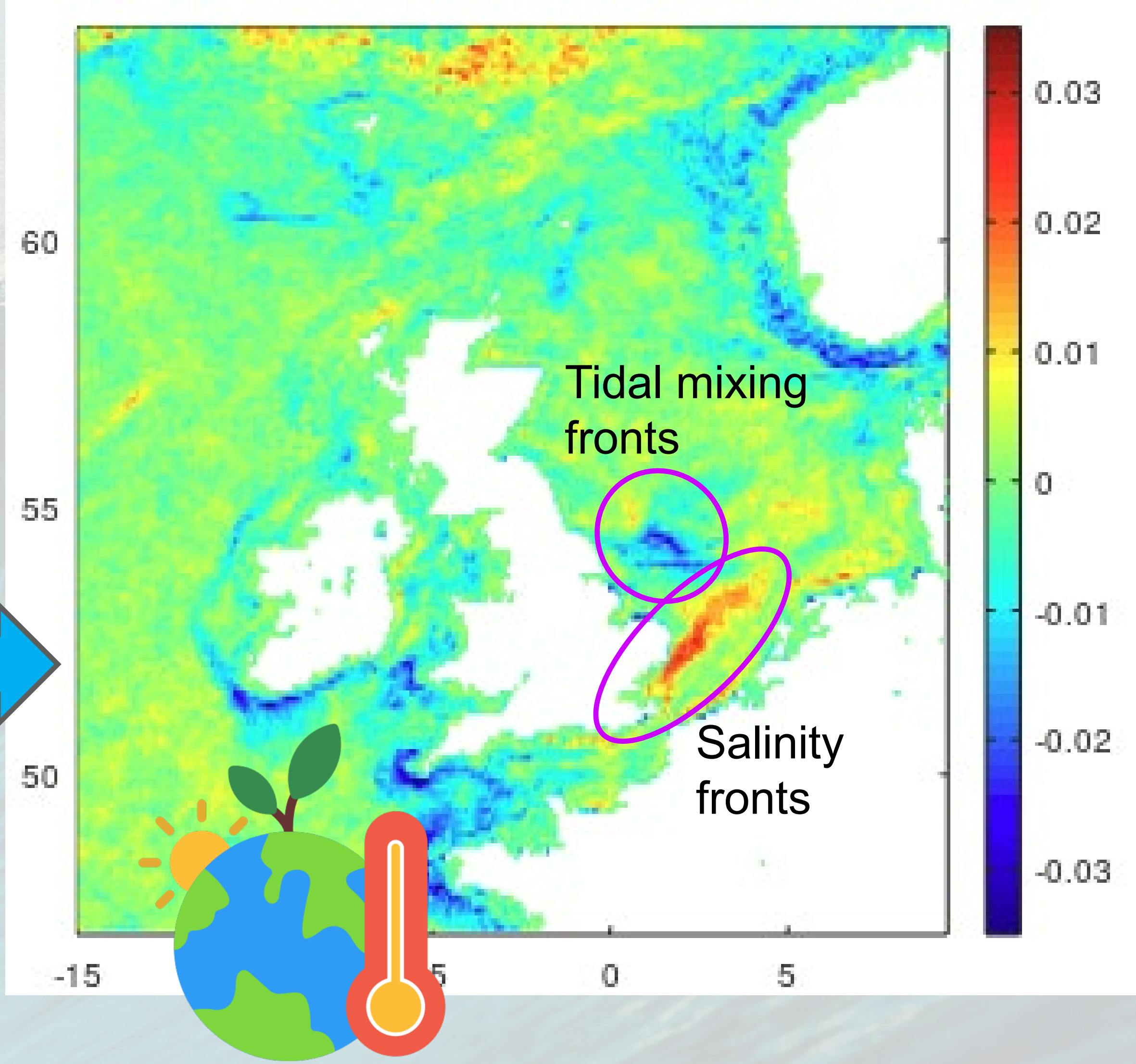




Correlation: thermal front strength vs. NAO

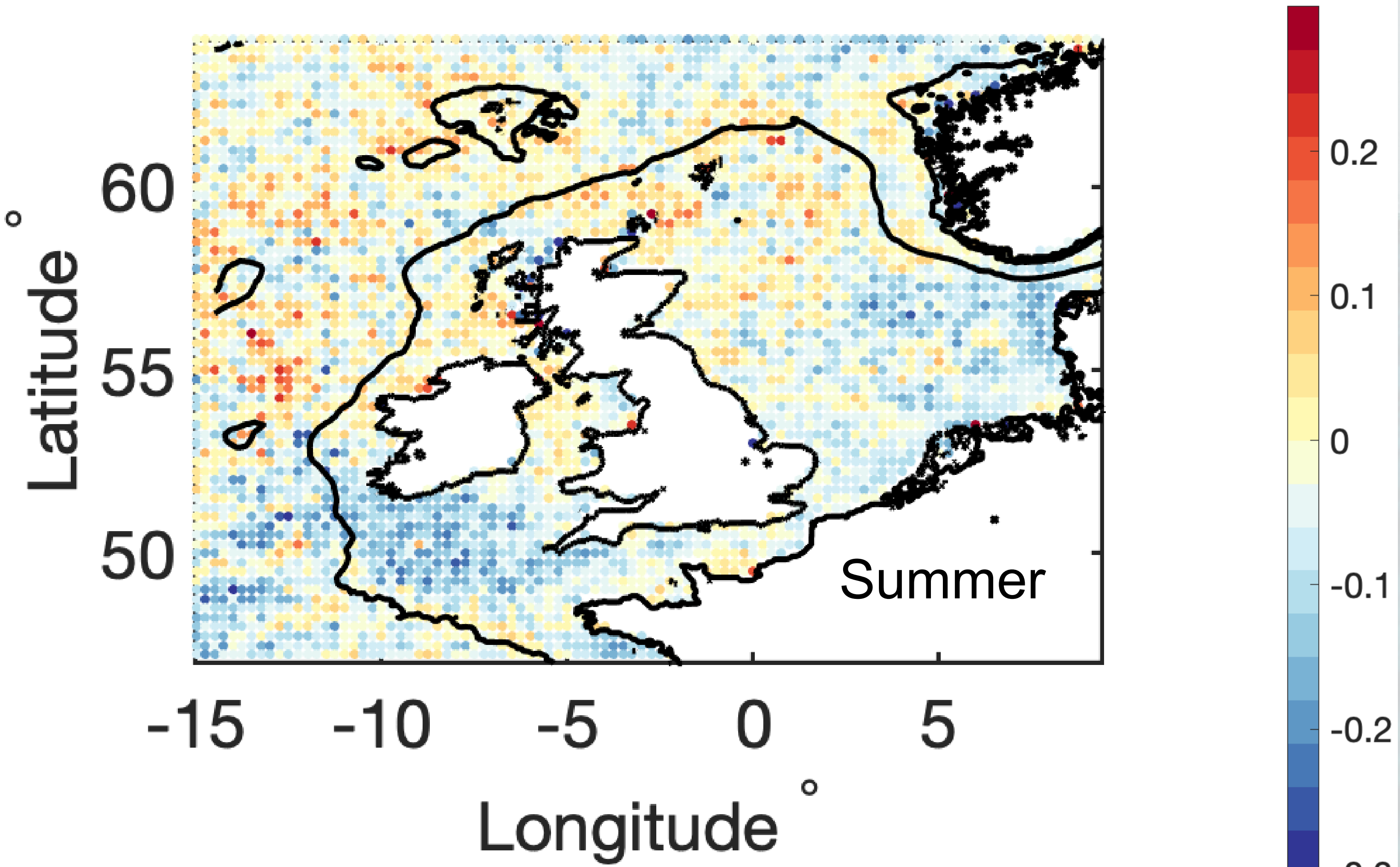


Drivers of short-term shelf-sea front variability: Wind

Wind speed vs. thermal front strength

Wind weakens thermal fronts in summer in most stratified areas.

Daily averaged ERA5 10m wind speed 35km resolution.



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Drivers of short-term shelf-sea front variability: Tide

