SAMS Scottish Association for Marine Science | A partner of UHI | Marine Biological Association | Newcastle University

Predicting the extent and standing stock of kelp species in the UK and Ireland

to upscale process rates to whole coastlines

Michael. T. Burrows, Tim M. Szewczyk, Dan A. Smale, Pippa J. Moore

Natural Environment Research Council

The Wildlife Trusts

NatureScot
NàdarAlba
Scotland's Nature Agency
Buidheann Nàdair na h-Alba

Scottish Government
Riaghaltas na h-Alba
gov.scot

HIE
Highlands and Islands Enterprise
Iomairt na Gàidhealtachd 's nan Eilean

marinescotland

Funders: 2013-2022

UK Government Agencies

Kelp contribution to coastal carbon dynamics

Blue Carbon

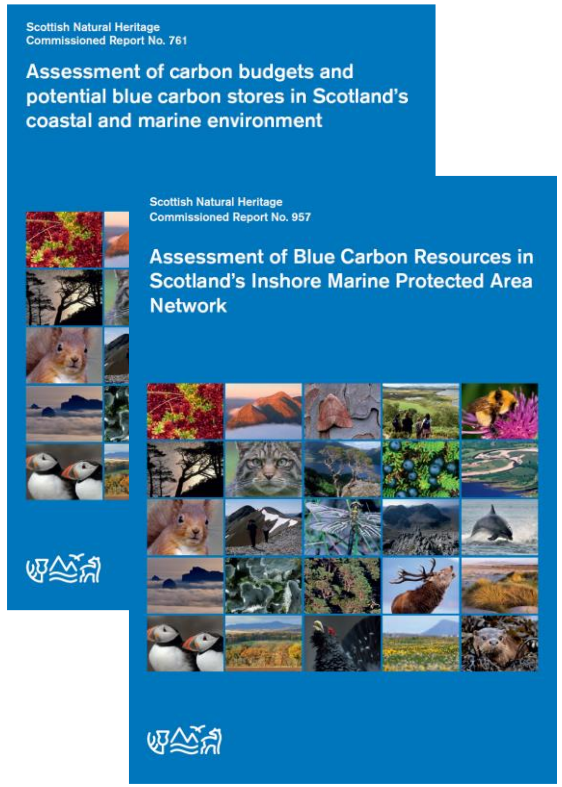
- **2014:** Assessment of carbon budgets and potential blue carbon stores in Scotland's coastal and marine environment
- **2017**: Assessment of blue carbon resources in Scotland's inshore MPA network
- **2022:** Optimising carbon sequestration opportunities in Argyll and Bute. [local region]
- **2021**: Assessment of Carbon Capture and Storage in Natural Systems within the English North Sea (Including within Marine Protected Areas)

Harvesting management

- **2018:** Wild seaweed harvesting as a diversification opportunity for fishermen

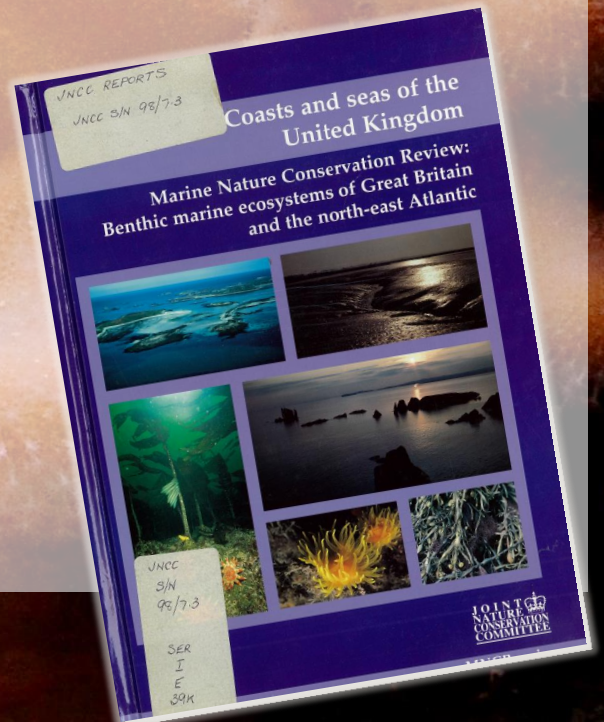
Kelp 'Good Environmental Status' indicator

- **2014:** Marine Strategy Framework Directive Indicators for UK Kelp Habitats Part 1: Developing proposals for potential indicators



UK Marine Nature Conservation Review (**MNCR)**

- 3557 dive surveys
- 5953 depths
- 1977-2001
- Data from http://data.nbn.org.uk

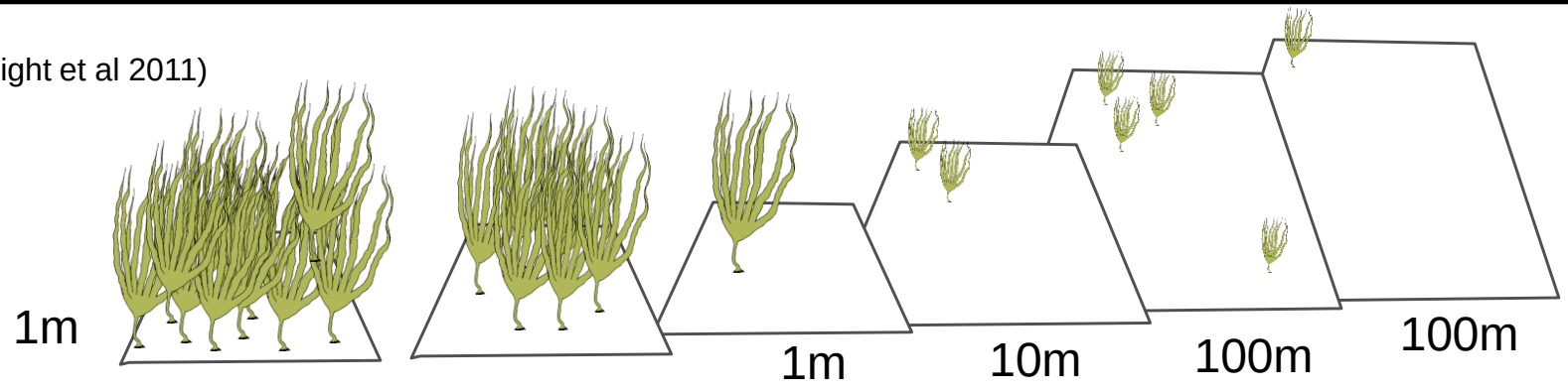


Categorical abundance data

Category	[S] Super-Abundant	[A] Abundant	[C] Common	[F] Frequent	[O] Occasional	[R] Rare	[N] Absent
Density (plants/m²)	>9 /m²	1-9 /m²	1-9 /10m²	1-9/100m²	1-9/1000m²	<1/1000m²	0
Percentage cover	>80%	40-79%	20-40%	10-20%	5-9%	1-5% or density	.

Biomass scales (kg/m²)	[S] Super-Abundant	[A] Abundant	[C] Common	[F] Frequent	[O] Occasional	[R] Rare	Source
Laminaria hyperborea							
Cover-scaled	28	12	6	3	1	0.2	
Density-scaled	25	25	0.833	0.0833	0.0083	0.0016	(Smith et al., 2021)
Saccharina latissima							
Density-scaled	6	6	0.2	0.02	0.002	0.0002	
Laminaria digitata	3	3	0.3	0.03	0.003	0.0003	(Gevaert et al., 2008)
Saccorhiza polyschides	3	3	0.3	0.03	0.003	0.0003	(Fernández, 2011)

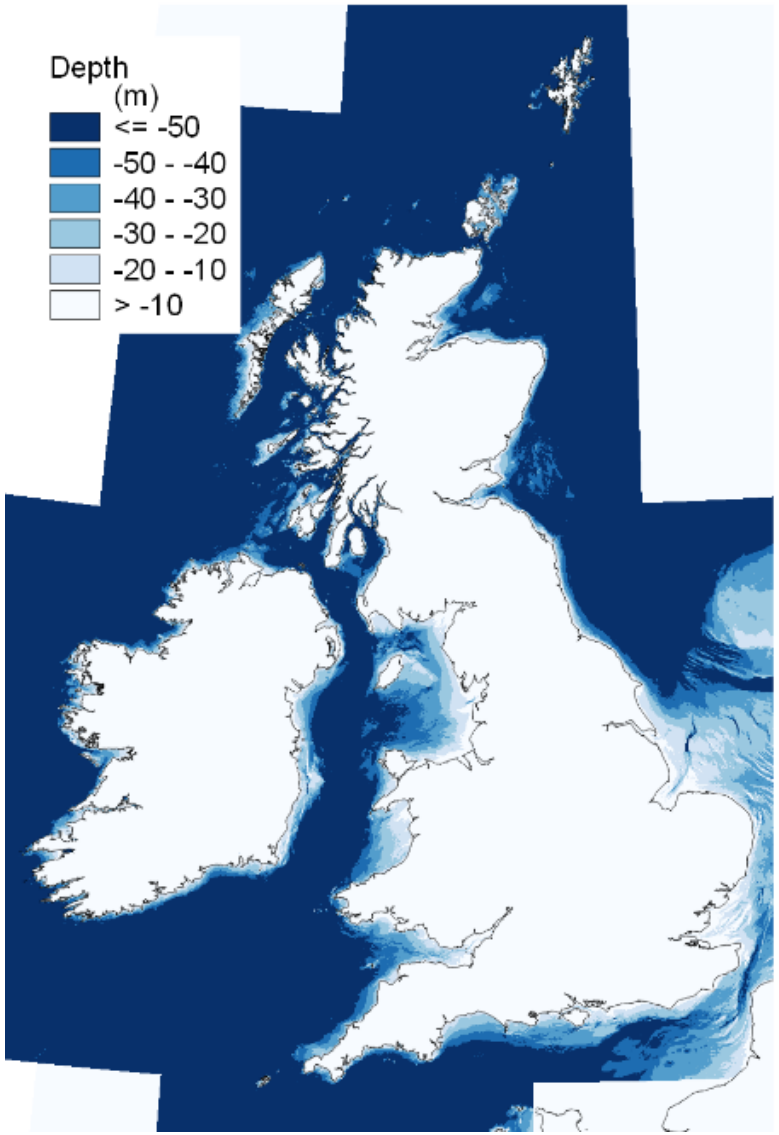
Laminaria digitata (Blight et al 2011)



