Supplement

Section S1. Materials

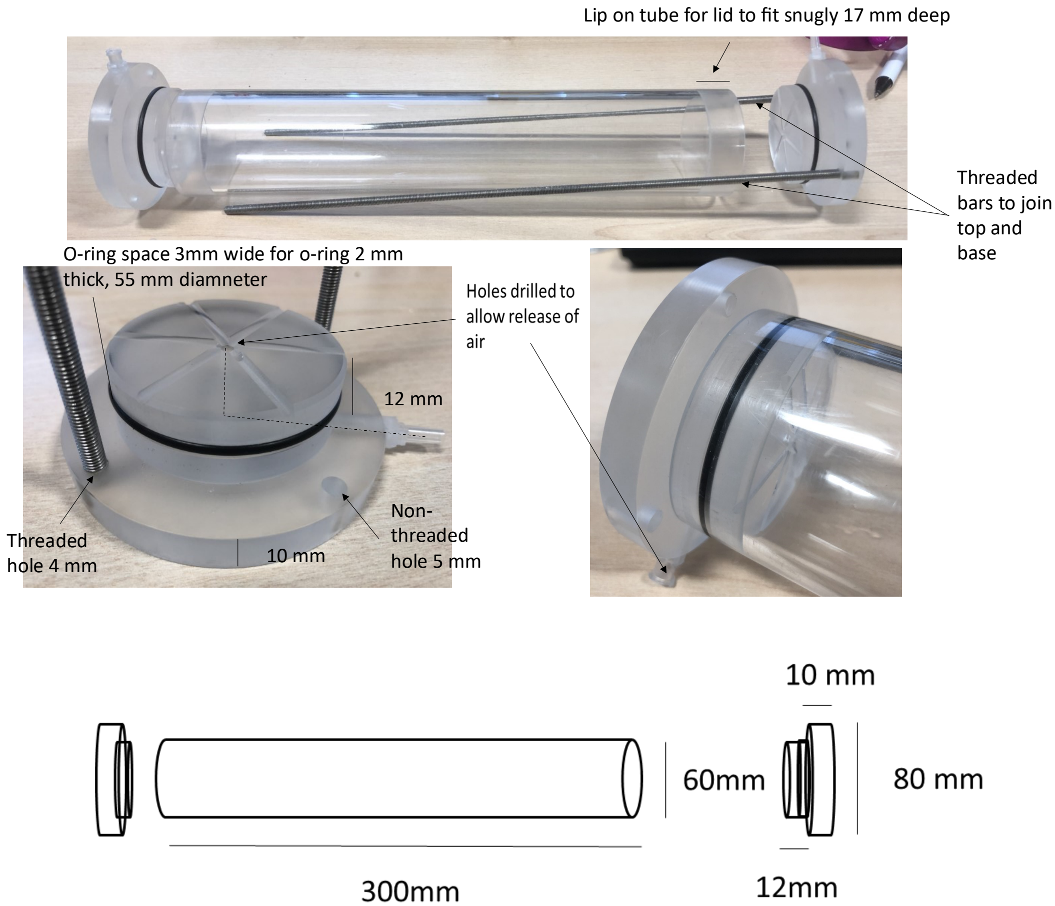

Fig. S1. Tube design and specifications

Section S2. Dry Mass calculations

Samples of fresh seaweed (from the experimental material) were cut to the same size as the incubated pieces to represent a similar mass of the samples that were being incubated. To standardise 'wetness' the pieces were allowed to dry for two minutes, then visible water was patted off with a paper towel before they were weighed wet (± 0.001g). Samples were then oven-dried at 60 °C for minimum of 48 hours and re-weighed. Percentage of total solids were then calculated using Equation S1. All incubated pieces of seaweed from all time periods were weighed before and after incubation and then oven-dried in the same standardised way.

$$\%\,Total\ Solids = \left(\frac{Dry\ Weight}{Wet\ Weight}\right) x\ 100 \qquad \text{Equation S1}$$

