Supplement to
Kelp decomposition hinges on physiology

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Figures

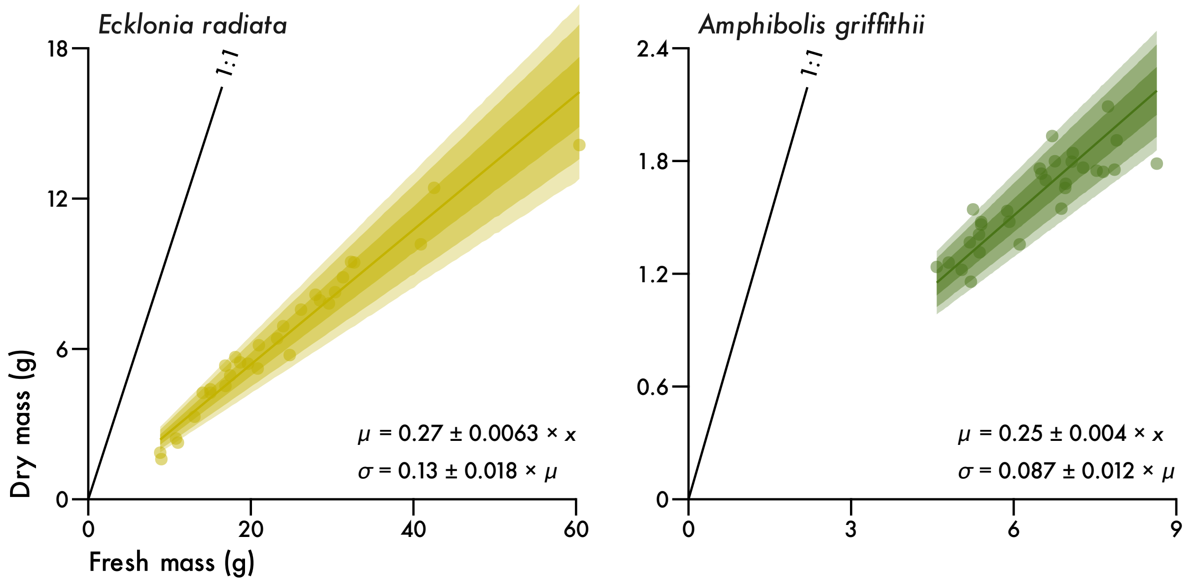

Figure S1. Mass relationship for kelp (*Ecklonia radiata*) and seagrass (*Amphibolis griffithii*). Each data point is a tissue sample measured before and after lyophilisation (n = 30 for each species). Lines and ribbons are the mean and 50%, 80% and 90% posterior probability intervals for predicted observations of dry mass (m_d in Equation 1). The functions describing the likelihood mean and standard deviation (μ and σ in Equation 1) are given in each panel. The slope is equivalent to the dry-fresh mass ratio.