A partner of UHI

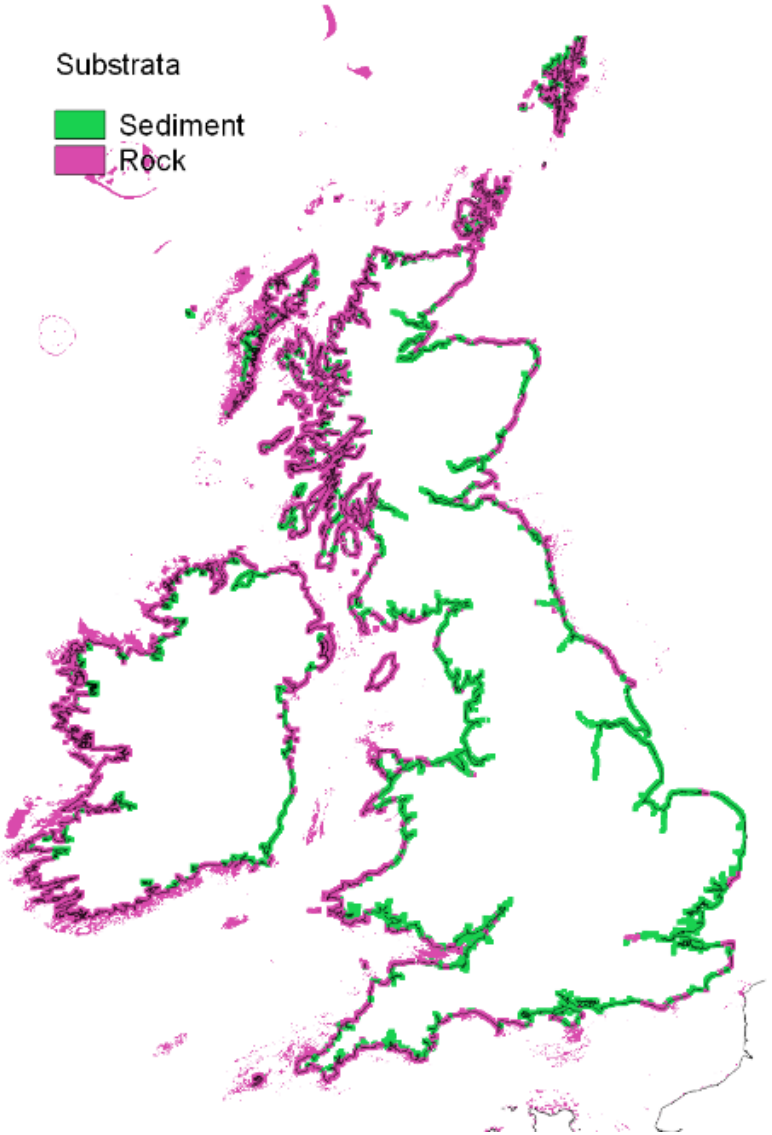
SAMS Scottish Association for Marine Science

Depth

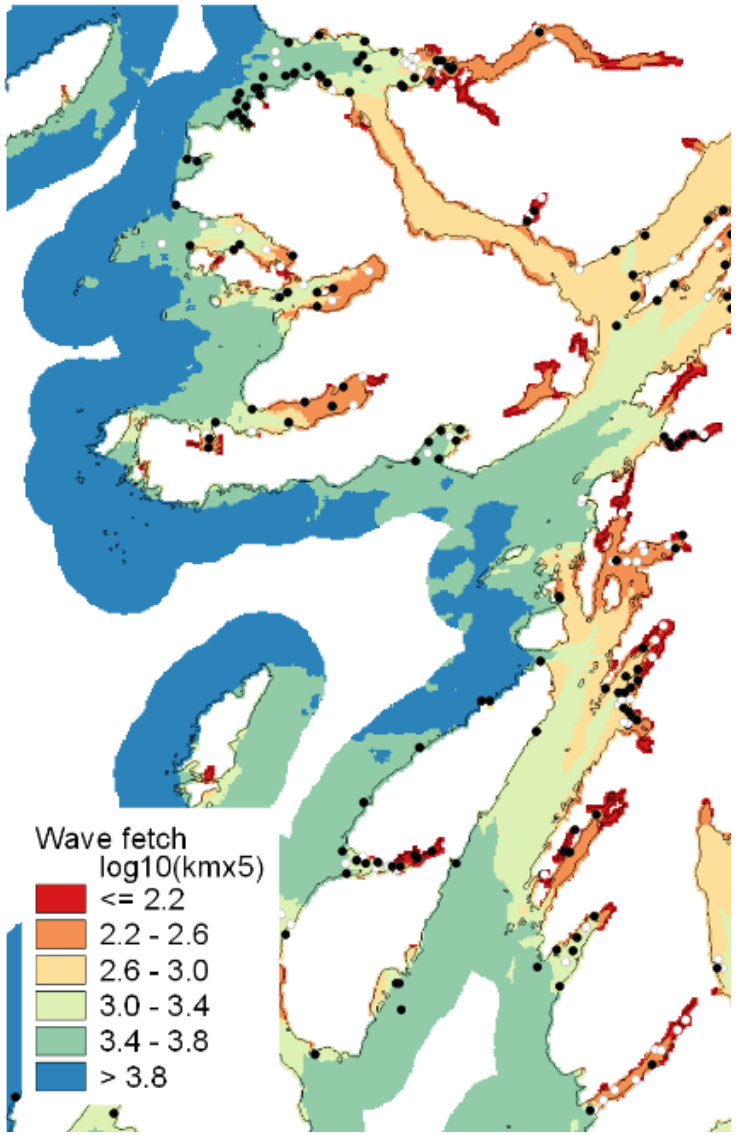


200-m resolution data

Substratum type



Wave fetch



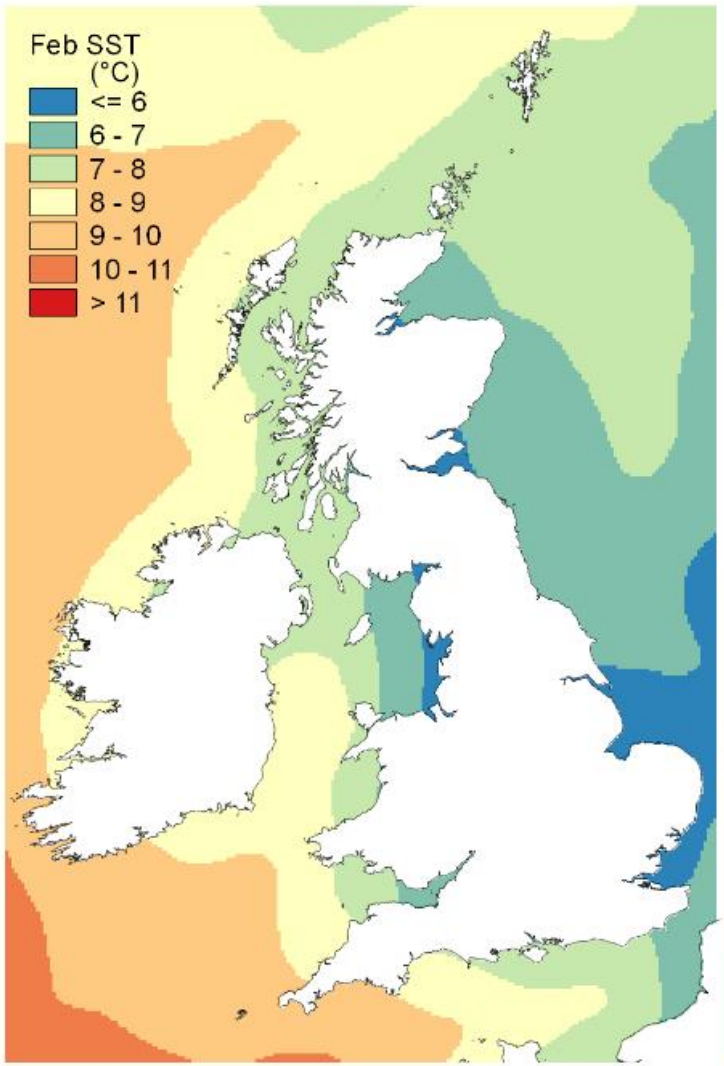
Burrows et al (2012)

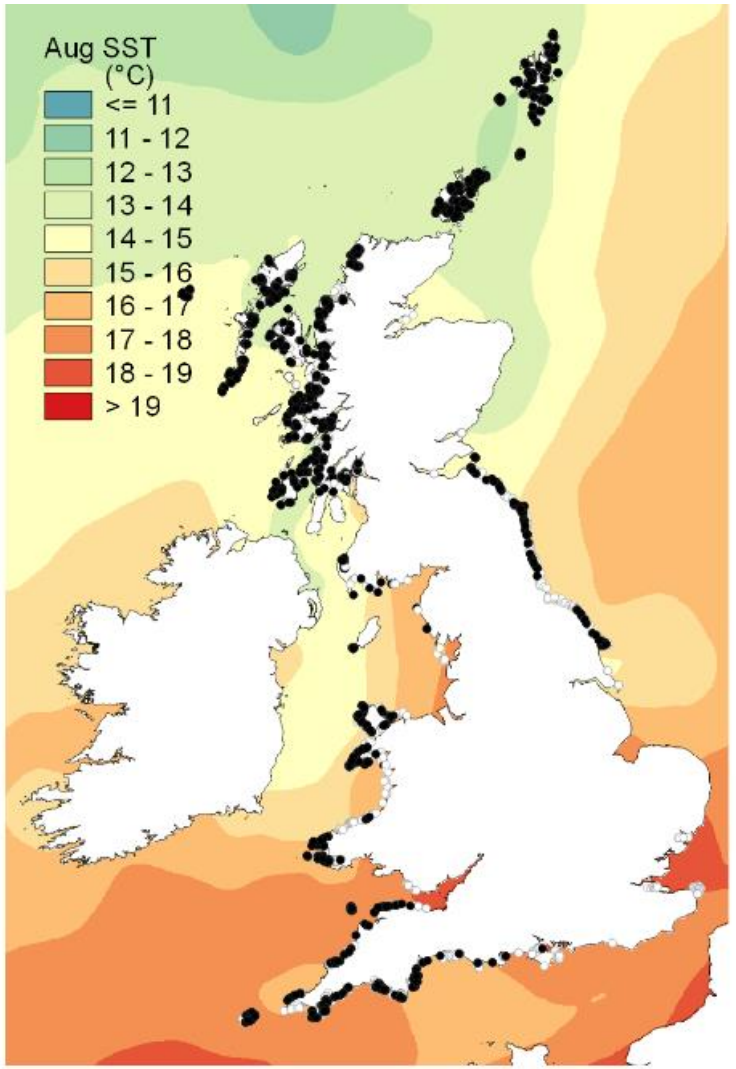
Predictors #1

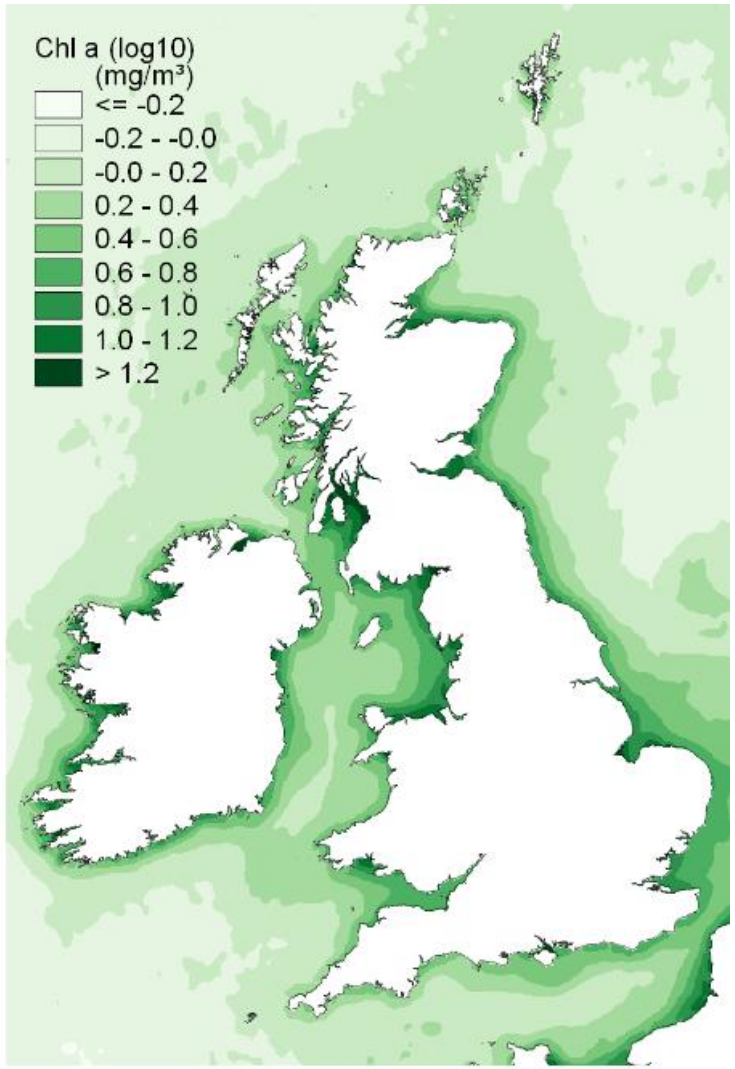
Winter temperature

Summer temperature

Chlorophyll *a* (mg/m^3)

