

Safety factors and nutrient uptake by seaweeds

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Appendix 1. Summary of kinetic constants (K_m and V_{max}) for ammonium uptake, calculated rates of uptake at 1.5 μM ammonium ($V_{1.5}$), calculated safety factors assuming a maximum ambient ammonium concentration of 1.5 μM [SF(1.5)] and $V_{max}:K_m$ for ammonium uptake by seaweeds, together with location of each species. inf.: infinity

Species	K_m (μM)	V_{max}	$V_{1.5}$	SF(1.5)	$V_{max}:K_m$	Location	Source
Green							
<i>Acrosiphonia centralis</i>	19.07	115.21	8.40	13.71	6.04	Baltic	Wallentinus (1984)
<i>Caulerpa cupressoides</i>	48.00	8.70	0.26	33.00	0.18	Virgin Islands	Williams & Fisher (1985)
<i>Chaetomorpha linum</i>	inf.			inf.		W. Australia	Lavery & McComb (1991)
<i>Chaetomorpha linum</i>	13.00	132.00	13.66	9.67	10.15	Denmark	Pedersen & Borum (1997)
<i>Cladophora</i> sp.	20.70	130.00	8.78	14.80	6.28	W. Australia	Gordon et al. (1981)
<i>Cladophora glomerata</i>	32.68	327.83	22.35	14.67	16.36	Baltic	Wallentinus (1984)
<i>Cladophora serica</i>	13.00	122.00	12.62	9.67	9.38	Denmark	Pedersen & Borum (1997)
<i>Codium decortcatum</i>	12.00	13.43	1.49	9.00	1.12	N. Carolina	Rosenberg & Paerl (1981)
<i>Codium fragile</i> subsp. <i>tomentosoides</i>	1.61	23.66	11.49	2.06	15.02	Rhode Island	Hanisak & Harlin (1978)
<i>Codium fragile</i>	25.00	81.00	4.58	17.67	3.24	Denmark	Pedersen & Borum (1997)
<i>Enteromorpha</i> sp.	14.35	9.30	0.74	12.49	0.58	Massachusetts	Fujita (1985)
<i>Enteromorpha ahlneriana</i>	16.64	409.40	33.85	12.09	24.60	Baltic	Wallentinus (1984)
<i>Enteromorpha compressa</i>	24.00	36.79	2.16	17.00	1.53	Baltic	Kautsky (1982)
<i>Enteromorpha intestinalis</i>	inf.		6.57	inf.		New Zealand	Taylor et al. (1998)
<i>Enteromorpha prolifera</i>	8.53	138.40	19.47	7.11	15.92	Oregon	O'Brien & Wheeler (1987)
<i>Ulva</i> sp.	14.40	146.00	13.77	10.60	10.14	S. Australia	Campbell (1999)
<i>Ulva</i> sp.	inf.			inf.		New Zealand	Taylor et al. (1998)
<i>Ulva curvata</i>	13.80			10.20		Connecticut	Duke et al. (1989)
<i>Ulva lactuca</i>	20.50	225.50	15.36	14.68	10.99	Denmark	Pedersen & Borum (1997)
<i>Ulva lactuca</i>	27.70	2.35	0.15	15.46	0.11	Massachusetts	Fujita (1985)
<i>Ulva lactuca</i>	5.20	50.00	11.19	4.47	9.62	Israel	Cohen & Neori (1991)
<i>Ulva rigida</i>	inf.			inf.		W. Australia	Lavery & McComb (1991)
Red							
<i>Agardhiella subulata</i>	3.90	15.86	4.41	3.60	4.07	Massachusetts	D'Elia & DeBoer (1978)
<i>Apophlaea lyallii</i>	42.08	11.56	0.40	29.05	0.27	New Zealand	Phillips (2001)
<i>Ceramium rubrum</i>	29.00	271.00	13.33	20.33	9.34	Denmark	Pedersen & Borum (1997)
<i>Ceramium rubrum</i>	3.60	25.20	7.41	3.40	7.00	Massachusetts	DeBoer & Whoriskey (1983)
<i>Ceramium tenuicorne</i>	16.93	143.43	15.66	9.16	12.59	Baltic	Wallentinus (1984)
<i>Chondrus crispus</i>	35.50	61.71	2.50	24.67	1.74	France	Amat & Braud (1990)
<i>Furcellaria lumbricalis</i>	6.53	4.88	0.93	5.26	0.78	Baltic	Wallentinus (1984)
<i>Gracilaria foliifera</i>	1.60	23.82	11.53	2.07	14.89	Massachusetts	D'Elia & DeBoer (1978)
<i>Gracilaria gracilis</i>	76.45	216.70	4.17	51.97	2.83	South Africa	Smit (2002)
<i>Gracilaria pacifica</i>	10.00	30.00	3.91	7.67	3.00	British Columbia	Thomas et al. (1987)
<i>Gracilaria tikvahiae</i>	24.83	2.67	0.16	16.90	0.11	Massachusetts	Fujita (1985)
<i>Gracilariopsis lemaneiformis</i>	40.00	68.00	2.46	27.67	1.70	N. Carolina	Vergara et al. (1995)
<i>Hypnea musciformis</i>	16.64	115.00	9.51	12.09	6.91	Virgin Islands	Haines & Wheeler (1978)
<i>Phyllophora truncata</i>	7.93	9.71	1.54	6.29	1.22	Baltic	Wallentinus (1984)
<i>Polysiphonia decipiens</i>	2.60	57.40	21.00	2.73	22.08	Melbourne	Campbell (1999)
<i>Porphyra</i> sp.	inf.			inf.		New Zealand	Taylor et al. (1998)
<i>Pterocladia capillacea</i>	45.00	65.00	2.10	31.00	1.44	New Zealand	Taylor et al. (1998)
<i>Rhodomela confervoides</i>	23.86	38.07	2.25	16.91	1.60	Baltic	Wallentinus (1984)
<i>Stictosiphonia arbuscula</i>	inf.		1.30	inf.		New Zealand	Phillips (2001)