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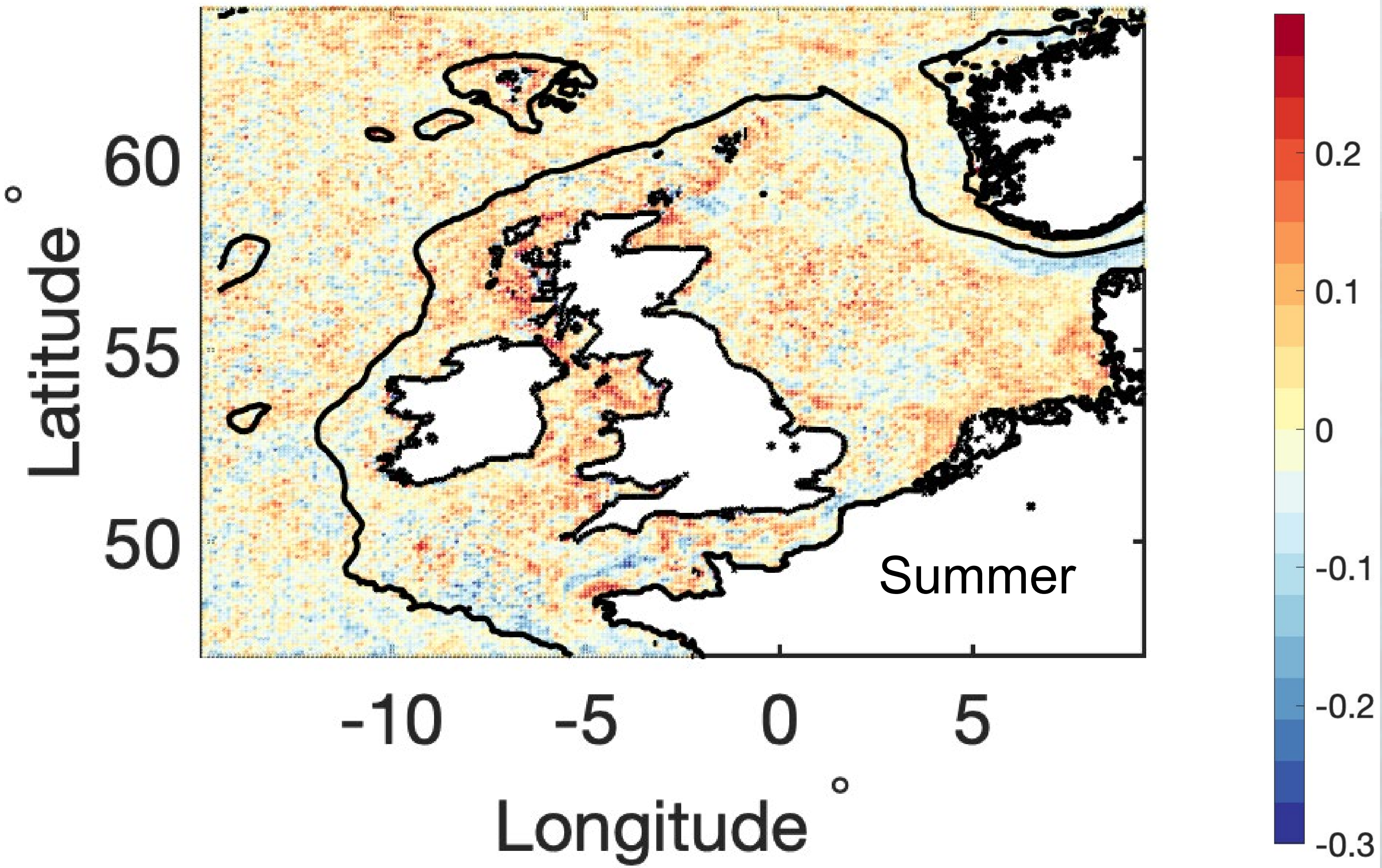
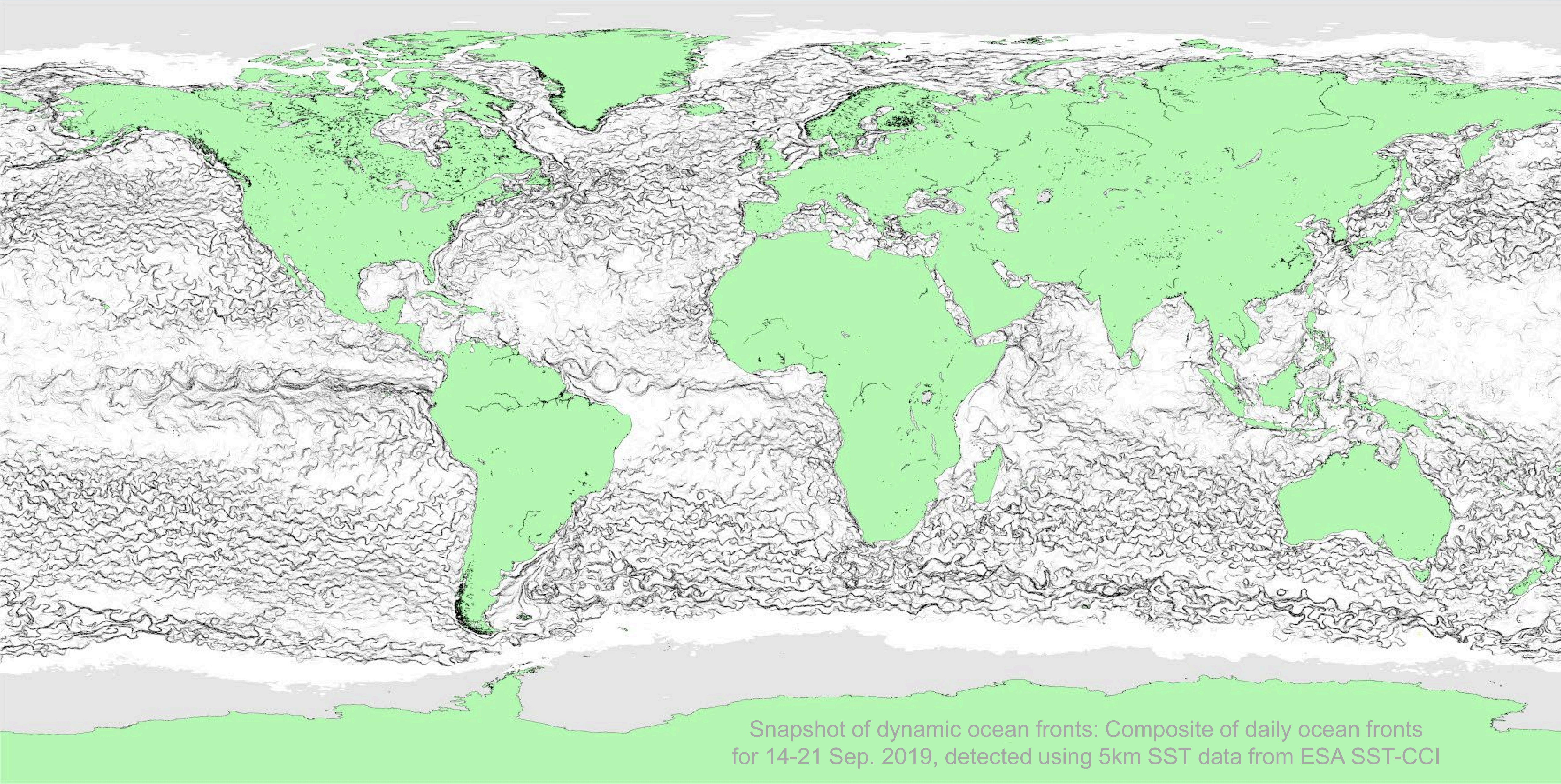
Tidal currents vs. thermal front strength

Spring tide increases SST contrast between mixed and stratified water.

Depth averaged speed of horizontal velocities from AMM7 7km resolution ocean model averaged over 25 hours



Scaling up ocean fronts for global biodiversity initiatives



Snapshot of dynamic ocean fronts: Composite of daily ocean fronts for 14-21 Sep. 2019, detected using 5km SST data from ESA SST-CCI

Future work and recommendations

Future work

- Complete statistical analysis to answer: How much, where and when do ocean fronts influence marine biodiversity?
- Describe results and uncertainties to The Crown Estate to ensure effective impact on marine spatial planning, informing future offshore windfarms.

Key recommendations

- Accelerate use of **ocean fronts within OBIS, GBiOS, GEO Atlas** as an efficient partial proxy for marine biodiversity.
- To assist in achieving **GBF Target 3** (30% protection by 2030) and the UN High Seas Treaty (Biodiversity beyond national jurisdiction).