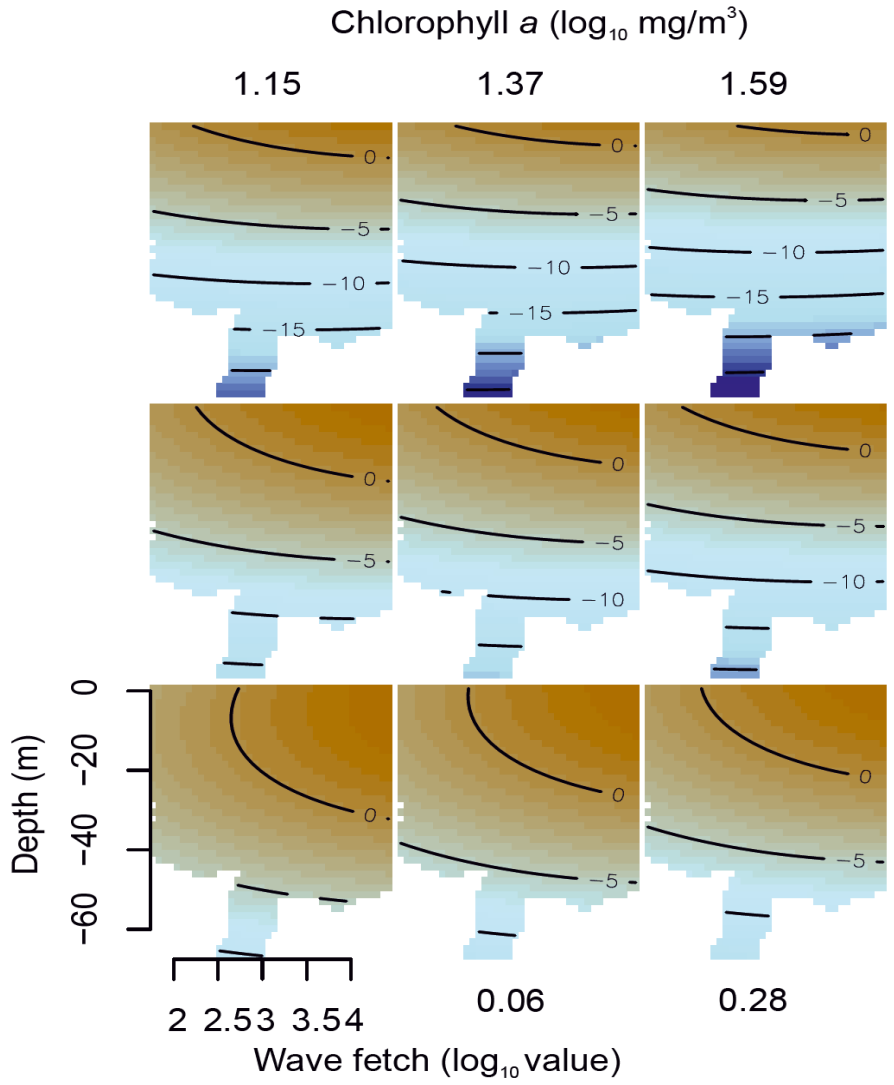




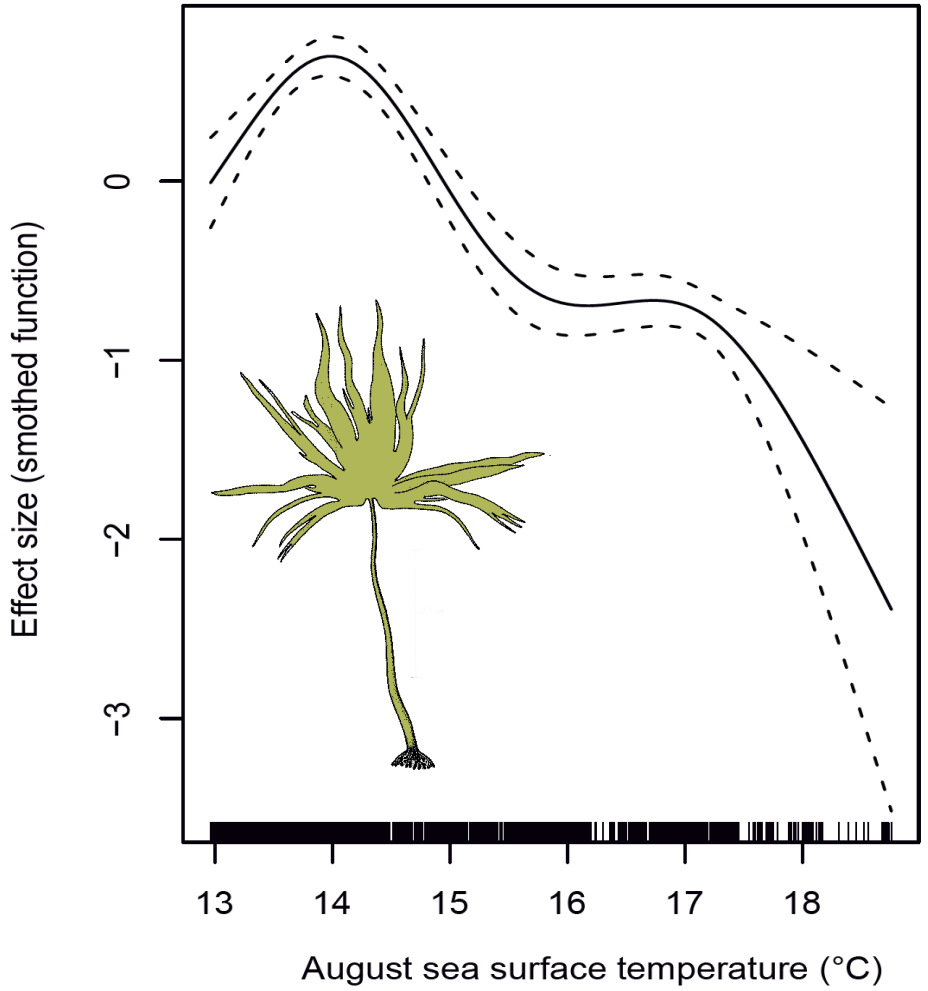


Predictors #2

Generalised Additive Model (GAM) of probability
that kelp abundance exceeds a particular abundance category: $P(\geq R)$