Appendix 1 (continued)

Species	K_m (μM)	V_{\max}	$V_{1.5}$	SF(1.5)	$V_{\max}:K_m$	Location	Source
Brown							
<i>Chorda filum</i>	3.44	23.64	7.18	3.29	6.87	Baltic	Wallentinus (1984)
<i>Chordaria flagelliformis</i>	4.35	61.95	13.63	4.54	18.48	Nova Scotia	Probyn & Chapman (1982), Rosenberg et al. (1984)
<i>Dictyosiphon foeniculaceus</i>	3.60	54.43	16.01	3.40	15.12	Baltic	Wallentinus (1984)
<i>Ecklonia radiata</i>	inf.			inf.		W. Australia	Paling (1991)
<i>Ectocarpus siliculosus</i>	3.46	39.79	12.03	3.31	11.50	Baltic	Wallentinus (1984)
<i>Elachista fucicola</i>	20.93	133.86	8.95	14.95	6.40	Baltic	Wallentinus (1984)
<i>Eudesme virescens</i>	4.78	38.14	9.11	4.19	7.98	Baltic	Wallentinus (1984)
<i>Fucus distichus</i>	4.00	60.00	16.36	3.67	15.00	British Columbia	Thomas et al. (1985)
<i>Fucus distichus</i>	3.61	13.90	4.08	3.41	3.85	Nova Scotia	Rosenberg et al. (1984)
<i>Fucus spiralis</i>	7.47	23.51	3.89	6.05	3.13	Massachusetts	Topinka (1978)
<i>Fucus vesiculosus</i>	14.93	24.62	2.05	12.01	1.60	Denmark	Wallentinus (1984), Pedersen & Borum (1997)
<i>Himantothallus grandifolius</i>	20.40			14.60		Antarctic	Korb & Gerard (2000)
<i>Hincksia sordida</i>	39.70	802.00	29.20	27.47	20.20	Melbourne	Campbell (1999)
<i>Laminaria abyssalis</i>	4.60	2.00	0.49	4.07	0.43	Brazil	Braga & Yoneshigue- Valentin (1996)
<i>Laminaria groenlandica</i>	inf.		0.27	inf.		British Columbia	Harrison et al. (1986)
<i>Laminaria solidungula</i>	12.70			9.47		Canadian Arctic	Korb & Gerard (2000)
<i>Macrocystis pyrifera</i>	4.85	20.00	4.41	4.54	3.77	S. California	Haines & Wheeler (1978), Wheeler (1979)
<i>Pilayella littoralis</i>	3.57	35.86	11.10	3.23	11.23	Baltic	Wallentinus (1984)
<i>Sargassum bacularia</i>	4.81	13.02	3.10	4.21	2.71	Great Barrier Reef	Schaffelke & Klumpp (1998)
<i>Scytosiphon lomentaria</i>	3.90	69.07	19.19	3.60	17.71	Baltic	Wallentinus (1984)
<i>Scytothamnus australis</i>	42.80	76.24	2.58	29.53	1.78	New Zealand	Phillips (2001)
<i>Undaria pinnatifida</i>	19.75	119.50	16.09	7.43	14.11	S. Australia	Campbell (1999)
<i>Xiphophora chondrophylla</i>	inf.		0.12	inf.		New Zealand	Taylor et al. (1998)
<i>Xiphophora gladiata</i>	36.69	8.72	0.34	25.46	0.24	New Zealand	Phillips (2001)