Section S3. Carbon calculations in water

In all analysis of the present study, the amount of carbon analysed (C_{norm}), be it DIC or DOC or percentage solids, was standardised to the amount of water in the tube (C_{stan}) by Equation S2 below:

$$C_{stan} = (C_{result}-C_{baseline})/V_t \qquad \text{Equation S2}$$

Where C_{result} is the output amount of C from analytical techniques (whether it is DOC or DIC), $C_{baseline}$ is the baseline amount of carbon in DOC or DIC form as an average of a) start values and b) blanks analysed at each incubation stage, and V_t refers to the volume of water in the tube. Carbon values are then reported in mg and not mg l^{-1}. Subsequently the amount of carbon released into the water was normalised (C_{norm}) to sample size using the Equation S3:

$$C_{norm} = C_{stan}/W_{sample} \qquad \text{Equation S3}$$

Where W_{sample} is the weight in grams of wet weight of each individual sample as they were placed in the tubes. This produces a final figure used in statistical analysis of mg C g^{-1} (milligrams of carbon per gram of tissue). The total carbon lost at each incubation period, in DIC and DOC form, were represented as proportions of the amount of carbon that entered the experiment in solid form. A percentage plot was produced and comparisons made to the estimated carbon lost through the change of mass before and after incubation (Figure 1, main article). In the present study, the average percentage of seaweed dry mass that was carbon was found to be consistent across tissues throughout the experiment (23.4% of dry weight, discussed below).

Section S4. Literature review of previous temperature intervals used to measure the labile–refractory nature of organic matter

Table S1. A range of different temperatures have been used to identify and elucidate the different temperatures that signify labile and different levels of recalcitrant ranges of organic (and inorganic) compounds during mass-loss through combustion. Changes in experimental parameters will produce different results in TGA experiments. There is no standard accepted set of temperature intervals to date.

Labile	Recalcitrant	Refractory	Carbonates	Method/flow	Reference
300-350	400-500	430-530		Oxygen-Helium	Capel et al., 2006; Lopez-Capel et al., 2005; Kaloustian et al., 2001; Lopez-Capel et al., 2006
200-400	400-550	550-650	650-900	Oxygen-Helium	Capel et al., 2006
130-280	280-520				Kristensen 1994
130-280	280-520			Atmospheric air	Kristensen 1990
130-280	280-520			Atmospheric air	Yuan et al., 2017
100-250	250-500			Atmospheric air	Loh et al., 2008
160-300	300-400	400-600	600-800	Nitrogen	Trevathan-Tacket et al., 2015
200-400	400-550	550-650		Nitrogen	Mauquoy et al., 2020
160-300	300-400	400-600	600-800	Argon	Lewis 2020

Section S5. Results of TGA mass loss assays Table S2. Mean (±sd) percentage mass lost at each temperature interval separated by species and plant part.