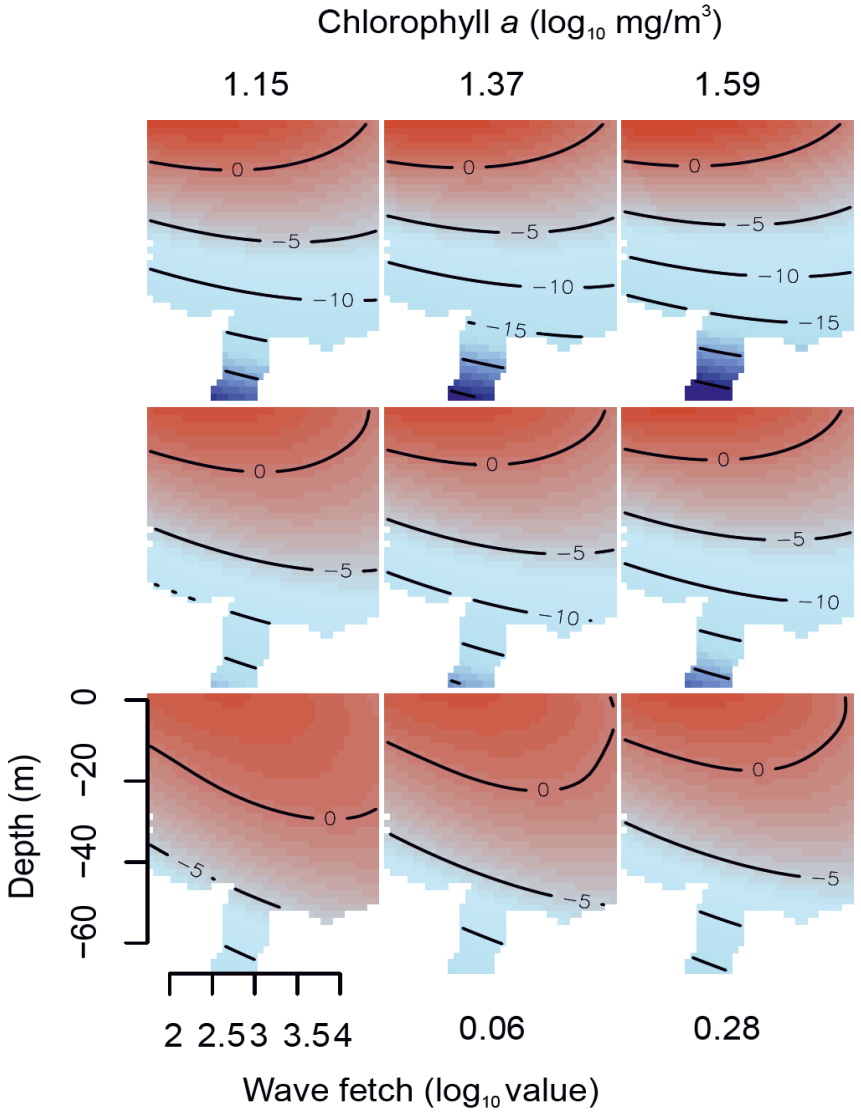


Laminaria hyperborea

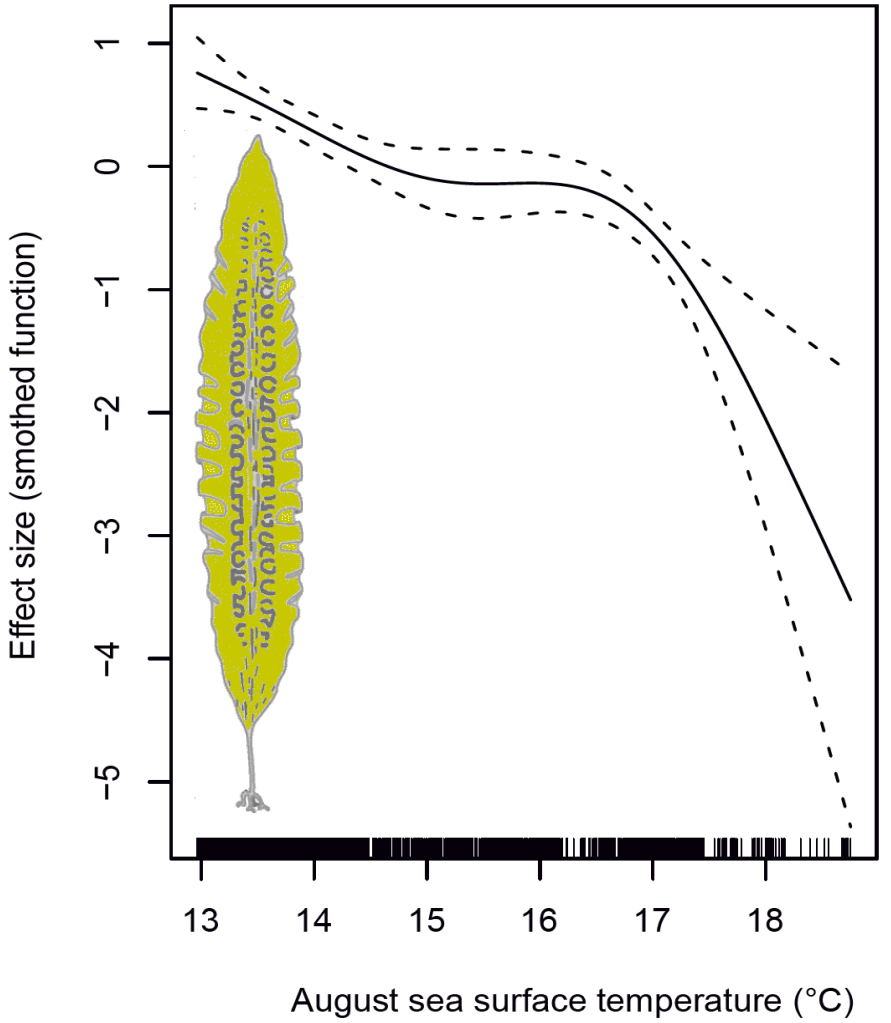


Laminaria hyperborea from (Blight et al 2011)

Generalised Additive Model (GAM) of probability
that kelp abundance exceeds a particular abundance category: $P(\geq R)$

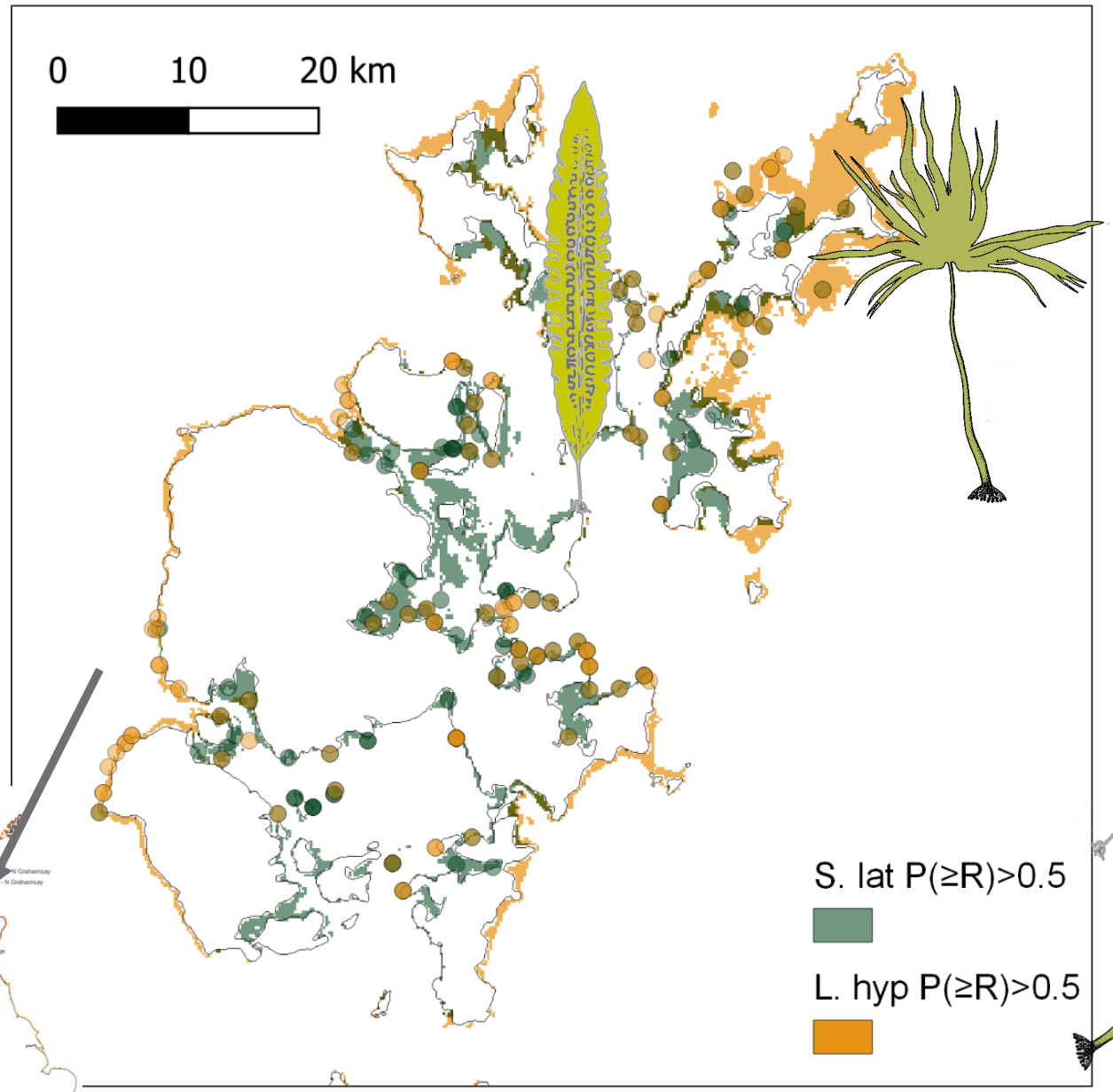


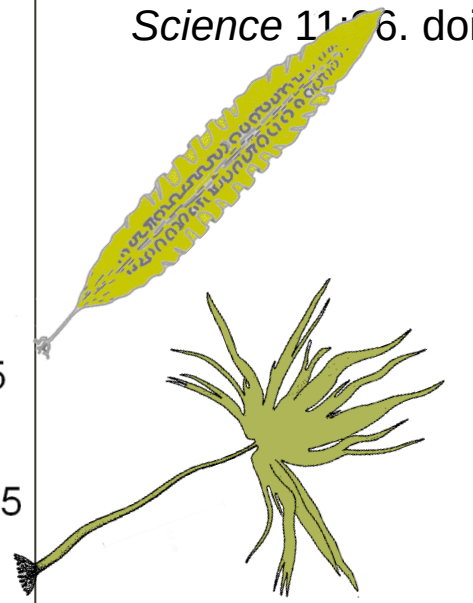
Saccharina latissima



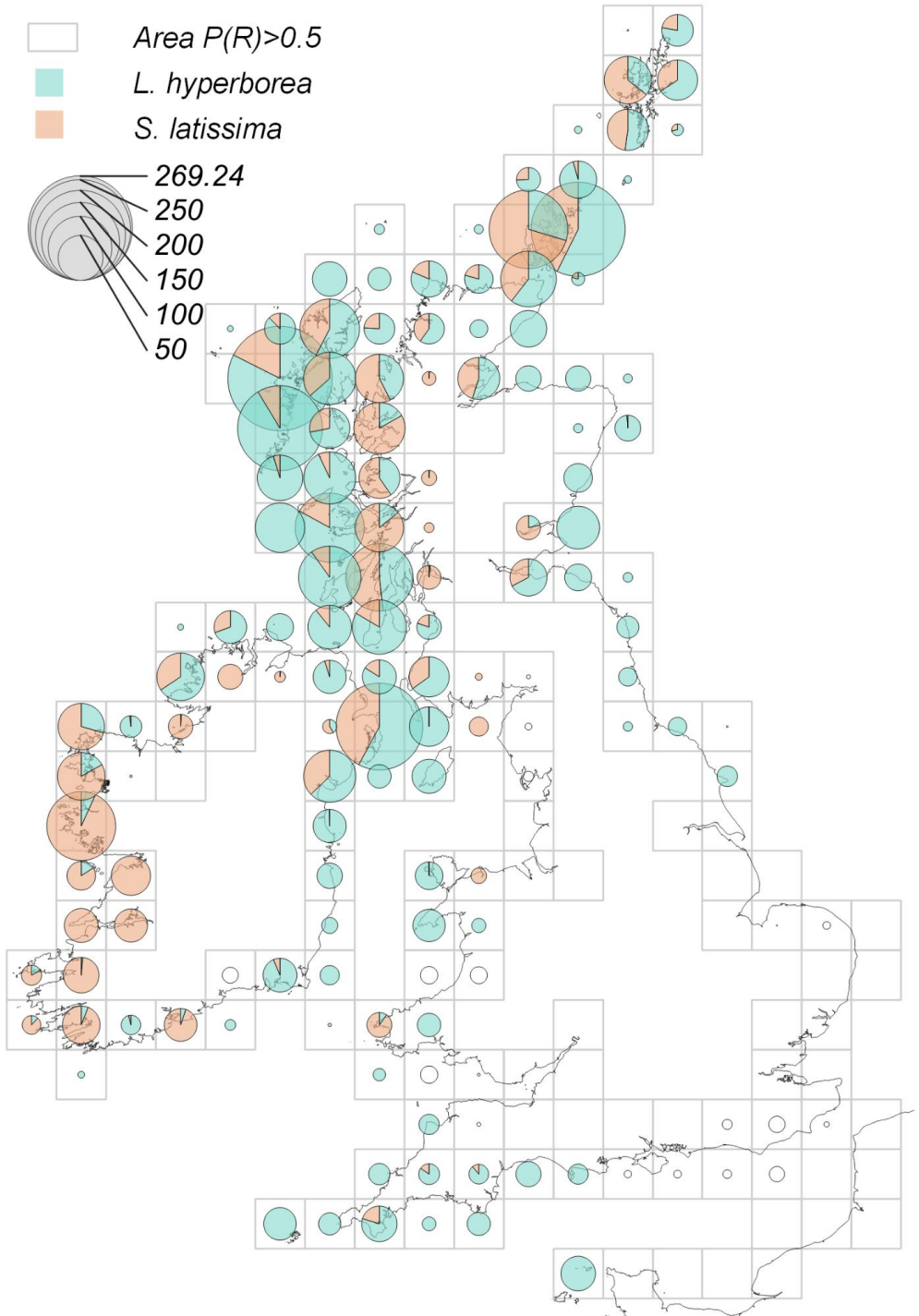
Saccharina latissima from (Peteiro & Freire 2013)

Local-scale predicted habitat suitability





Porter, J. S., W. E. N. Austin, M. T. Burrows, D. Clarke, G. Davies, N. Kamenos, C. Smeaton, C. Page, and A. Want. 2020. ‘Blue Carbon Audit of Orkney Waters’. *Scottish Marine and Freshwater Science* 11:6. doi: 10.7489/12262-1.