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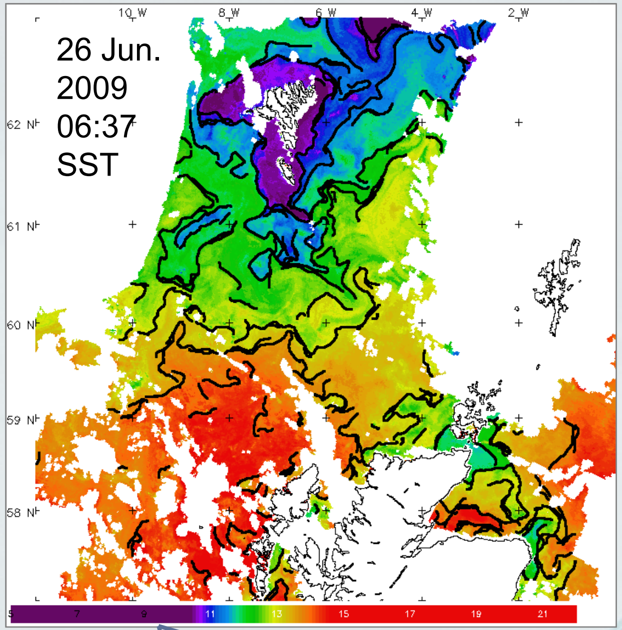
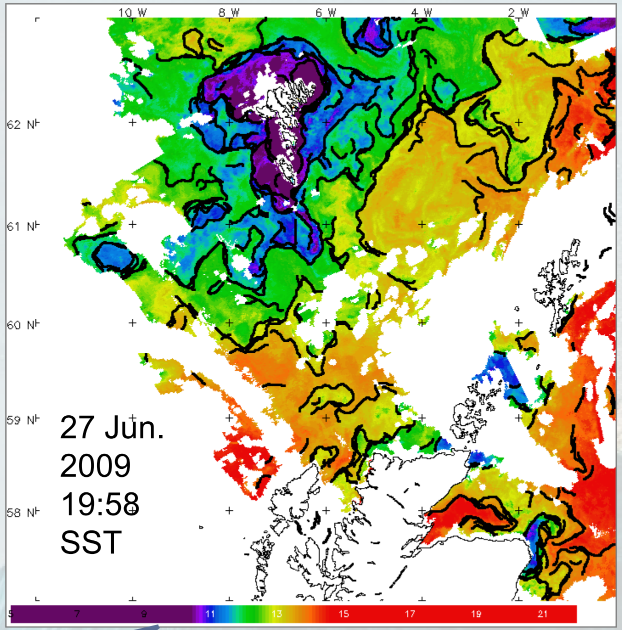
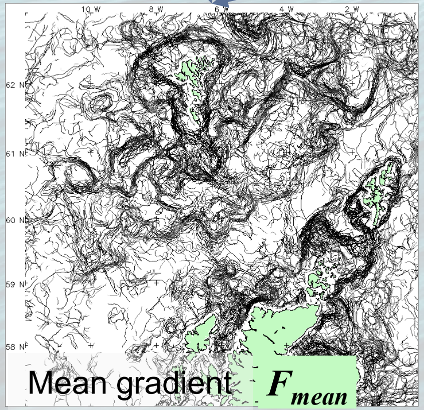
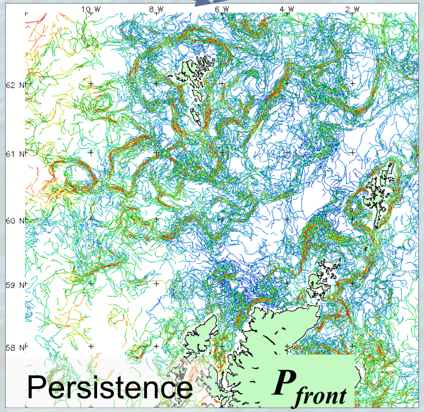
Extra slides