Days	Species	Material	n	TI1	sd	TI2	sd	TI3	sd	TI4	sd
0	L. digitata	Blade	4	43.21	5.88	13.01	1.52	7.17	1.05	7.62	2.53
0	L. digitata	Holdfast	4	29.25	2.32	11.01	0.94	6.92	0.51	5.88	0.95
0	L. digitata	Stipe	4	31.82	1.33	8.89	0.21	6.70	0.27	5.08	0.31
0	L. hyperborea	Blade	4	44.81	7.52	14.71	2.97	6.63	1.03	4.79	0.57
0	L. hyperborea	Holdfast	4	27.57	2.21	11.49	1.01	7.50	0.32	7.64	2.11
0	L. hyperborea	Stipe	4	29.38	2.08	9.52	0.21	6.72	0.24	5.72	1.12
0	S. latissima	Blade	4	34.35	4.82	12.97	1.94	6.60	0.47	5.27	1.23
0	S. latissima	Holdfast	4	23.73	2.72	11.92	1.17	7.44	0.62	5.05	0.68
0	S. latissima	Stipe	4	29.97	2.18	11.32	0.68	7.98	0.30	4.81	0.84
7	L. digitata	Blade	5	41.38	26.68	19.69	14.48	11.75	7.63	8.93	5.40
7	L. digitata	Holdfast	4	29.52	1.19	12.85	2.79	8.33	1.65	5.85	0.85
7	L. digitata	Stipe	3	29.75	3.62	9.33	1.19	7.44	0.59	4.30	2.30
7	L. hyperborea	Blade	3	28.74	8.76	14.16	1.80	7.81	0.60	5.95	0.34
7	L. hyperborea	Holdfast	4	27.72	5.25	11.41	1.73	7.67	0.78	7.94	3.65
7	L. hyperborea	Stipe	5	29.67	2.53	9.81	0.36	7.22	0.30	5.37	0.49
7	S. latissima	Blade	3	20.39	1.59	11.07	1.48	6.13	0.61	9.71	3.72
7	S. latissima	Holdfast	3	23.45	3.22	13.00	1.09	8.25	0.75	5.55	0.18
7	S. latissima	Stipe	4	28.61	3.98	11.94	0.65	8.52	0.54	5.53	1.89
14	L. digitata	Blade	5	24.09	4.77	10.67	1.14	7.90	1.07	6.16	0.78
14	L. digitata	Holdfast	4	30.58	1.64	10.81	0.27	7.32	0.21	2.89	2.28
14	L. digitata	Stipe	8	27.27	2.59	10.72	0.85	7.25	0.39	4.26	1.41
14	L. hyperborea	Blade	4	23.22	3.85	11.63	2.08	8.08	0.70	5.33	3.02
14	L. hyperborea	Holdfast	4	26.25	6.15	10.94	2.12	7.18	0.79	7.98	3.67
14	L. hyperborea	Stipe	4	29.80	3.31	9.16	0.26	6.83	0.36	5.78	0.47
14	S. latissima	Blade	4	22.88	2.60	12.05	1.23	8.05	0.40	5.75	0.42
14	S. latissima	Holdfast	4	23.19	1.91	12.18	0.57	7.87	0.48	4.72	0.57
14	S. latissima	Stipe	4	27.04	4.32	11.89	1.27	8.26	0.71	4.41	0.36
21	L. digitata	Blade	5	21.32	3.17	10.97	1.59	7.82	0.72	6.28	0.79
21	L. digitata	Holdfast	5	22.75	4.36	12.27	1.28	7.93	0.62	6.08	1.57
21	L. digitata	Stipe	4	29.05	2.13	11.21	1.44	7.80	0.67	5.87	0.21
21	L. hyperborea	Blade	4	22.24	3.80	10.65	0.98	8.28	0.33	6.54	0.57
21	L. hyperborea	Holdfast	5	22.17	3.30	12.39	1.17	8.22	0.59	5.20	0.31
21	L. hyperborea	Stipe	4	26.27	4.00	12.08	1.09	7.76	0.43	5.53	1.26
21	S. latissima	Blade	9	18.81	2.11	10.28	1.65	7.98	0.87	3.74	3.05
21	S. latissima	Holdfast	4	25.42	2.69	13.01	1.12	8.67	0.63	4.97	0.65
21	S. latissima	Stipe	4	29.73	1.41	12.26	0.72	8.77	0.37	5.06	0.19

Section S6. Refractory potential

To show the differences in the refractory nature of compounds within the material at the different time intervals. The refractory potential (Rp) index defined by Kristensen, (1990) was applied to temperature intervals TI1 and TI2 using the below formula:

$$Rp = \frac{TI2}{(TI1+TI2)} \qquad \text{Equation S4}$$

The effects of the three factors days incubated, plant part, and species (as above) and their interactions on the dependant continuous variable refractory potential (Rp) were tested with a three-way ANOVA. The output was tested for normal distribution but plotting residuals against fitted values and with a Q-Q plot.