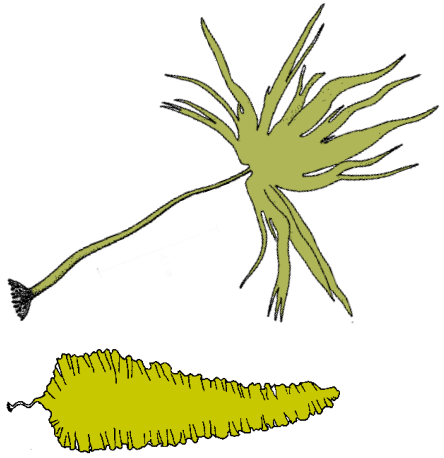
50 x 50km boxes

Predicted extent (km^2)

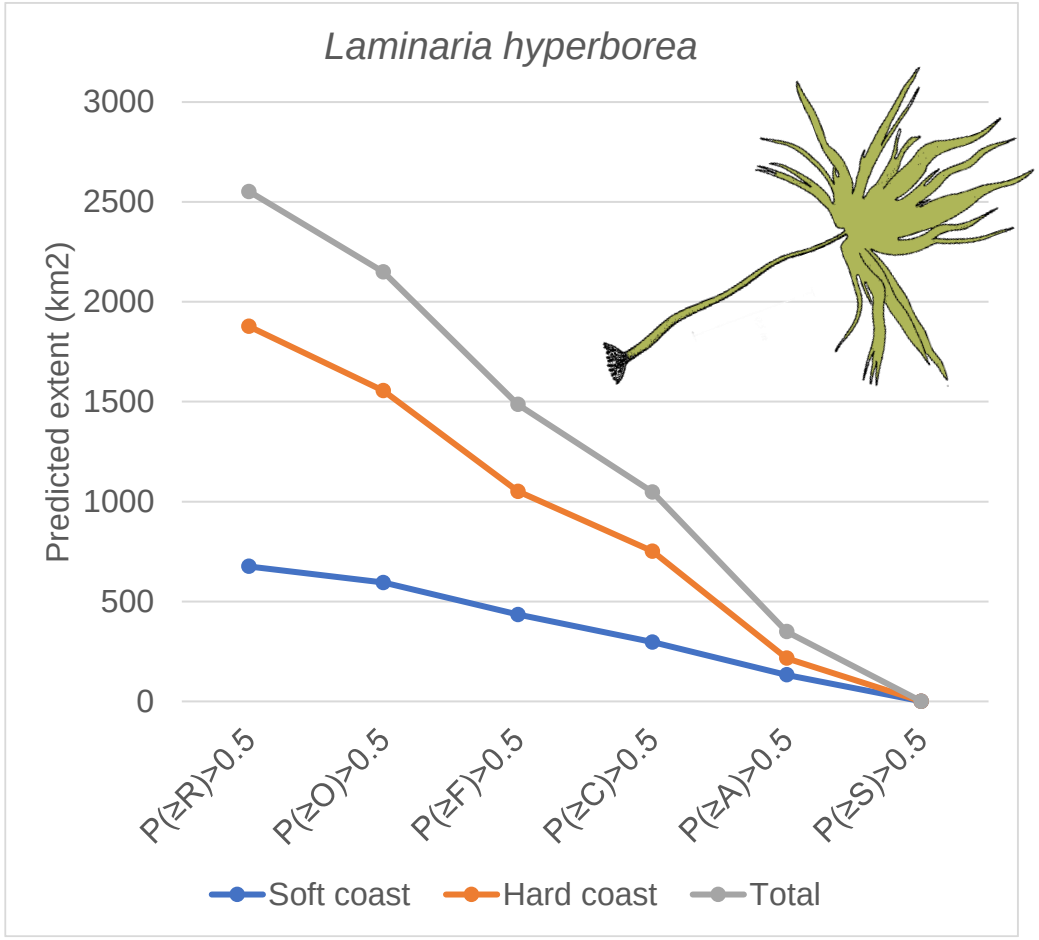
where $P(\geq R > 0.5)$

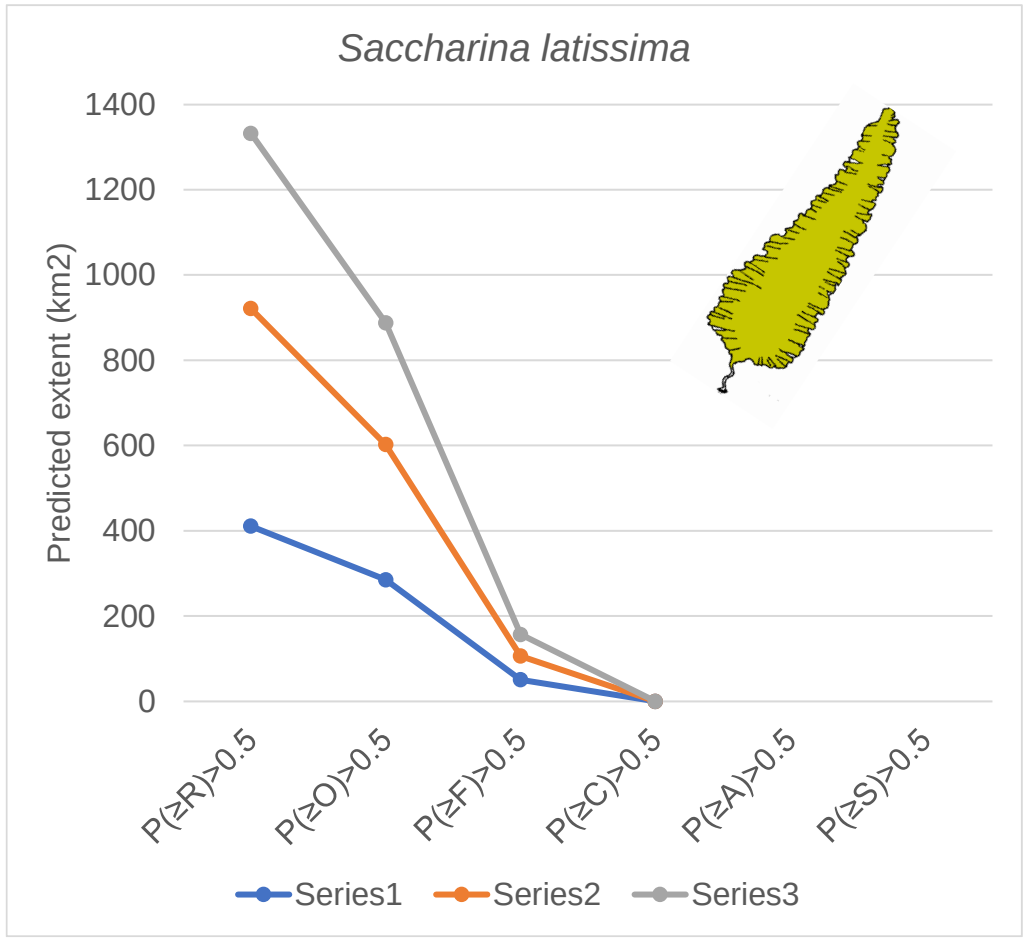
UK-scale extent estimates (km²)

		Area (km²)			Biomass (Mt FW)		
	Threshold	Soft	Hard	Total	M	Soft	Hard
Laminaria hyperborea	P(≥R)>0.5	675	**1877**	2552	(1)	7.83	19.74
Saccharina latissima	P(≥R)>0.5	411	**921**	1332	(1)	0.47	0.91
Alaria esculenta	P(≥R)>0.25	172	428	600	(1)	0.02	0.04
Saccorhiza polyschides	P(≥R)>0.25	26	229	256	(1)	0.01	0.08
Laminaria_digitata	P(≥R)>0.25	27	55	82	(1)	0.03	0.04
All kelp species	P(≥R)>0.5	1863	**3812**	5676			



Predicted extent is dependent on threshold abundance for '*kelp habitat*'

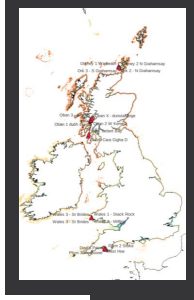




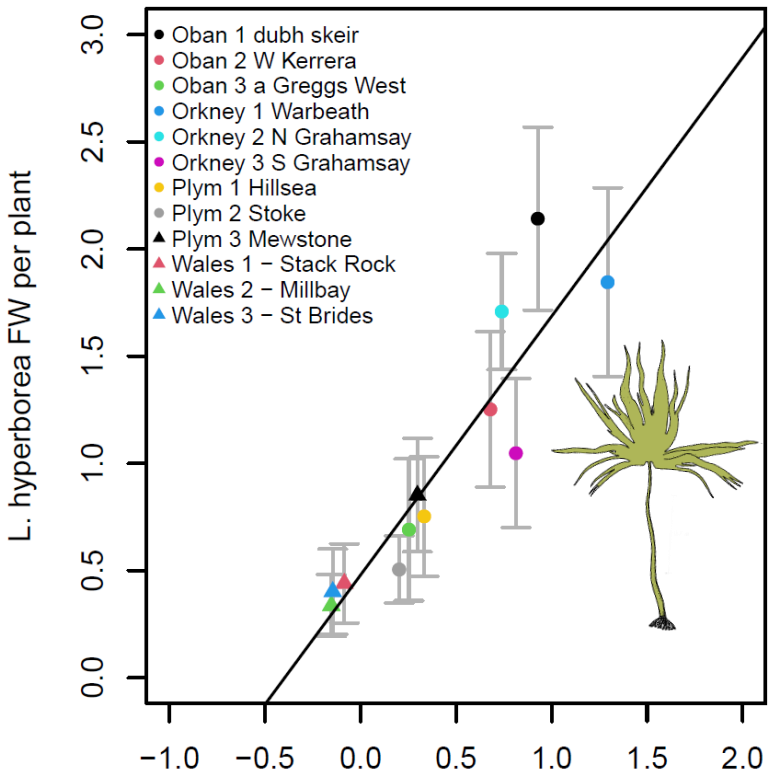
Compared with 19,000 km^2 (Yesson et al., 2015). (1 record per 3x3km)