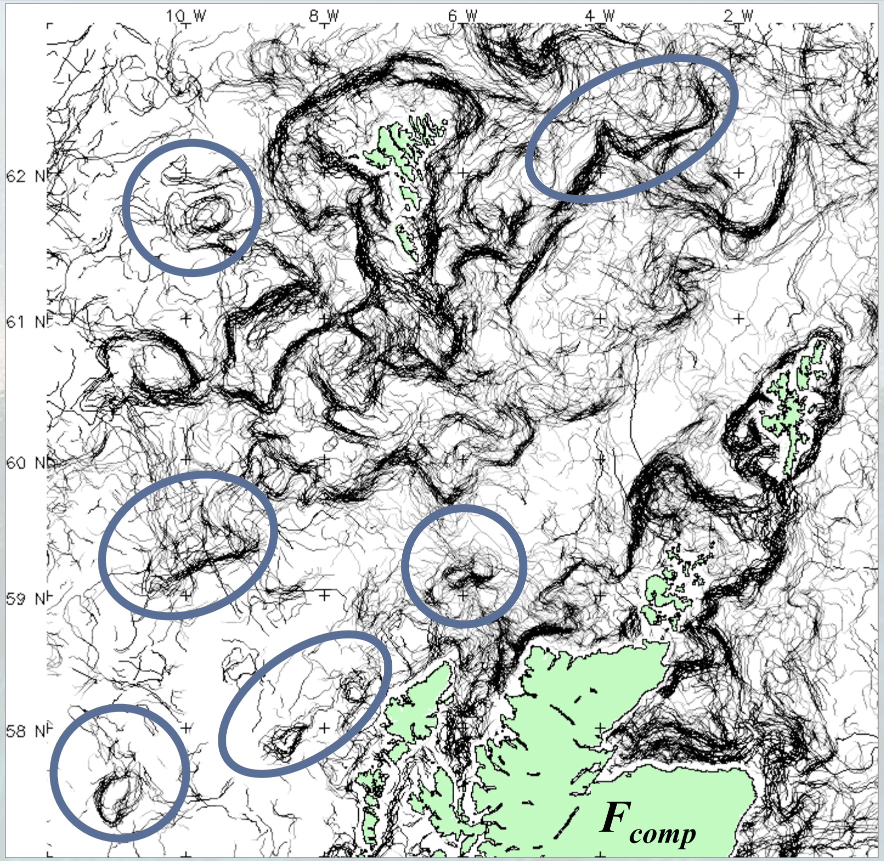
Detecting oceanic fronts

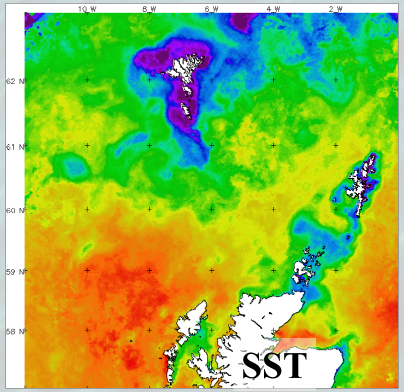












Miller, P.I., (2009) Composite front maps for improved visibility of dynamic oceanic fronts on cloudy data, *Journal of Marine Systems*.