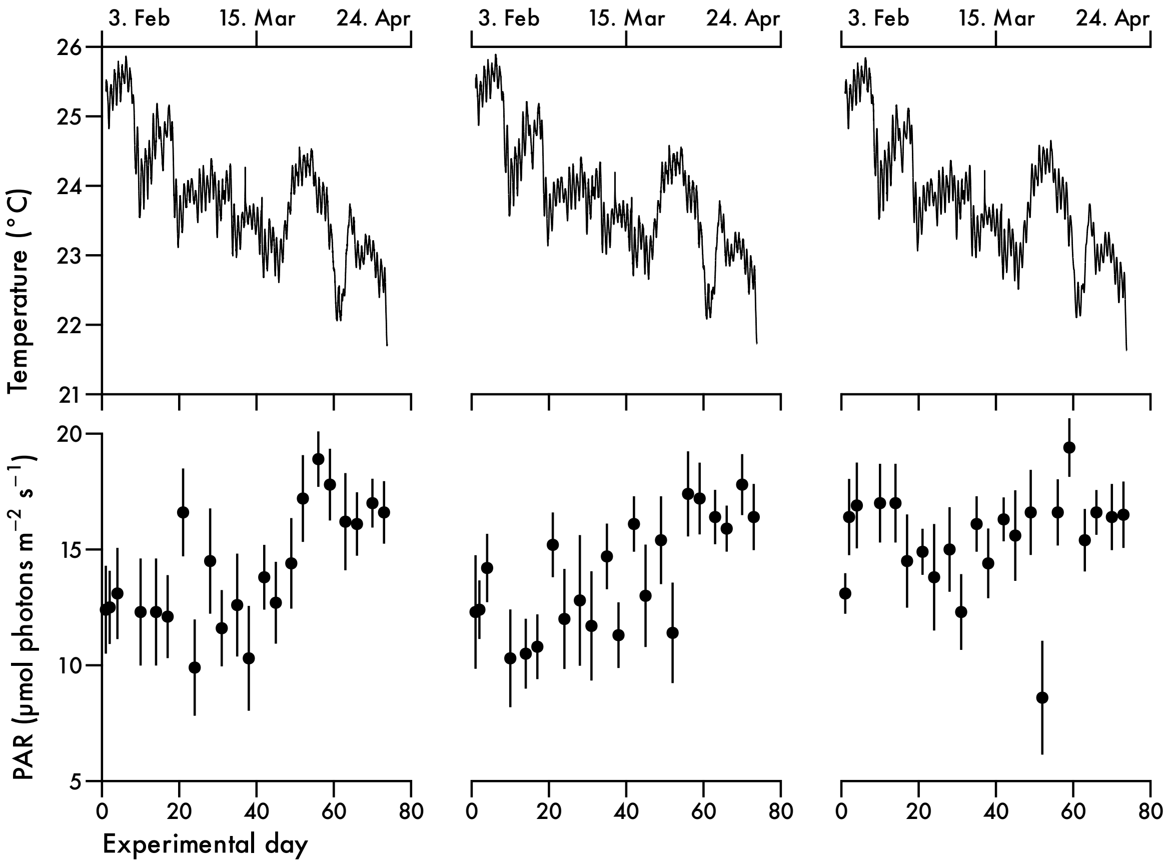

Figure S2. Temperature and photosynthetically active radiation (PAR) over the duration of the experiment on *Ecklonia radiata* and *Amphibolis griffithii*. The experiment was conducted in austral summer and autumn, starting on 3rd February and ending after 73 days on 17th April 2025. Each panel is an experimental tank (1–3 from left to right). Temperature was not controlled and represents ambient coastal seawater temperature, measured every 5 minutes (n = 20972 per tank). PAR was delivered by an artificial source on a 12–12-h light–dark cycle. Measurements were only taken during the light phase with points and error bars (mean ± standard deviation, n = 10) representing single timepoints with spatial variation.