Section S7. First order decomposition as an exponential decay process (*k*)

The general expression of decomposition is in the form of a first order rate equation. To first test if the decay was first order (and not zero, or second order), the natural logarithm of the reactant (dry mass) was plotted against time. A straight line, negative relationship confirmed that first order was the correct kinetics for both blade and stipe material (R^2 = 0.99 and 0.93 respectively). Since carbon content for kelp species in the present study is a constant proportion of dry mass (23.4% ± 2.7), changes in dry mass were used to calculate *k*. By taking W_t as the dry mass of macroalgal material at a given time (t) and W_0 as the dry mass at time zero, the single pool negative exponential decay model is written as follows (see Laliberté et al., 2012):

$$W_t = W_0\, e^{-kt} \qquad \text{Equation S5}$$

Logging both sides of the equation:

$$Log(W_t) = log(W_0) – kt \qquad \text{Equation S6}$$

Then re-arranging for *k*:

$$(Log(W_t) - log(W_0))/t = -k \qquad \text{Equation S7}$$

The decomposition constant (*k*) can then be used to calculate the half-life ($T_{1/2}$) in days of seaweed material.

$$T_{1/2} = k^{-1}.\ Ln(2) \qquad \text{Equation S8}$$

Section S8. Total Carbon in seaweed tissues through experiment

No significant differences were found in total organic carbon content from dried samples analysed throughout the incubation experiments, even when testing the effect of time on total carbon and species as a covariate (ANCOVA, df = 28, p = 0.67). The mean percentage of dry weight that was total carbon was 23.4% (SD ± 2.7)

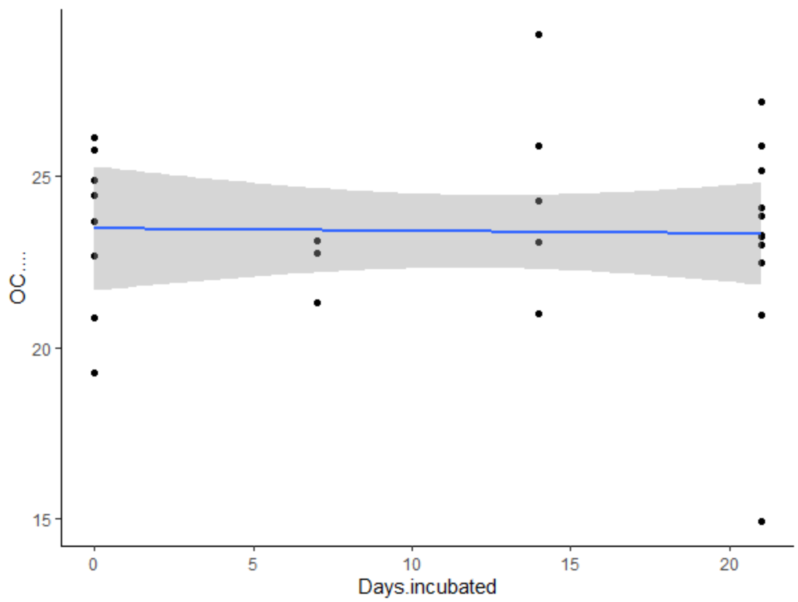

Figure S2. Comparison of total carbon in subset of incubated pieces with different ages. No significant differences exist in total carbon as kelp pieces get older. (ANCOVA, df = 28, P = 0.65). Mean OC content of seaweed pieces was therefore assumed to be 23.4% of dry weight (SD ± 2.7).

Section S9. Coefficients

Table S3. Coefficients (Est below) of GLM analyses of concentrations of dissolved inorganic carbon and dissolved organic carbon (DIC and DOC) released during incubation of kelp material.

Model = mg.l ~ Days + Material * Species. Family = Gamma (link = "log")	(DIC)	(DIC)	(DIC)	(DIC)	(DOC)	(DOC)	(DOC)	(DOC)
	Est	Error	t-value	P	Est	Error	t-value	P
Intercept (0 days incubation)	2.88	0.22	12.87	**<0.01***	2.75	0.41	6.64	**<0.01***
7 Days	0.37	0.20	1.90	0.06	3.67	0.36	10.12	**<0.01***
14 Days	0.71	0.19	3.63	**<0.01***	4.32	0.36	12.04	**<0.01***
21 Days	1.36	0.19	6.99	**<0.01***	5.08	0.36	14.13	**<0.01***
Holdfast	1.60	0.21	7.50	**<0.01***	-2.10	0.33	-6.28	**<0.01***
Stipe	0.07	0.20	0.38	0.71	-2.04	0.32	-6.46	**<0.01***
L. hyperborea	0.24	0.21	1.12	0.26	-0.49	0.34	-1.45	0.15
S. latissima	0.24	0.21	1.17	0.24	-1.40	0.33	-4.26	**<0.01***
Holdfast - *L. hyperborea*	-0.14	0.31	-0.47	0.64	0.73	0.49	1.48	0.14
Stipe - *L. hyperborea*	1.01	0.30	3.40	**<0.01***	0.96	0.47	2.03	**0.04***
Holdfast - *S. latissima*	-1.31	0.30	-4.31	**<0.01***	-0.10	0.48	-0.22	0.82
Stipe - *S. latissima*	-0.17	0.29	-0.57	0.57	-0.18	0.46	-0.38	0.71