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Internal Waves

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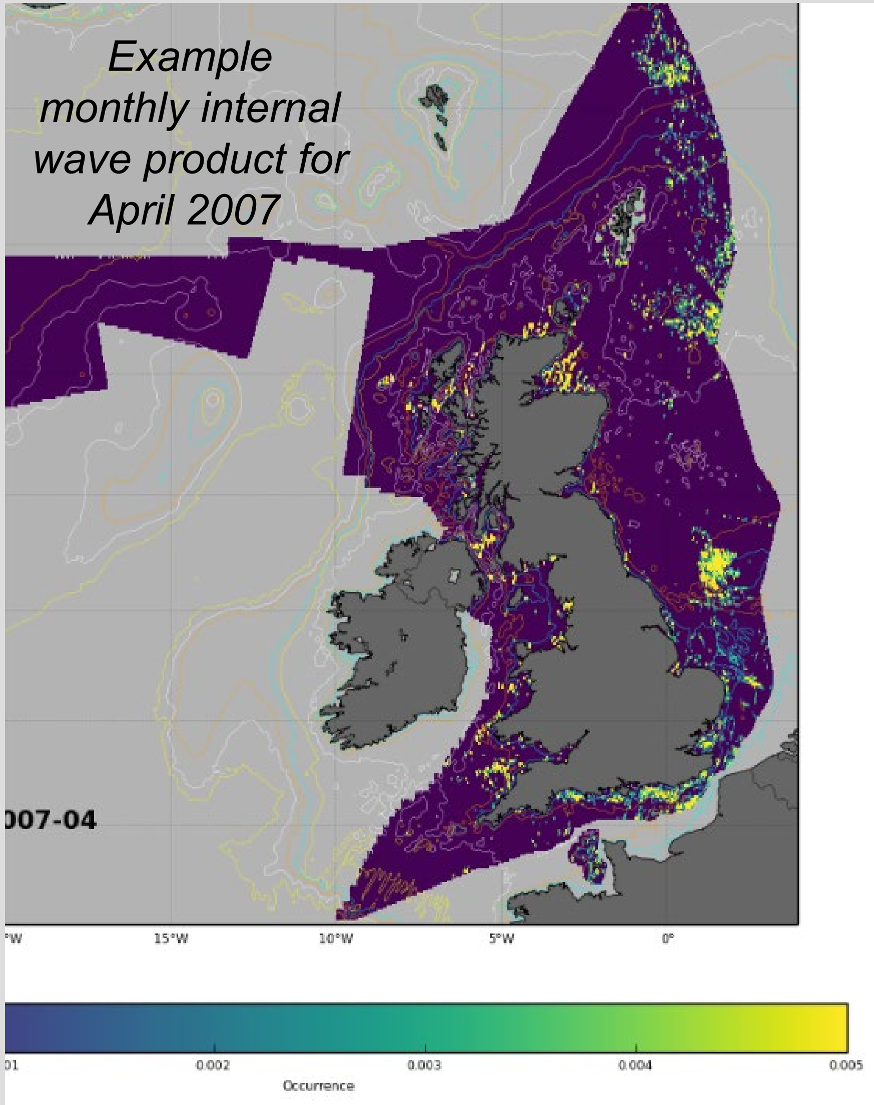
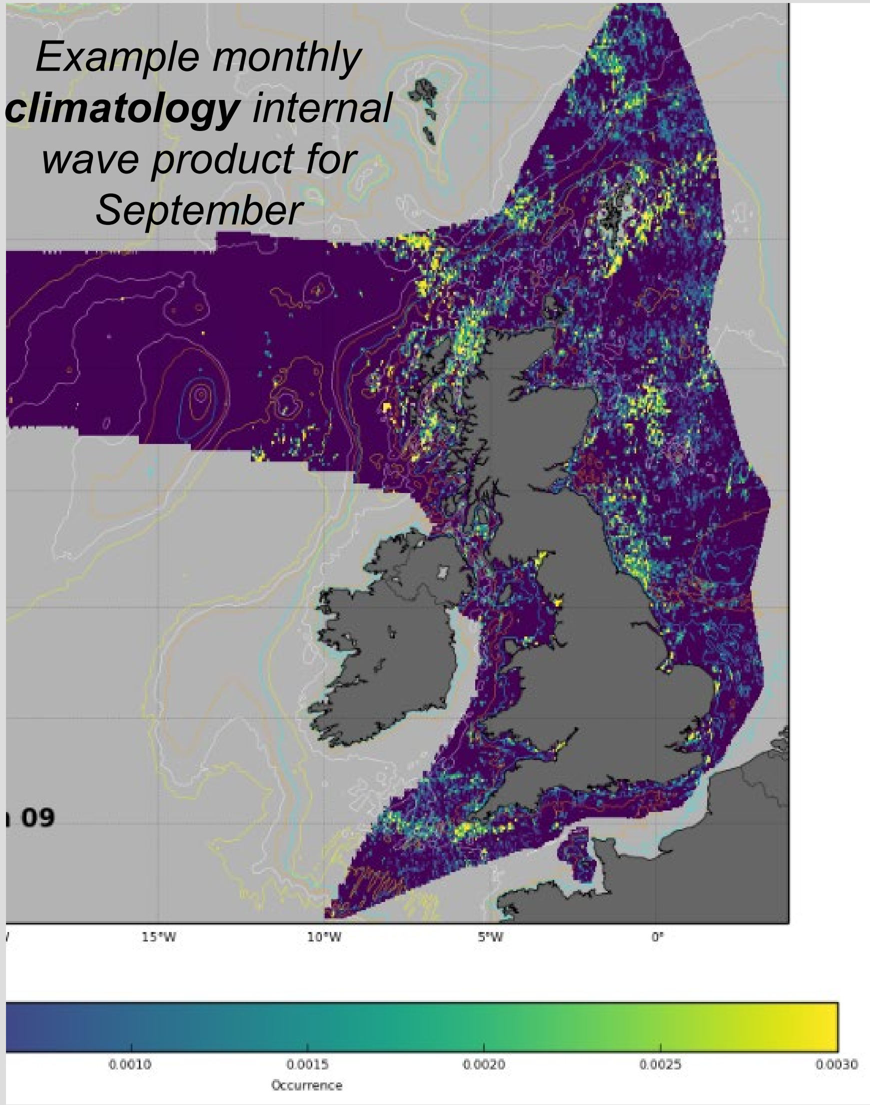
Density of internal waves