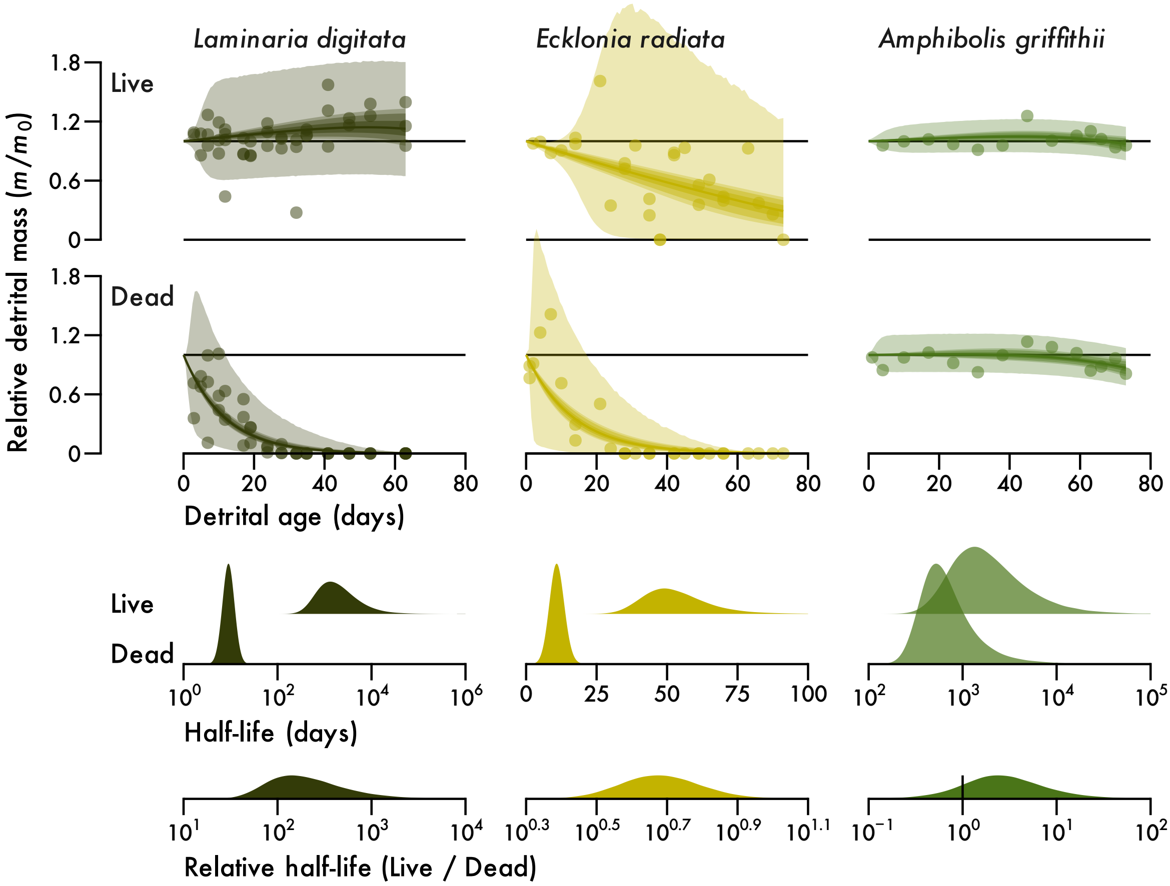

Figure S3. Decomposition of kelp (*Laminaria digitata* and *Ecklonia radiata*) is determined by physiology, unlike decomposition of seagrass (*Amphibolis griffithii*). Detrital mass is given as fresh mass (cf. Figure 2). Each data point is a destructively sampled litterbag (n = 86 for *L. digitata*, n = 54 for *E. radiata*, n = 27 for *A. griffithii*). Lines and ribbons are the median and 50%, 80% and 90% posterior probability intervals for the likelihood mean or expected value of the optimal model (μ_m in Equation 2). The widest ribbon in the 90% probability interval for predicted observations (m in Equation 2). Distributions are posterior probabilities for the exponential decay constant (k in Equation 3) and their ratios (ratio = 1 means estimates are identical). Summary statistics for these distributions are given in Table S4.

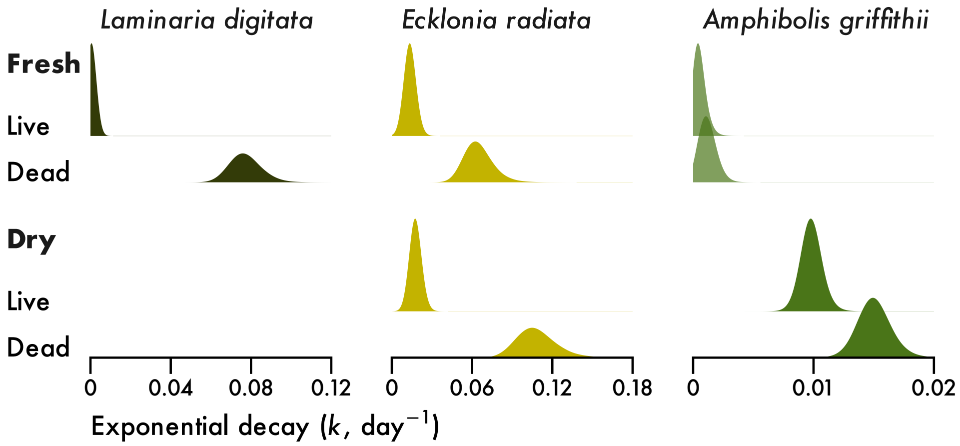

Figure S4. The difference between fresh and dry mass decomposition estimates. Distributions are posterior probabilities for the exponential decay constant (k in Equation 3) estimated from the experimental data. Summary statistics for these distributions are given in Table S3.