Section S10. Standard seaweed compounds analysed for peak comparison.

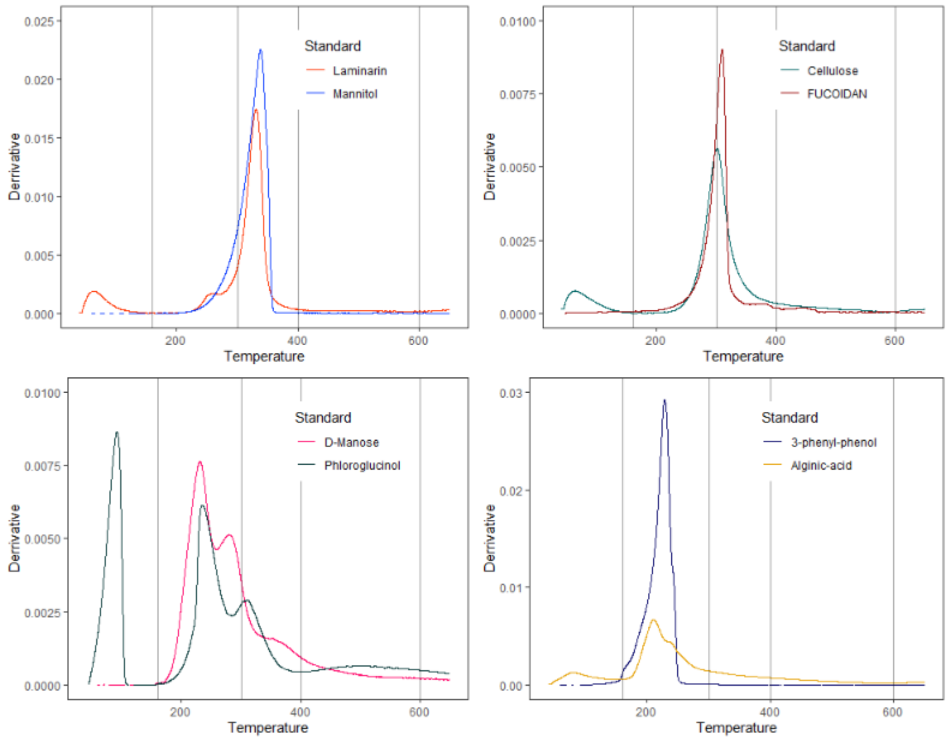

Figure S3. Degradation peaks of standard macroalgal compounds (as labelled) analysed by thermos-gravimetry. Peak demonstrates the temperature at which maximum loss of mass occurred during thermogravimetric analysis.

Section S11. Decomposition rates

Table S4. Decomposition rates of blades, stipes and holdfasts. Holdfast was not presented in main text given the large variation and uncertainty in half life.

Plant part	Period	W_t	W_o	t	k	t (half-life)
Blade	0-7	13.3	15.5	7	0.022	31.7
Blade	0-14	10.8	15.5	14	0.026	26.9
Blade	0-21	8.6	15.5	21	0.028	24.7
Holdfast	0-7	13.5	16.6	7	0.030	23.4
Holdfast	7-14	15.5	16.6	14	0.005	145.7
Holdfast	14-21	13.6	16.6	21	0.010	72.7
Stipe	0-7	12.7	13.3	7	0.007	97.1
Stipe	7-14	12.1	13.3	14	0.007	99.5
Stipe	14-21	12.0	13.3	21	0.005	143.0