The maps were generated by automatic processing of the ENVISAT Advanced Synthetic Aperture Radar (ASAR) data archive over the period from Oct. 2006 to Apr. 2012

The principle of internal wave detection in SAR images is based on high sensitivity to small-scale roughness of the ocean surface induced by wind.

The density values were calculated for multiple radar images and then averaged in space and time.

The derived dataset:

- monthly density maps
- monthly climatology maps
- seasonal variability maps
- 6-month variability maps
- annual variability maps

Date Range: 2006-10 to 2012-04

Location: 48N to 64N, -5W to 25W

FRONTWARD Study area

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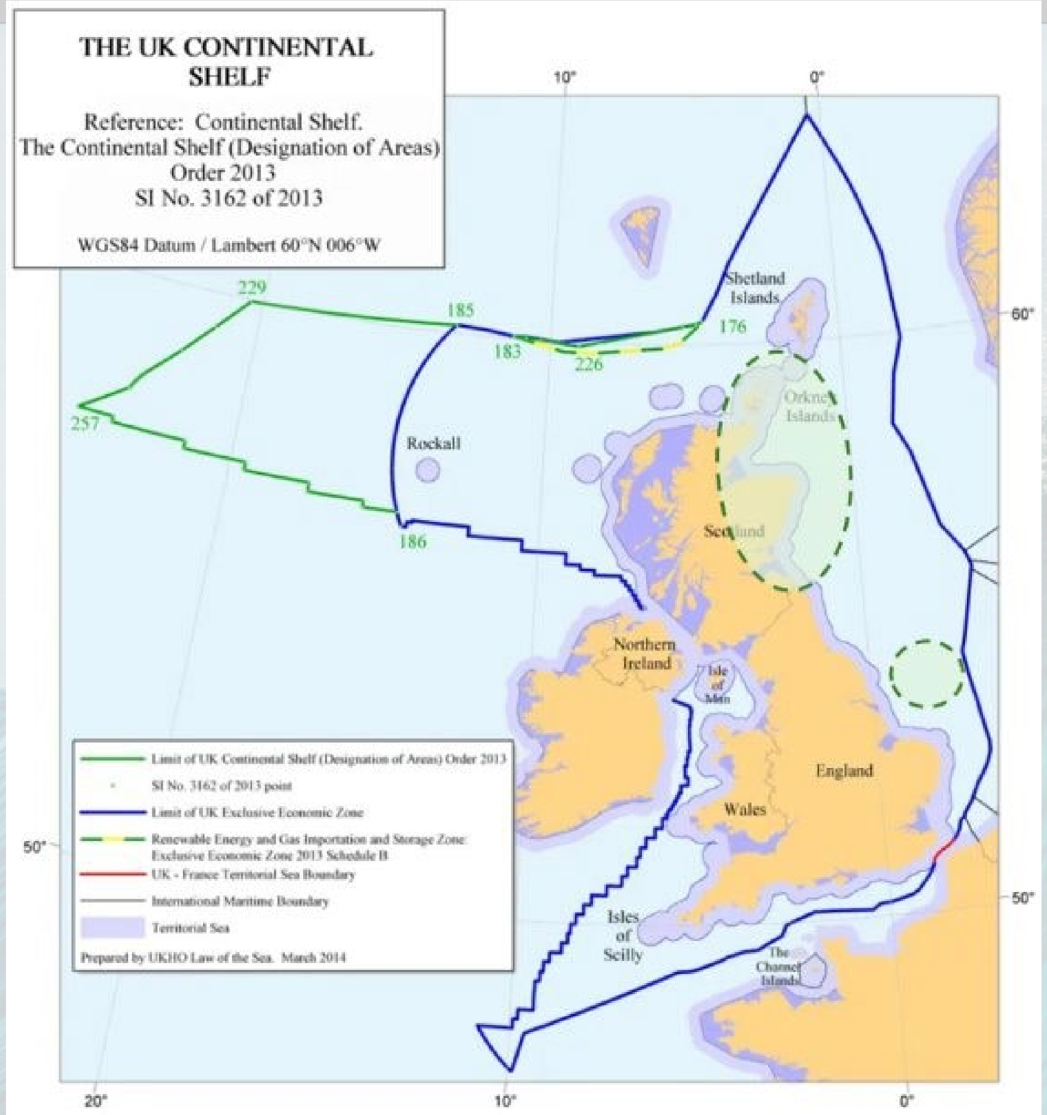
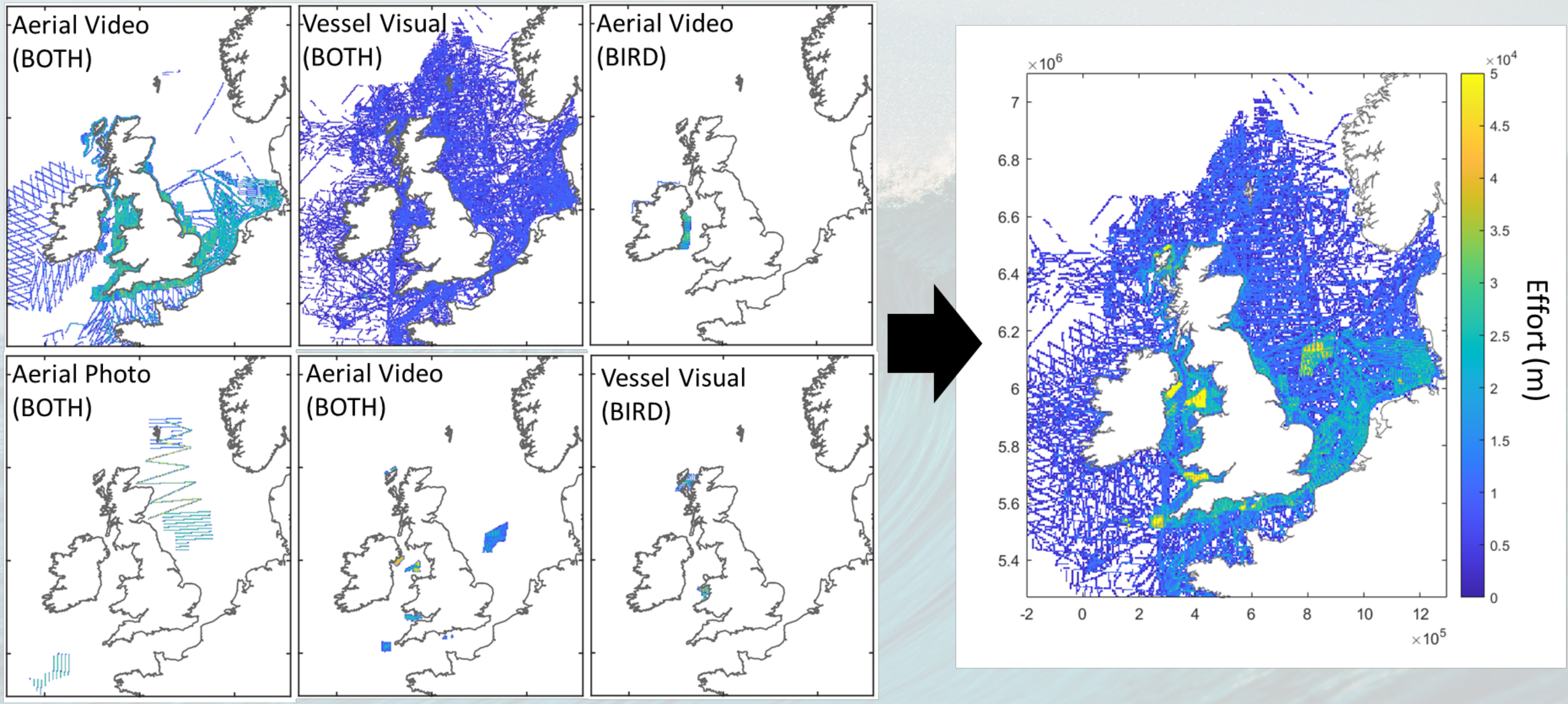


Region of study is the UK Exclusive Economic Zone EEZ shown by the blue line. Case study regions are indicated in green dashed ellipses: Dogger Bank, shallow region off east England, and NE Scotland, a deeper region.