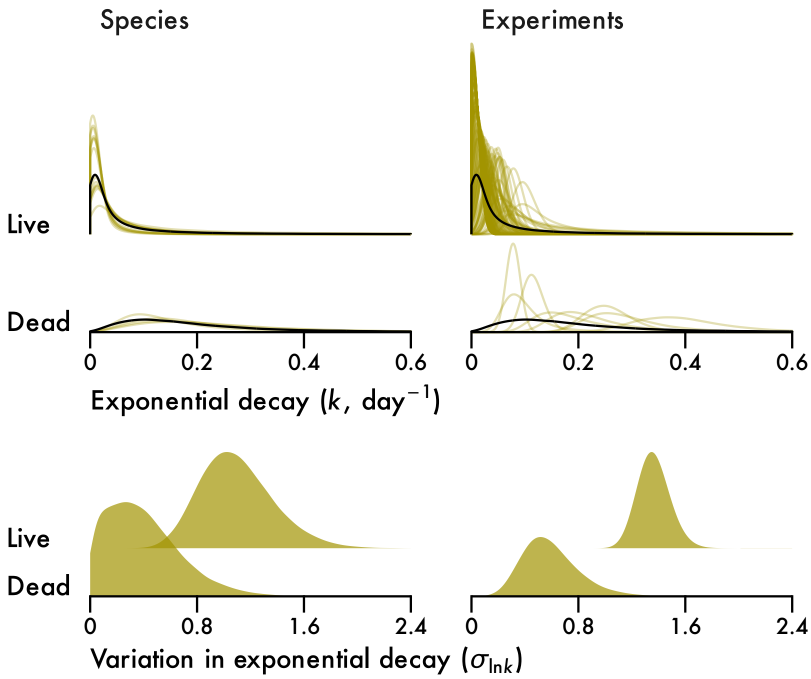

Figure S5. Interspecific and experimental variation in the exponential decay constant (k in Equation 3). Lines are probability distributions for each species and experiment (coloured) or unobserved species and experiments (black). Shaded areas are probability distributions for the interspecific and experimental standard deviations of k on the logarithmic scale ($\sigma_{\ln k}$ in Equation 3). Summary statistics for these distributions are given in Tables S5 and S6.

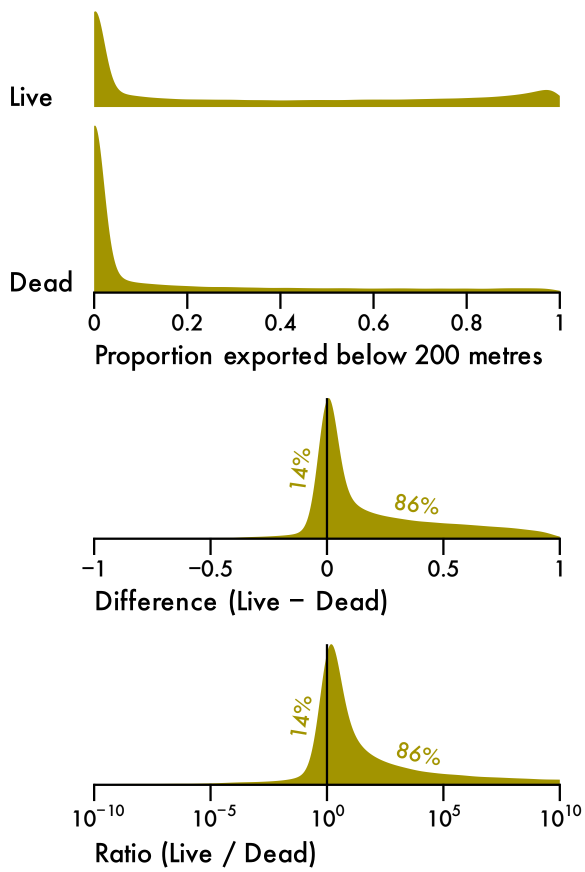

Figure S6. Detrital physiology affects estimates of kelp CO_2 removal. The proportion of carbon exported below 200 metres depth, which is frequently assumed to be sequestered by retention in deep ocean currents, is calculated as Ee^{-kt} where E is the exported proportion of production, k is the exponential decay constant (day^{-1}) derived from the meta-analysis (Table S5) and t is the coastal residence time (days). Since E is beta-distributed and k and t are log-normally distributed, the resulting distribution is a proportion bounded by 0 and 1. Large uncertainty therefore leads to a concertation of probability density near the bounds, as can be seen in the top panel. Percentages are probabilities either side of the identity line at difference = 0 and ratio = 1.

