

Ecological performance differs between range centre and trailing edge populations of a cold-water kelp: implications for estimating net primary productivity

Nathan G King^{1,2*}, Pippa J Moore², Albert Pessarrodona³, Michael T Burrows⁴, Joanne Porter⁵, Mathilde Bue², Dan A Smale⁶.

^{1*} Centre of Applied Marine Sciences, Bangor University, Menai Bridge, UK

² Institute of Biological, Environmental and Rural Sciences, Aberystwyth University, Aberystwyth, UK

³ UWA Oceans Institute and School of Biological Sciences, University of Western Australia, Fairway, Crawley, WA 6009, Australia

⁴ Scottish Association for Marine Science, Dunbeg, Oban, Argyll PA37 1QA, UK

⁵ International Centre for Island Technology, Heriot Watt University, Stromness, KW16 3AW, UK

⁶ Marine Biological Association of the United Kingdom, The Laboratory, Plymouth, PL1 2PB, UK

*Corresponding email: n.king@bangor.ac.uk

ORCID 0000-0003-0907-544X

Table S1. Results of univariate permutational ANOVA to test for differences in kelp density between sites and regions.

	df	Psuedo-F	p(perm)	Unique perms
Region	1	0.51	0.59	7
Site(Region)	4	1.22	0.31	9943

Table S2. Results of univariate permutational ANOVA to test for differences in individual kelp length between sites nested within region and season. Bold text indicates significant difference ($p < 0.05$)

	df	Psuedo-F	p(perm)	Unique perms
Region	1	0.97	0.3507	706
Season	1	36.5	0.0044	9702
Site(Region)	4	7.6	0.0001	9954
Region x Season	1	2.1	0.2236	9831
Season x Site(Region)	4	4.4	0.0024	9947

Table S3. Results of univariate permutational ANOVA to test for differences in individual kelp weight between sites nested within region and season. Bold text indicates significant difference ($p < 0.05$)

	df	Psuedo-F	p(perm)	Unique perms
Region	1	23.1	0.0236	708
Season	1	8.9	0.0436	9832
Site(Region)	4	3.8	0.0054	9940
Region x Season	1	10.3	0.0308	9869
Season x Site(Region)	4	4.8	0.001	9942

Table S4. Results of univariate permutational ANOVA to test for differences in individual kelp lamina elongation rates between sites nested within region and season. Bold text indicates significant difference ($p < 0.05$)

	df	Psuedo-F	p(perm)	Unique perms
Region	1	0.05	0.8002	714
Season	1	40.8	0.0033	9778
Site(Region)	4	20.0	0.0001	9954
Region x Season	1	0.05	0.8387	9853
Season x Site(Region)	4	15.5	0.0001	9957

Table S5. Results of univariate permutational ANOVA to test for differences in the heaviest basal segment between sites nested within region and season. Bold text indicates significant difference ($p < 0.05$)

	df	Psuedo-F	p(perm)	Unique perms
Region	1	3.3	0.04	719
Season	1	4.2	0.1051	9894
Site(Region)	4	20.0	0.0001	9949
Region x Season	1	4.0	0.1088	9838
Season x Site(Region)	4	6.3	0.0004	9952

Table S6. Results of univariate permutational ANOVA to test for differences in individual kelp biomass accumulation between sites nested within region and season. Bold text indicates significant difference ($p < 0.05$)

	df	Psuedo-F	p(perm)	Unique perms
Region	1	11.8	0.08	702
Season	1	71.0	0.003	9853
Site(Region)	4	6.4	0.0001	9942
Region x Season	1	8.2	0.0475	9891
Season x Site(Region)	4	6.3	0.0001	9952

Table S7. Results of univariate permutational ANOVA to test for differences in individual kelp tissue carbon between sites nested within region and season. Bold text indicates significant difference ($p < 0.05$)

	df	Pseudo-F	p(perm)	Unique perms
Region	1	137.6	0.003	9566
Season	1	2.6	0.17	60
Site(Region)	4	2.3	0.07	9955
Region x Season	1	1.4	0.29	9712
Season x Site(Region)	4	0.79	0.55	9940

Table S8. Results of univariate permutational ANOVA to test for differences in site level standing stock between regions and seasons. Bold text indicates significant difference ($p < 0.05$)

	df	Pseudo-F	p(perm)	Unique perms
Season	1	1.4	0.298	8840
Region	1	14.526	0.0054	5763
Region x Season	1	5.61	0.032	8678

Table S9. Monthly productivity characteristics of *Laminaria digitata*. Values represent mean values from two sites (Mount Batten and West Hoe) in Plymouth Sound, UK. WW:DW represents the wet weight to dry weight ratio and is the relative contribution of each month to the overall level of annual productivity.

	WW:DW (x)	% Carbon (C)	Productivity (g DW d ⁻¹)	Proportion
January	0.138494	26.38081417	0.252659	9.358141
February	0.142568	26.38081417	0.333775	12.44401
March	0.141941	26.58522347	0.395961	14.67196
April	0.150459	26.79689292	0.530958	19.82506
May	0.154442	28.97555583	0.283718	10.65565
June	0.170706	28.98011668	0.230037	8.648616
July	0.170695	28.53545167	0.123735	4.626911
August	0.188511	28.91051167	0.036254	1.36171
September	0.175528	28.91051167	0.086669	3.213226
October	0.190924	28.78841042	0.104741	3.813171
November	0.164412	28.78841042	0.12609	4.635315
December	0.148015	28.78841042	0.183472	6.746237

1 **Table S10.** Site level sampling information for *L. digitata* surveys. # harv is the number of individuals recovered and harvested at the end of each growth period and represent
2 the level of replication for that site/period.