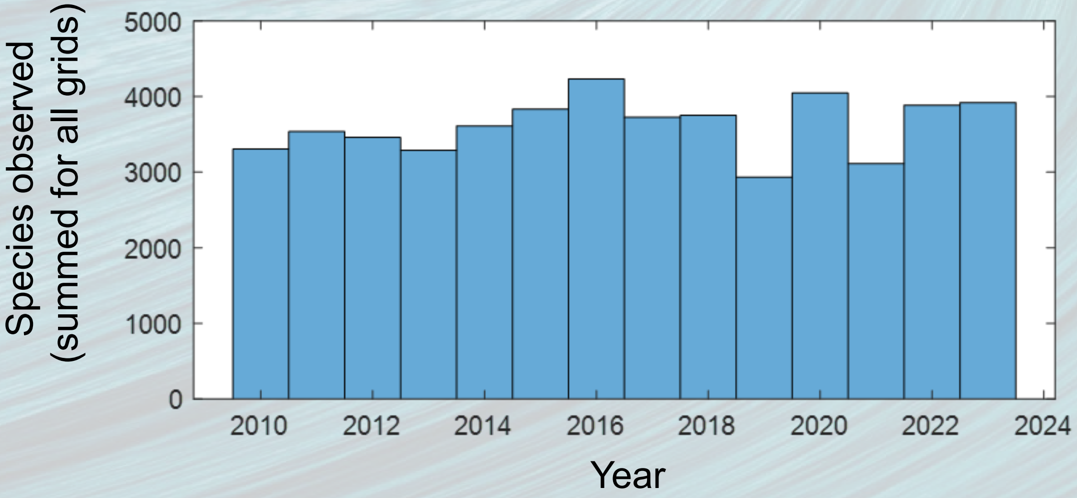
Biodiversity index – survey effort

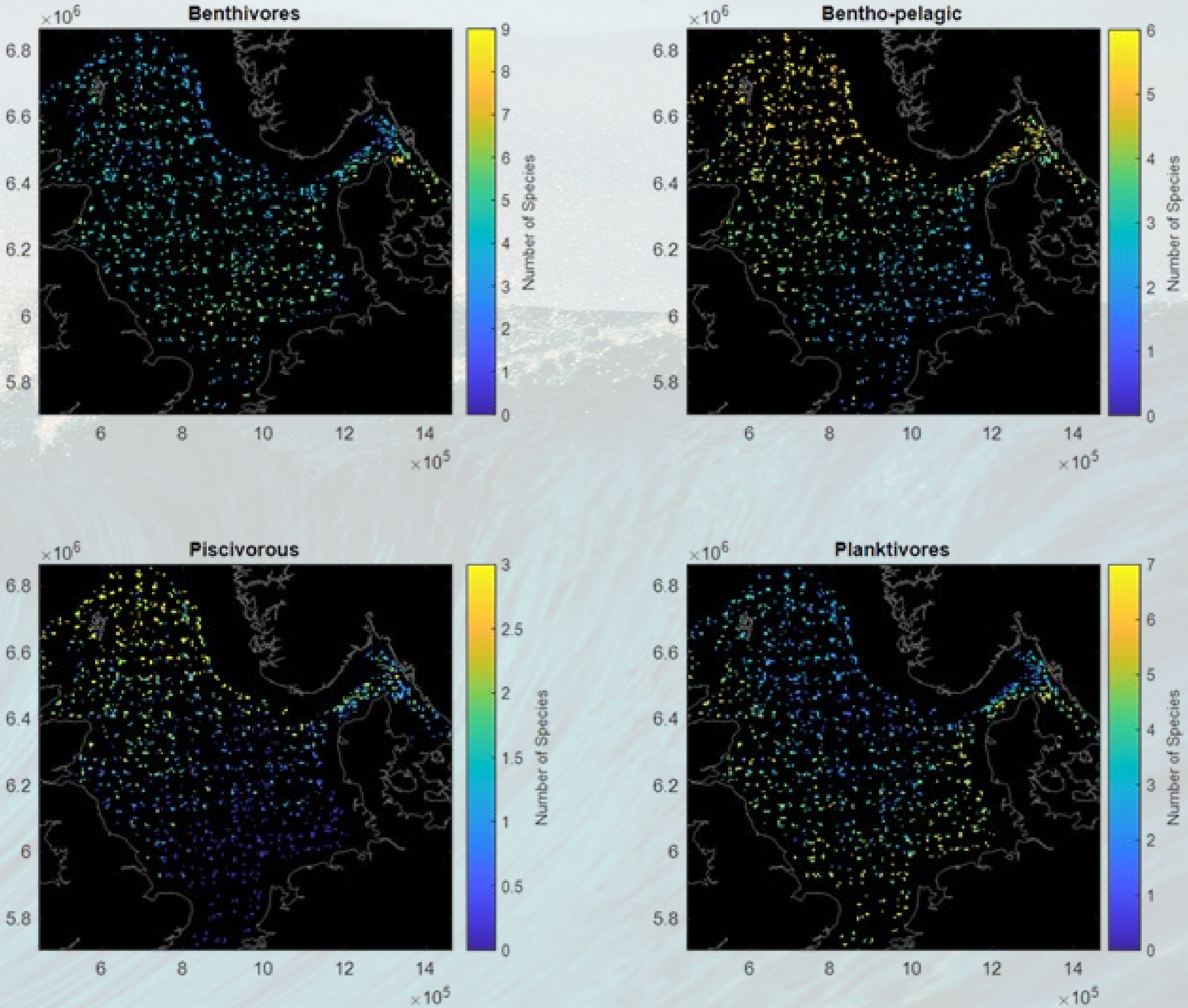
Effort across multiple survey types are threshold for type/method. These are then combined during the modelling process. This example is birds only. Data span from 1980 to 2024 and include the months April to September.



Fish data structure

- Yearly surveys conducted throughout the North Sea
- Catch-per-unit-effort for each species
- Surveys in each ICES square (30 x 30 nautical miles)
- This is converted to 5 km grid squares to match the fish and mammal data
- We observe very different patterns in species distributions for each foraging group





Background on route to Biodiversity

Species selection (fish)

- Ecologically and commercially important species (25)
- Species that are key prey to seabirds and marine mammals.
- Trophic representation and functional groups - include species to capture full range of ecosystem interactions (i.e., commercial fish tend to be common and play a large ecological role).
- Broad spatial distributions across North Sea.
- Remove rare species with low abundance or those with limited spatial coverage.

Species selection (birds/mammals)

- Marine Ecosystems Research Programme (MERP) methodology : 15 bird species and 11 mammal species.
- These are species that are considered resident, prevalent, and predominately pelagic-associated
- In addition, common seal and grey seal were included in the mammal species.

First input to Marine Data Exchange

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