Tables

Table S1. Kelp and terrestrial forest turnover and predicted decomposition. Decomposition is expressed as exponential decay (*k*) and half-life (ln2 / *k*). *k* is given as % for readability. All estimates are strictly positive and given as median (ln mean ± standard deviation).

	Turnover (year^{-1})	**Decay (% day^{-1})**	**Half-life (days)**
Terrestrial forests	0.16 (−1.9 ± 1.4)	0.33 (−1.2 ± 2.9)	211 (5.4 ± 2.9)
Kelp forests	2.7 (1 ± 0.88)	1.5 (0.46 ± 2.4)	46 (3.8 ± 2.4)
Agarum clathratum	1.5 (0.38 ± 0.78)	1.1 (0.1 ± 2.3)	65 (4.1 ± 2.3)
Durvillaea antarctica	2.3 (0.85 ± 0.82)	1.4 (0.37 ± 2.4)	50 (3.9 ± 2.4)
Ecklonia cava	2.4 (0.86 ± 0.82)	1.4 (0.38 ± 2.4)	50 (3.9 ± 2.4)
Ecklonia cava subsp. *kurome*	2.7 (1 ± 0.84)	1.5 (0.46 ± 2.4)	45 (3.8 ± 2.4)
Ecklonia maxima	3.5 (1.3 ± 0.81)	1.8 (0.61 ± 2.5)	39 (3.6 ± 2.5)
Ecklonia radiata	2.2 (0.77 ± 0.77)	1.3 (0.33 ± 2.4)	52 (3.9 ± 2.4)
Eisenia arborea	3.1 (1.1 ± 0.84)	1.6 (0.53 ± 2.5)	43 (3.7 ± 2.5)
Eisenia bicyclis	2.4 (0.88 ± 0.83)	1.4 (0.39 ± 2.4)	49 (3.8 ± 2.4)
Hedophyllum nigripes	3.5 (1.2 ± 0.8)	1.8 (0.6 ± 2.5)	40 (3.6 ± 2.5)
Hedophyllum sessile	2.2 (0.81 ± 0.82)	1.4 (0.34 ± 2.4)	51 (3.9 ± 2.4)
Himantothallus grandifolius	2.6 (0.96 ± 0.83)	1.5 (0.43 ± 2.4)	47 (3.8 ± 2.4)
Laminaria digitata	2.1 (0.77 ± 0.76)	1.3 (0.33 ± 2.4)	52 (3.9 ± 2.4)
Laminaria hyperborea	1.4 (0.34 ± 0.76)	1 (0.079 ± 2.3)	66 (4.2 ± 2.3)
Laminaria ochroleuca	2.6 (0.95 ± 0.78)	1.5 (0.44 ± 2.4)	46 (3.8 ± 2.4)
Laminaria pallida	3 (1.1 ± 0.81)	1.6 (0.51 ± 2.4)	43 (3.7 ± 2.4)
Laminaria setchellii	1.4 (0.35 ± 0.82)	1.1 (0.082 ± 2.3)	66 (4.2 ± 2.3)
Laminaria solidungula	1.3 (0.28 ± 0.8)	1 (0.045 ± 2.3)	68 (4.2 ± 2.3)
Lessonia corrugata	2.6 (0.96 ± 0.83)	1.5 (0.44 ± 2.4)	46 (3.8 ± 2.4)
Lessonia nigrescens	4.1 (1.4 ± 0.81)	2 (0.7 ± 2.5)	36 (3.5 ± 2.5)
Lessonia trabeculata	1.8 (0.6 ± 0.79)	1.2 (0.24 ± 2.4)	56 (4 ± 2.4)
Lessoniopsis litoralis	3.2 (1.2 ± 0.82)	1.7 (0.56 ± 2.5)	41 (3.7 ± 2.5)
Macrocystis laevis	3.4 (1.2 ± 0.84)	1.7 (0.59 ± 2.5)	40 (3.6 ± 2.5)
Macrocystis pyrifera	5.5 (1.7 ± 0.77)	2.3 (0.87 ± 2.6)	31 (3.4 ± 2.6)
Neoagarum fimbriatum	3.8 (1.3 ± 0.8)	1.8 (0.64 ± 2.5)	38 (3.6 ± 2.5)
Nereocystis luetkeana	2.9 (1.1 ± 0.79)	1.6 (0.5 ± 2.4)	44 (3.7 ± 2.4)
Phyllariopsis purpurascens	3.6 (1.3 ± 0.84)	1.8 (0.61 ± 2.5)	39 (3.6 ± 2.5)
Pleurophycus gardneri	2.4 (0.88 ± 0.8)	1.4 (0.39 ± 2.4)	49 (3.8 ± 2.4)
Postelsia palmiformis	3.5 (1.2 ± 0.81)	1.7 (0.6 ± 2.5)	40 (3.6 ± 2.5)
Pterygophora californica	3.1 (1.1 ± 0.84)	1.6 (0.54 ± 2.5)	42 (3.7 ± 2.5)
Saccharina angustata	3.2 (1.2 ± 0.84)	1.7 (0.55 ± 2.5)	42 (3.7 ± 2.5)
Saccharina latissima	2.5 (0.92 ± 0.76)	1.5 (0.42 ± 2.4)	47 (3.8 ± 2.4)
Saccorhiza polyschides	3.3 (1.2 ± 0.78)	1.7 (0.58 ± 2.5)	40 (3.7 ± 2.5)
Undaria pinnatifida	3.3 (1.2 ± 0.83)	1.7 (0.57 ± 2.5)	41 (3.7 ± 2.5)