Models vs measured populations

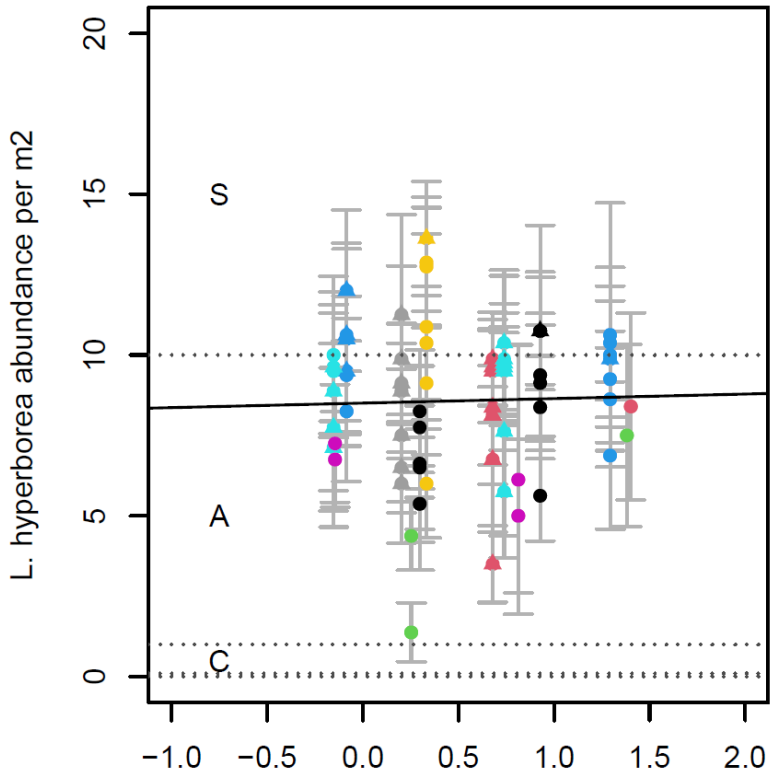
Laminaria hyperborea



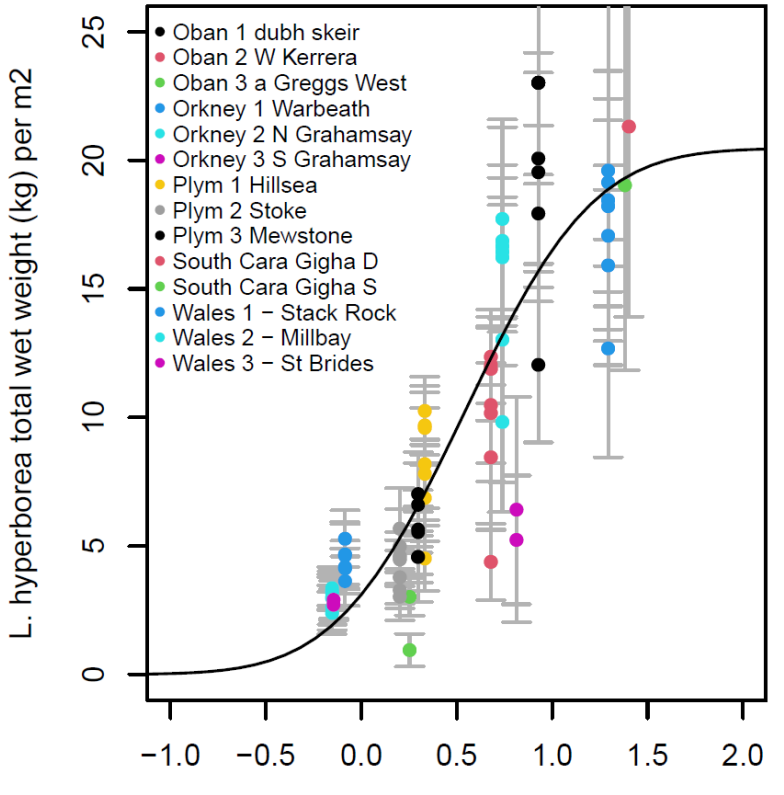
Plant weight (kg w/w)



Plant density (per m^2)



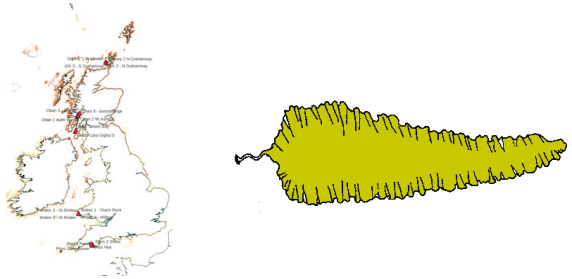
Biomass density (kg per m^2)



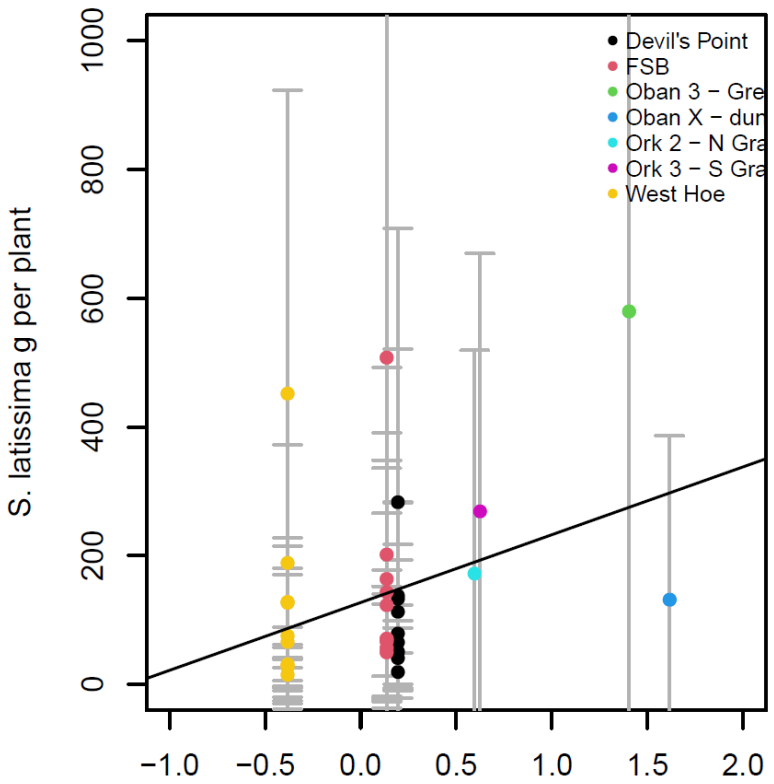
Habitat suitability from GAM model

Smale et al. 2020. 'Environmental Factors Influencing Primary Productivity of the Forest-Forming Kelp *Laminaria Hyperborea* in the Northeast Atlantic'. *Scientific Reports* 10(1). doi: 10.1038/s41598-020-69238-x.

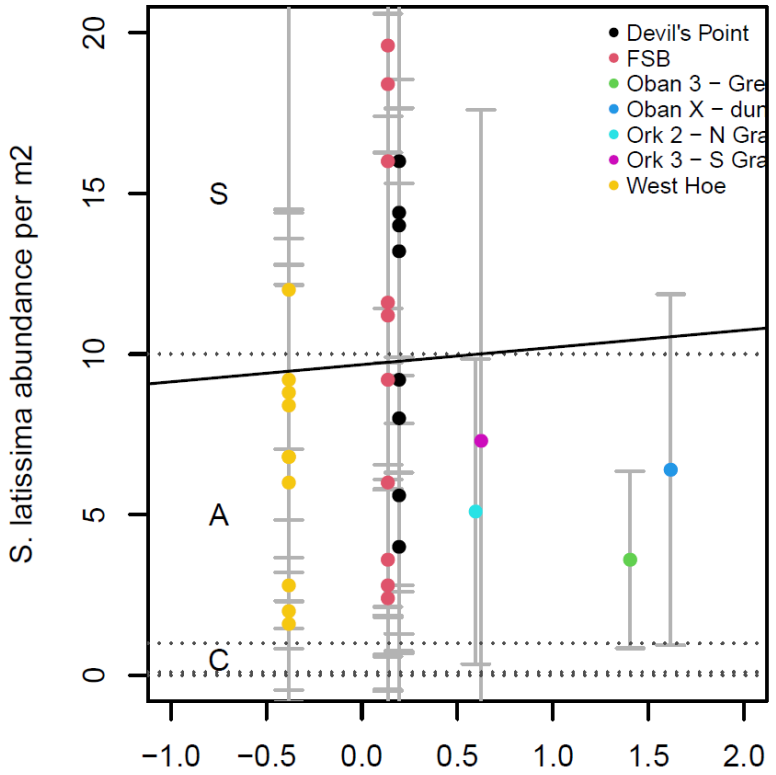
Saccharina latissima



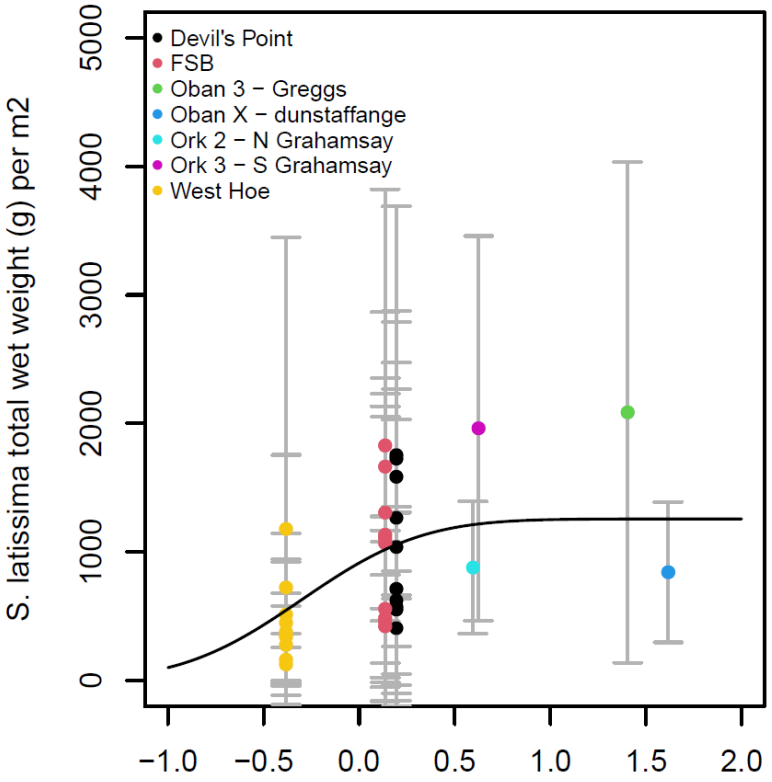
Plant weight (kg w/w)



Plant density (per m^2)



Biomass density (kg per m^2)



Habitat suitability from GAM model

Smale et al. 2020. 'Environmental Factors Influencing Primary Productivity of the Forest-Forming Kelp *Laminaria Hyperborea* in the Northeast Atlantic'. *Scientific Reports* 10(1). doi: 10.1038/s41598-020-69238-x.

Scaling up biomass

- **Method #1**: Estimated habitat extent × average biomass per unit area

$$Biomass_{total} = \sum Area|\left(P(\geq R) > 0.5\right) \cdot \sum P(Cat_i)B_i$$

- **Method #2**: Pixel-level predicted biomass density summed over habitat extent [exceeding a set abundance threshold]

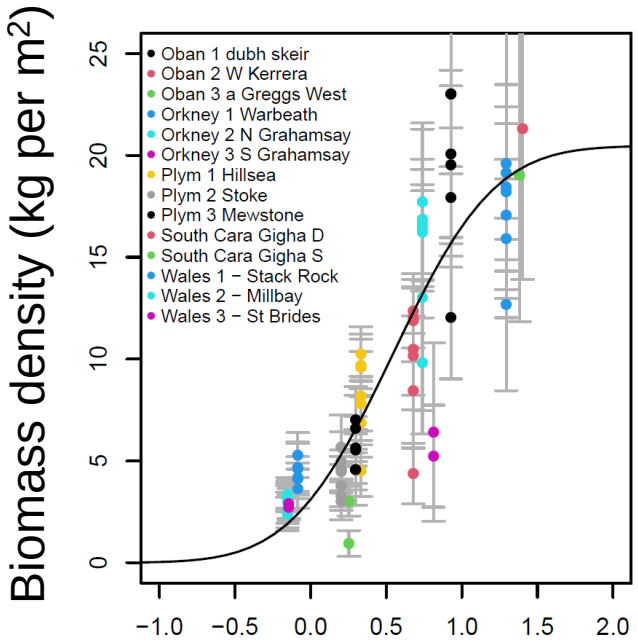
$$Biomass_{total} = \sum Area|\left(P(\geq Cat_j) > 0.5\right) \cdot \sum_{i=R}^{i=A} P(Cat_i)_{xy}B_i$$

Scaling up biomass

- **Method #3**: Habitat extent from summed likelihood of ‘Abundant’ kelp × predicted local biomass per unit area from observed relationship