Site	Peak growth season					Reduced growth season				
	Start	End	Days in situ	# harv	% N	Start	End	Days in situ	# harv	% N
RC1	22/03/15	06/05/15	45	13	1.71 (0.05)	2/8/15	13/9/15	42	14	0.97 (0.03)
RC2	21/03/15	04/05/15	44	9	1.97 (0.02)	4/8/15	14/9/15	41	9	0.97 (0.13)
RC3	18/03/15	29/04/15	42	17	2.14 (0.13)	27/7/15	7/9/15	42	10	1.4 (0.04)
TE1	05/04/15	15/05/15	40	14	2.5 (0.8)	13/8/15	24/9/15	42	11	1.4 (0.08)
TE2	06/04/15	16/05/15	40	16	1.74 (0.02)	14/8/15	25/9/15	42	15	1.38 (0.18)
TE3	07/04/15	17/05/15	40	13	1.94 (0.08)	15/8/15	27/9/15	44	12	1.40 (0.05)

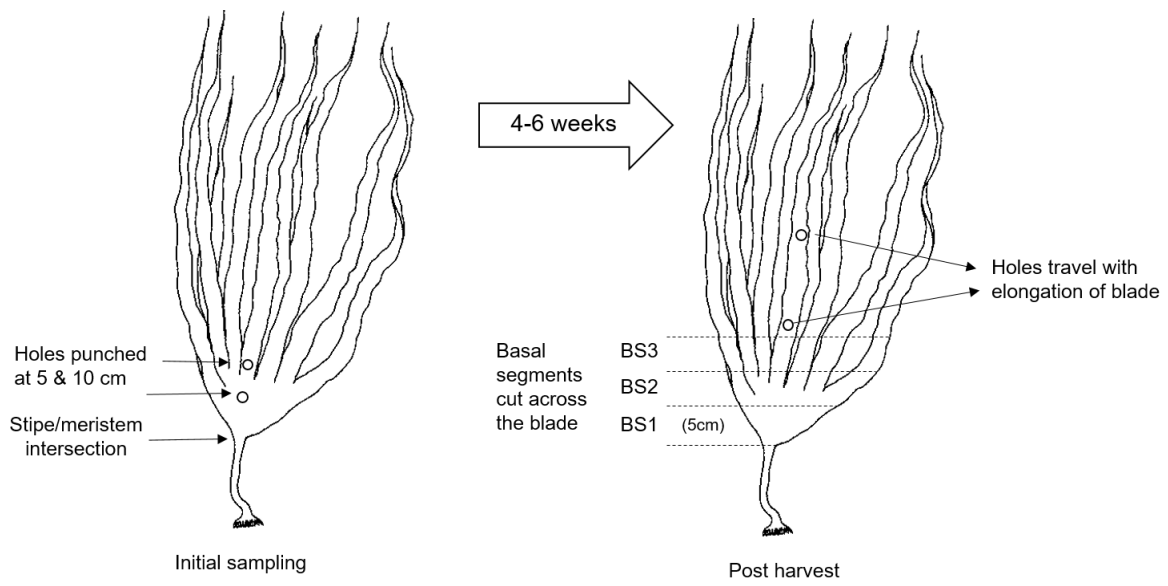
3

4 **Table S11.** Site level information for equations 2-5. Proportion of annual productivity is based on two reference sites in Plymouth Sound UK (Table S8). Mean density (D) was
5 only taken in the peak growth season.

	W - Mean plant biomass (grams)		D – mean density (m ²)		X – Fresh Weight :Dry Weight		C - % Carbon		B – Biomass accumulation (FW g day ⁻¹)		Proportion of annual productivity		SS – Standing stock of carbon (g C m ⁻²)		aNPP – annual estimate of NPP (g C m ⁻²)	
	Peak	Reduced	Peak	Reduced	Peak	Reduced	Peak	Reduced	Peak	Reduced	Peak	Reduced	Peak	Reduced	Peak	Reduced
RC1	728	398	6.8	na	0.14	0.18	30.1	34.6	3.06	0.58	19.8	1.36	207	167	134	554
RC2	573	267	9.4	na	0.14	0.18	30.8	35.2	2.97	0.29	19.8	1.36	231	158	185	386
RC3	999	312	9.4	na	0.14	0.18	30.3	33.1	4.40	0.42	19.8	1.36	397	174	270	535
TE1	273	169	6.5	na	0.14	0.18	29.2	32.7	1.78	0.22	19.8	1.36	72	64	73	196
TE2	253	250	7.3	na	0.14	0.18	29.8	33.1	1.31	0.26	19.8	1.36	102	107	61	258
TE3	172	328	8.4	na	0.14	0.18	30.8	33.6	2.23	0.32	19.8	1.36	62	166	124	373

6

7



10 **Figure S1.** Process of hole punching method for *Laminaria digitata* estimates.

11 Blight, A. Foster-Smith, R. Egerton, J. McAllen, R., and Savidge, G. (2011). Development of a methodology for
 12 quantitative assessment of Ireland's inshore kelp resource. Report No. 2009-3195 Marine Institute, 68.