Table S2. Kelp forest in contrast with terrestrial forest turnover and predicted decomposition (cf. Table S1). For turnover and decay rates, ratio = kelp forests / terrestrial forests; for turnover time and half-life, ratio = terrestrial forests / kelp forests. *P* = *P*($\log_{10}$ ratio > 0). All estimates are median (90% probability interval).

	Kelp forests	**Terrestrial forests**	**$\log_{10}$ ratio**	**P**
Turnover (year^{-1})	2.7 (0.64–12)	0.16 (0.017–1.5)	1.2 (0.087–2.4)	0.96
Decay (% day^{-1})	1.5 (0.032–89)	0.33 (0.0027–29)	0.63 (−1.4–3.1)	0.7
Turnover time (days)	135 (32–566)	2317 (251–21549)	1.2 (0.087–2.4)	0.96
Half-life (days)	46 (0.78–2156)	211 (2.4–25720)	0.63 (−1.4–3.1)	0.7

Table S3. Decomposition parameters (Equations 2 and 3) estimated from the experimental data based on fresh and dry mass. Half-life ($t_{½}$) is not an independent parameter; it derives from k ($t_{½} = \ln 2 / k$). The exponential rates k, α and τ are given as % for readability and are not to be confused with linear rates. k, $t_{½}$, μ and τ are strictly positive and given as median (ln mean ± standard deviation) while α is given as mean ± standard deviation.

	Conventional model		**Macroalgal model**		
	k (% day^{-1})	$t_{½}$ (days)	α (% day^{-1})	μ (days)	τ (% day^{-1})
Laminaria digitata					
Fresh					
Live	0.041 (−3.3 ± 0.96)	1673 (7.6 ± 0.96)	0.38 ± 0.17	87 (4.5 ± 0.31)	2.4 (0.87 ± 0.36)
Dead	7.7 (2 ± 0.1)	9 (2.2 ± 0.1)	−8.6 ± 0.92	83 (4.4 ± 0.47)	11 (2.4 ± 0.11)
Ecklonia radiata					
Fresh					
Live	1.3 (0.28 ± 0.21)	52 (4 ± 0.21)	−1.2 ± 0.31	72 (4.2 ± 0.5)	3.9 (1.4 ± 0.23)
Dead	6.4 (1.9 ± 0.16)	11 (2.4 ± 0.16)	−7.5 ± 1.1	85 (4.4 ± 0.41)	10 (2.3 ± 0.14)
Dry					
Live	1.7 (0.56 ± 0.16)	40 (3.7 ± 0.16)	−1.9 ± 0.58	76 (4.2 ± 0.59)	4.4 (1.5 ± 0.22)
Dead	11 (2.4 ± 0.13)	6.5 (1.9 ± 0.13)	−8.8 ± 1.4	91 (4.5 ± 0.46)	11 (2.4 ± 0.15)
Amphibolis griffithii					
Fresh					
Live	0.042 (−3.3 ± 0.91)	1659 (7.5 ± 0.91)	0.18 ± 0.093	91 (4.6 ± 0.29)	2.5 (0.92 ± 0.33)
Dead	0.11 (−2.3 ± 0.7)	612 (6.5 ± 0.7)	0.075 ± 0.11	86 (4.5 ± 0.28)	2.7 (0.97 ± 0.32)
Dry					
Live	0.98 (−0.022 ± 0.084)	71 (4.3 ± 0.084)	−0.86 ± 0.094	104 (4.7 ± 0.37)	3.3 (1.2 ± 0.26)
Dead	1.5 (0.41 ± 0.092)	46 (3.8 ± 0.092)	−1.3 ± 0.11	111 (4.8 ± 0.39)	3.7 (1.3 ± 0.23)