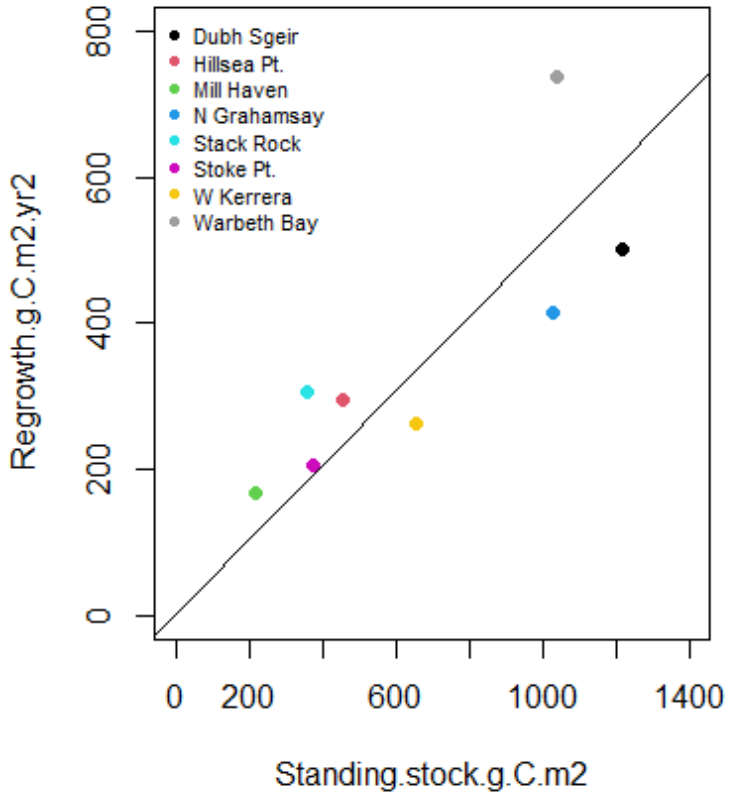
$$Biomass_{total} = \sum Area \cdot P(\geq A) \cdot B_{f,A}$$

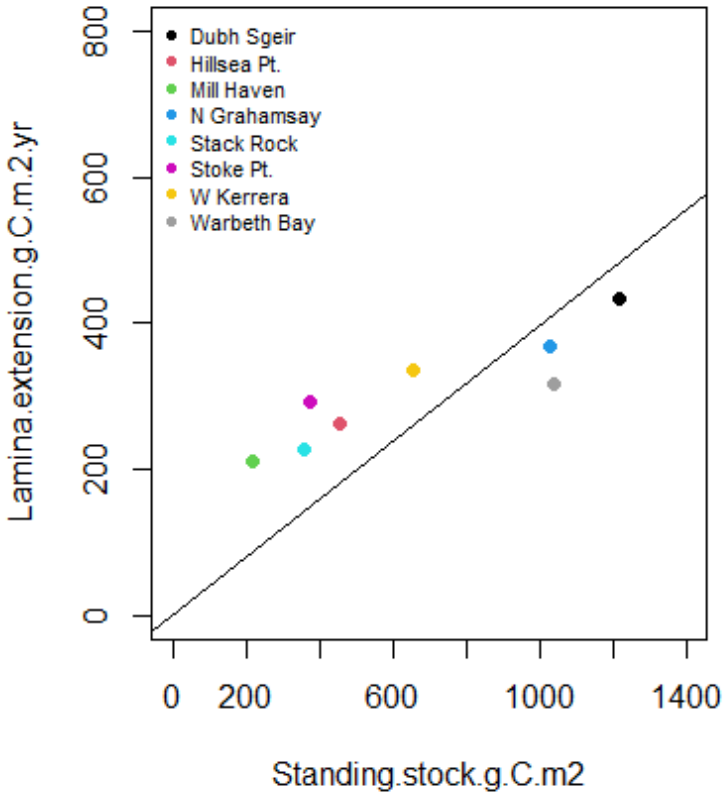
where $B_{f,A} = f\big(P(\geq R)\big)$



Habitat suitability from GAM model

Growth is proportional to biomass density





Smale, D. A., Pessarrodona, A., King, N., Burrows, M. T., Yunnie, A., Vance, T., & Moore, P. (2020). Environmental factors influencing primary productivity of the forest-forming kelp *Laminaria hyperborea* in the northeast Atlantic. *Scientific Reports*

Regrowth in cleared areas $gCm^{-2}yr^{-1}$= 0.51(±0.06) × standing stock gCm^{-2}, $R^2 = 0.91$

Lamina extension $gCm^{-2}yr^{-1}$= 0.40(±0.05) × standing stock gCm^{-2}, $R^2 = 0.91$

A partner of UHI

SAMS Scottish Association for Marine Science

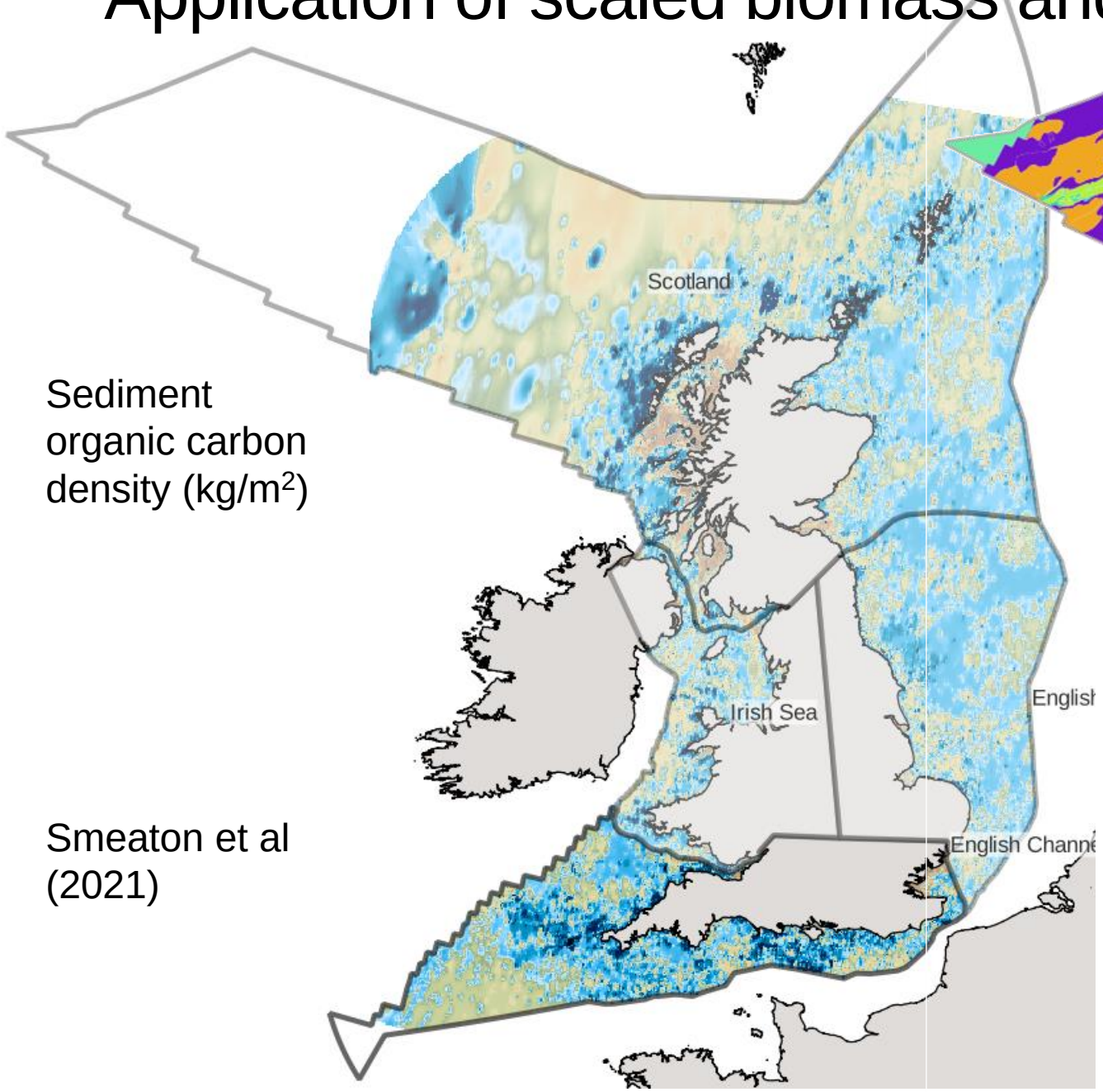
Biomass (Mt) and Production estimates (Mt/yr)

		Extent			Biomass					Production		
		(km²)			Method	(Mt FW)		(Mt DW)	(Mt C)	PPR (MtC/yr)	PPExt (MtC/yr)	PPtot
										P:B		
Species	Threshold	Soft	Hard	Total		Soft	Hard	Hard		0.510	0.397	0.907
Laminaria hyperborea	P(≥R)>0.5	675	1877	**2552**	**(2)**	6.41	17.10	**3.42**	**1.07**	**0.545**	**0.424**	**0.969**
	P(≥A)>0.5	133	216	348	**(2)**	1.78	2.87	0.57	0.18	0.091	0.071	0.163
Sum P(≥A), Scaled Bio		768	1380	**2148**	**(3)**	3.15	7.64	**1.53**	0.48	0.244	0.190	0.433
											PPExt	
										P:B	2.286	2.286
Saccharina latissima	P(≥R)>0.5	411	921	**1332**	**(2)**	0.31	0.81	**0.16**	**0.05**		**0.115**	**0.115**
	P(≥O)>0.5	285	602	888	**(2)**	0.24	0.61	0.12	0.04		0.087	0.087
	P(≥F)>0.5	51	106	157	**(2)**	0.05	0.15	0.03	0.01		0.022	0.022
Sum P(≥A), Scaled Bio		167	335	**502**	**(3)**	0.08	0.22	0.04	0.01		0.031	0.031