Table S4. The effect of physiology on half-life (days) of kelp and seagrass detritus, estimated from the experimental data based on fresh mass (cf. Table 1). ratio = Live / Dead and *P* = *P*($\log_{10}$ ratio > 0) = *P*(Live > Dead). All estimates are median (90% probability interval).

	Live	**Dead**	**$\log_{10}$ ratio**	**P**
Kelp				
Laminaria digitata	1673 (514–11205)	9 (7.6–11)	2.3 (1.7–3.1)	1
Ecklonia radiata	52 (37–75)	11 (8.3–14)	0.68 (0.5–0.88)	1
Seagrass				
Amphibolis griffithii	1659 (547–10153)	612 (297–2545)	0.42 (−0.31–1.2)	0.84

Table S5. Decomposition parameters accounting for experimental variation (Equations 2 and 3) estimated in the kelp meta-analysis. Half-life ($t_{½}$) is not an independent parameter; it derives from *k* ($t_{½}$ = ln2 / *k*). The exponential rates *k*, *α* and *τ* are given as % for readability and are not to be confused with linear rates. *k*, $t_{½}$, *μ* and *τ* are strictly positive and given as median (ln mean ± standard deviation) while *α* is given as mean ± standard deviation. L = Live, D = Dead.

	Conventional model		**Macroalgal model**		
	k (% day^{-1})	$t_{½}$ (days)	*α* (% day^{-1})	*μ* (days)	*τ* (% day^{-1})
Unobserved kelps					
L	2 (0.7 ± 1.8)	35 (3.5 ± 1.8)	−2.6 ± 5.3	74 (4.3 ± 1.1)	7 (1.9 ± 0.55)
D	17 (2.8 ± 0.84)	4.2 (1.4 ± 0.84)	−9.8 ± 6.4	82 (4.4 ± 0.55)	12 (2.5 ± 0.39)
Alaria esculenta					
L	2.6 (0.94 ± 1.6)	27 (3.3 ± 1.6)	−5.3 ± 4.1	98 (4.5 ± 1.2)	8.7 (2.1 ± 0.45)
Costaria costata					
L	7.8 (2.1 ± 1.6)	8.8 (2.2 ± 1.6)	−7.9 ± 4.4	93 (4.5 ± 1.1)	11 (2.4 ± 0.4)
Ecklonia radiata					
L	3.2 (1.2 ± 1.4)	21 (3.1 ± 1.4)	−5.9 ± 3.5	112 (4.7 ± 1)	9.6 (2.2 ± 0.39)
D	17 (2.8 ± 0.7)	4.1 (1.4 ± 0.7)	−8.8 ± 3.8	92 (4.5 ± 0.5)	12 (2.5 ± 0.27)
Himantothallus grandifolius					
L	0.49 (−0.74 ± 1.6)	142 (5 ± 1.6)	−0.006 ± 2	96 (4.6 ± 1)	4.8 (1.5 ± 0.53)
Laminaria digitata					
L	0.5 (−0.69 ± 1.4)	138 (4.9 ± 1.4)	−0.061 ± 1.9	75 (4.3 ± 0.94)	5.3 (1.6 ± 0.43)
D	13 (2.6 ± 0.72)	5.3 (1.6 ± 0.72)	−8.1 ± 3.7	88 (4.5 ± 0.52)	11 (2.4 ± 0.28)
Laminaria hyperborea					
L	0.4 (−0.92 ± 1.4)	174 (5.2 ± 1.4)	−0.39 ± 1.5	181 (5.2 ± 1)	4.5 (1.4 ± 0.47)
Laminaria ochroleuca					
L	0.72 (−0.33 ± 1.4)	96 (4.6 ± 1.4)	0.29 ± 2.2	42 (3.8 ± 0.96)	6.2 (1.8 ± 0.37)
Laminaria solidungula					
L	2.2 (0.77 ± 1.6)	32 (3.5 ± 1.6)	−1.9 ± 3.2	74 (4.3 ± 1.1)	6.4 (1.8 ± 0.48)
Macrocystis pyrifera					
L	0.68 (−0.39 ± 1.4)	103 (4.6 ± 1.4)	0.68 ± 3.3	59 (4.1 ± 0.93)	9.4 (2.2 ± 0.39)
Neoagarum fimbriatum					
L	0.85 (−0.18 ± 1.6)	82 (4.4 ± 1.6)	−0.28 ± 2.5	80 (4.4 ± 1.1)	5.4 (1.6 ± 0.51)
Nereocystis luetkeana					
L	2.8 (1 ± 1.4)	25 (3.2 ± 1.4)	−2.6 ± 2.9	39 (3.7 ± 1.3)	6.9 (1.9 ± 0.41)
D	22 (3.1 ± 0.73)	3.2 (1.2 ± 0.73)	−13 ± 6.2	82 (4.4 ± 0.55)	15 (2.7 ± 0.35)
Saccharina latissima					
L	0.71 (−0.34 ± 1.4)	97 (4.6 ± 1.4)	−0.57 ± 1.7	88 (4.5 ± 0.93)	5.1 (1.6 ± 0.44)
D	20 (3 ± 0.75)	3.5 (1.3 ± 0.75)	−11 ± 5.3	81 (4.4 ± 0.55)	14 (2.6 ± 0.34)
Saccorhiza polyschides					
L	2.9 (1.1 ± 1.5)	24 (3.2 ± 1.5)	−4.8 ± 3.4	101 (4.5 ± 1.3)	8.2 (2.1 ± 0.42)
Undaria pinnatifida					
L	3 (1.1 ± 1.5)	23 (3.1 ± 1.5)	−4.3 ± 3.9	51 (3.9 ± 1.1)	8.8 (2.2 ± 0.4)

Table S6. The effect of physiology on interspecific and experimental variation in kelp decomposition, expressed as standard deviation hyper-parameters (σ, mean ± standard deviation). Δ = Live − Dead, ratio = Live / Dead and $P = P(\Delta > 0) = P(\log_{10}$ ratio $> 0) = P$(Live > Dead).

	Live	Dead	Δ	$\log_{10}$ ratio	P
Conventional model					
$\sigma_{\ln k}$					
Interspecific	1.1 ± 0.27	0.4 ± 0.28	0.7 ± 0.39	0.58 ± 0.46	0.96
Experimental	1.4 ± 0.11	0.59 ± 0.21	0.77 ± 0.24	0.39 ± 0.16	1
Macroalgal model					
σ_{a}					
Interspecific	0.039 ± 0.012	0.036 ± 0.026	0.0032 ± 0.029	0.14 ± 0.37	0.62
Experimental	0.023 ± 0.0046	0.024 ± 0.022	−0.0011 ± 0.022	0.14 ± 0.41	0.6
$\sigma_{\ln \mu}$					
Interspecific	0.58 ± 0.24	0.25 ± 0.19	0.32 ± 0.31	0.47 ± 0.56	0.85
Experimental	0.84 ± 0.19	0.23 ± 0.18	0.61 ± 0.26	0.72 ± 0.49	0.98
$\sigma_{\ln \tau}$					
Interspecific	0.38 ± 0.11	0.22 ± 0.15	0.15 ± 0.19	0.36 ± 0.47	0.8
Experimental	0.31 ± 0.078	0.15 ± 0.13	0.16 ± 0.15	0.54 ± 0.56	0.86