Application of scaled biomass and process rates

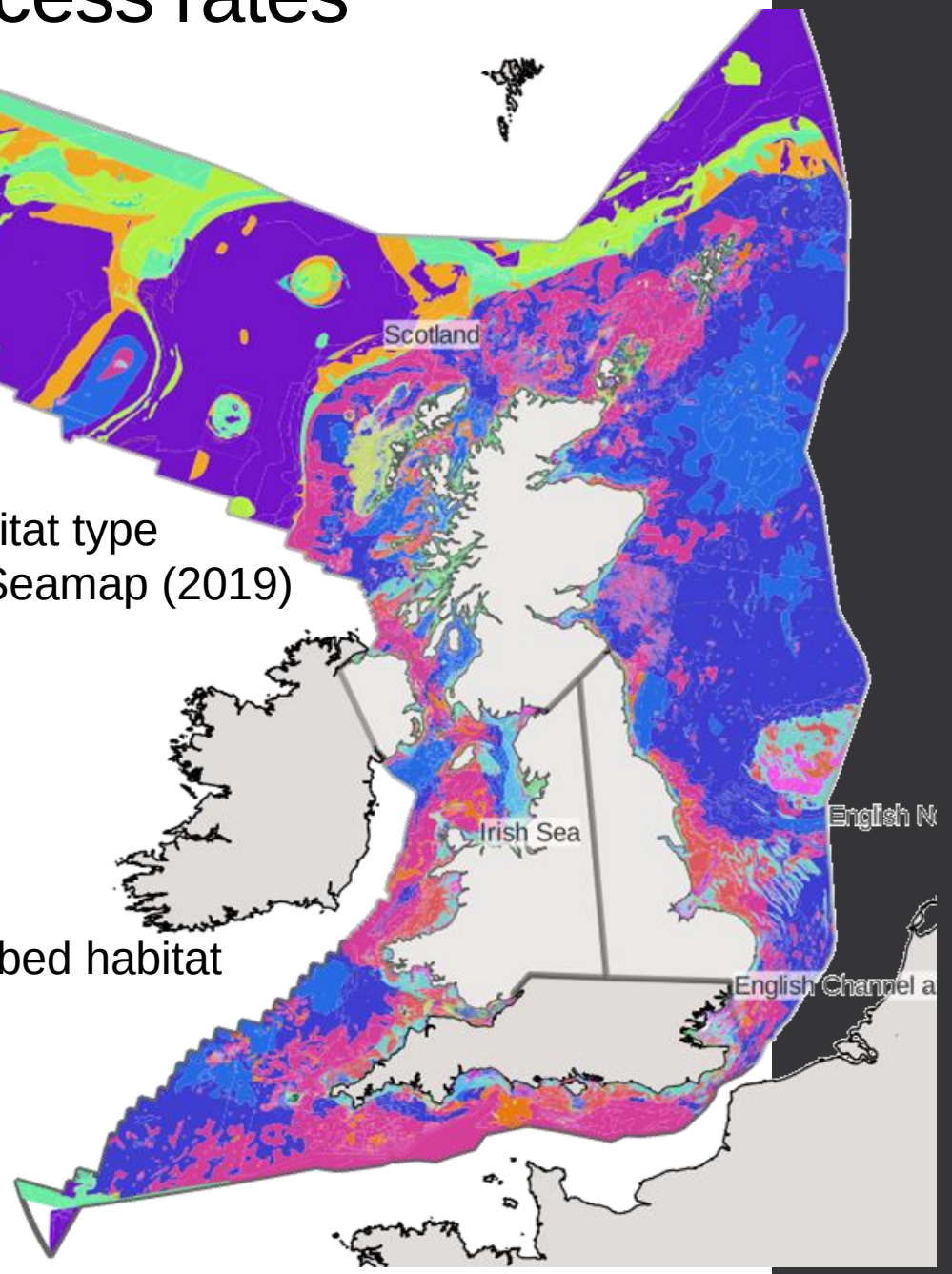
Sediment organic carbon density (kg/m^2)

Smeaton et al (2021)



Habitat type EUSeamap (2019)

Seabed habitat



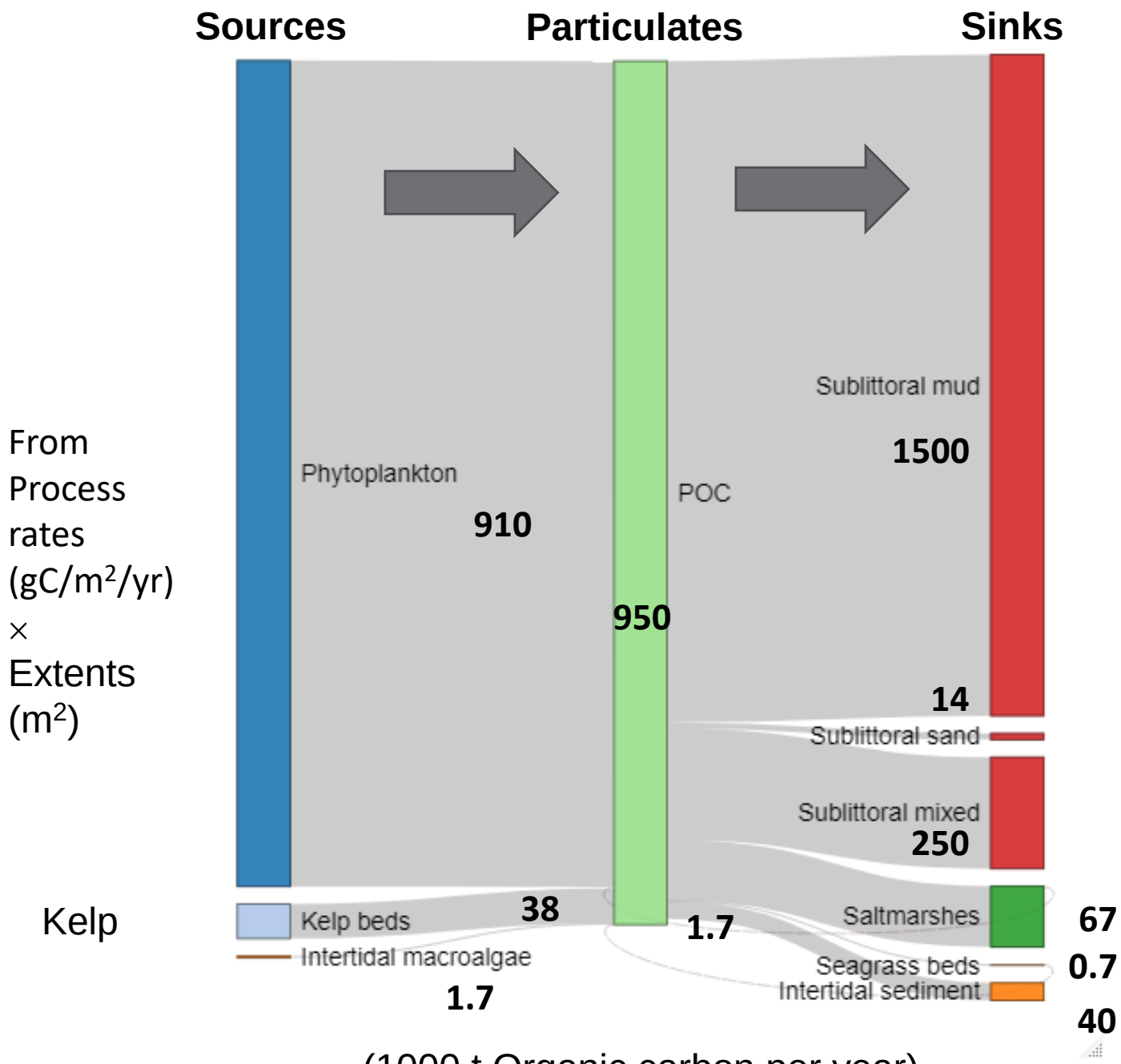
A regional (blue) **Carbon budget**

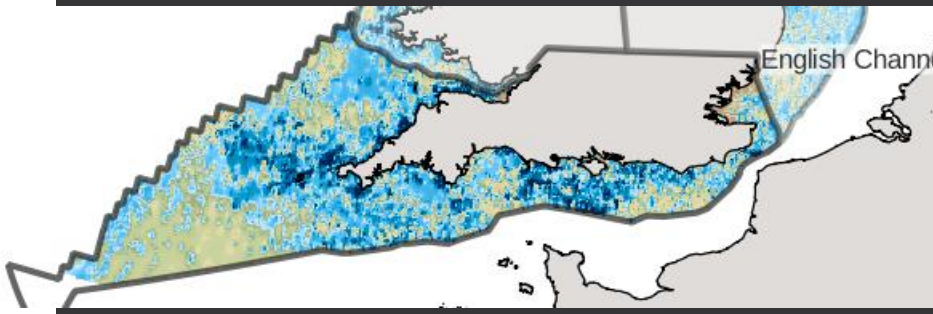
English Channel and Western Approaches

English Channel and Western Approaches 2022

Habitat		Extent (km²)	Organic carbon: Stock (Mt C) [0.1m depth]	Organic carbon: Stock (g C/m2)	Organic carbon: Production rate (g C/m²/yr)	Organic carbon: Total production (1000t C/yr)	Organic carbon: Outflux (1000t C/yr)	Organic carbon: Influx (1000t C/yr)	Organic carbon: Storage rate (g C/m²/yr)	Organic carbon: Storage capacity (1000t C/yr)	Inorganic carbon: Stock (Mt C) [1m depth]	Inorganic carbon: Stock (kg C/m²) [1m depth]	Inorganic carbon: Storage rate (g C/m²/yr)	Inorganic carbon: Storage capacity (1000t C/yr)	Inorganic carbon: Outflux (1000t C/yr)	Inorganic carbon: Influx (1000t C/yr)
Phytoplankton		111469			81	9069	907									
All sediment	(Method 1)	111469	35.8	322				1190	10.4	1190	905	8.1	3.4	384		
Biogenic habitats		1357	0.8		314	424	43	70		70						
Total / Average		112826	36.6		84	9494	950	1260		1260	905			384		

Habitat	Extent (km²)	Organic carbon: Stock (1000t C)	Organic carbon: Stock (g C/m²)	Organic carbon: Production rate (g C/m²/yr)	Organic carbon: Total production (1000t C/yr)	Organic carbon: Outflux (1000t C/yr)	Organic carbon: Influx (1000t C/yr)	Organic carbon: Storage rate (g C/m²/yr)	Organic carbon: Storage capacity (1000t C/yr)	Inorganic carbon: Stock (1000t C)	Inorganic carbon: Stock (kg C/m²)	Inorganic carbon: Storage rate (g C/m²/yr)	Inorganic carbon: Storage capacity (1000t C/yr)	Inorganic carbon: Outflux (1000t C/yr)	Inorganic carbon: Influx (1000t C/yr)
Vegetated habitats															
Kelp beds	1141.3	102.6	90	332	379.1	37.9		0	0						
Intertidal macroalgae	45.1	6.1	122	378	15.0	1.7		0	0						
Seagrass beds	49.3	117.9	2390	274	13.5	1.4	3.6	100.4	5.0						
Saltmarshes	121.3	529.9	4085	138	16.8	1.7	66.7	129.0	68.4						
Biogenic reefs															
Modiolus modiolus beds	NA														
Sabellaria reefs	NA														
Total	1357.1	756.5		314	424.4	42.6	70.3	15.2	73.3						



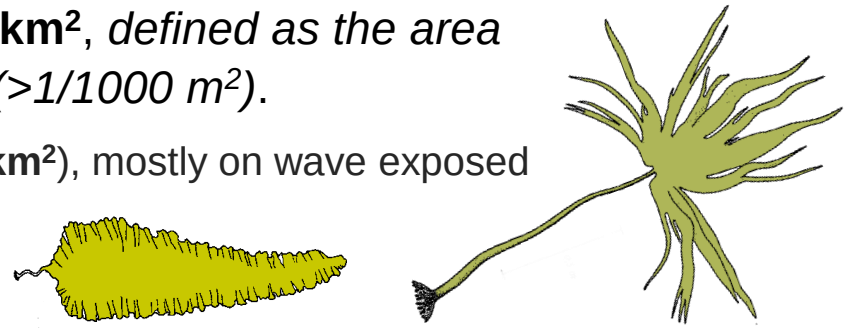


Organic carbon dynamics

English Channel and Western Approaches Region

Summary

- Habitat extents for GB kelp species were derived from models relating categorical abundance data to depth, wave exposure, chlorophyll concentrations and summer temperatures
- Models predict kelp cover in Great Britain and Ireland as **3800km²**, *defined as the area where plants are more likely to be found during diver surveys (>1/1000 m²)*.
  - *Laminaria hyperborea* is the most extensive kelp (P(≥R)>0.5, **2552 km²**), mostly on wave exposed coastlines
  - *Saccharina latissima* is next most extensive (P(≥R)>0.5, **1332 km²**),
  - **BUT extent estimates are entirely dependent on abundance thresholds (low -> greater)**



- Production rates (gC/m²/yr) scale directly with biomass density (gC/m²), giving total process rates from biomass across the study region
  - *Laminaria hyperborea* 0.54 MtC/yr from regrowth, **0.45 MtC/yr** from extension
  - *Saccharina latissima* **0.12 MtC/yr** from extension

Thanks!