Appendix 2. Summary of kinetic constants (K_m and V_{\max}) for nitrate uptake, calculated rates of uptake at 5 μM nitrate (V_5), calculated safety factors assuming a maximum ambient nitrate concentration of 5 μM [SF(5)] and $V_{\max}:K_m$ for nitrate uptake by seaweeds, together with location of each species

Species	K_m (μM)	V_{\max}	V_5	SF(5)	$V_{\max}:K_m$	Location	Source
Green							
<i>Chaetomorpha linum</i>	inf.			inf.		W. Australia	Lavery & McComb (1991)
<i>Chaetomorpha linum</i>	3.00	30.00	18.75	1.60	10.00	Denmark	Pedersen & Borum (1997)
<i>Cladophora glomerata</i>	5.27	115.72	56.54	2.05	40.18	Baltic	Wallentinus (1984)
<i>Cladophora serica</i>	5.00	17.00	8.50	2.00	3.40	Denmark	Pedersen & Borum (1997)
<i>Codium fragile</i> subsp. <i>tomentosoides</i>	4.28	6.83	3.55	1.92	2.00	Rhode Island	Hanisak & Harlin (1978)
<i>Codium fragile</i>	5.00	9.00	4.50	2.00	1.80	Denmark	Pedersen & Borum (1997)
<i>Enteromorpha</i> sp.	16.60	129.40	29.95	4.32	7.80	Nova Scotia	Harlin (1978)
<i>Enteromorpha ahlnneriana</i>	1.73	27.80	20.65	1.35	16.07	Baltic	Wallentinus (1984)
<i>Enteromorpha intestinalis</i>	17.22	64.65	14.55	4.44	3.75	New Zealand	Rees et al. (unpubl.)
<i>Enteromorpha prolifera</i>	7.81	122.20	48.87	2.50	22.67	Oregon	O'Brien & Wheeler (1987)
<i>Ulva lactuca</i>	5.00	20.00	10.00	2.00	4.00	Denmark	Pedersen & Borum (1997)
<i>Ulva rigida</i>	25.68	71.89	11.72	6.14	2.80	W. Australia	Lavery & McComb (1991)
Red							
<i>Agardhiella subulata</i>	2.40	11.67	7.89	1.48	4.86	Massachusetts	D'Elia & DeBoer (1978)
<i>Apophlaea lyallii</i>	9.26	2.19	0.77	2.85	0.24	New Zealand	Phillips (2001)
<i>Ceramium rubrum</i>	7.57	5.99	2.38	2.51	0.79	Baltic	Wallentinus (1984)
<i>Ceramium tenuicorne</i>	3.91	18.67	10.69	1.75	5.56	Baltic	Wallentinus (1984)
<i>Furcellaria lumbricalis</i>	15.29	3.19	0.63	5.02	0.19	Baltic	Wallentinus (1984)
<i>Gracilaria foliifera</i>	2.48	9.71	6.49	1.50	3.92	Massachusetts	D'Elia & DeBoer (1978)
<i>Gracilaria gracilis</i>	5.80	26.28	12.16	2.16	4.53	South Africa	Smit (2002)
<i>Gracilaria pacifica</i>	6.00	4.00	1.82	2.20	0.67	Vancouver	Thomas et al. (1987)
<i>Hypnea musciformis</i>	4.90	28.50	14.39	1.98	5.82	Virgin Islands	Haines & Wheeler (1978)
<i>Phyllophora truncata</i>	9.21	1.69	0.60	2.84	0.18	Baltic	Wallentinus (1984)
<i>Pterocladia capillacea</i>	14.19	14.20	3.70	3.84	1.00	New Zealand	Rees et al. (unpubl.)
<i>Rhodomela confervoides</i>	4.46	12.14	6.42	1.89	2.72	Baltic	Wallentinus (1984)
<i>Stictosiphonia arbuscula</i>	18.68	16.21	4.21	3.85	1.43	New Zealand	Phillips (2001)

Appendix 2 (continued)

Species	K_m (μM)	V_{\max}	V_5	SF(5)	$V_{\max}:K_m$	Location	Source
Brown							
<i>Chorda filum</i>	0.60	6.63	5.92	1.12	11.05	Baltic	Wallentinus (1984)
<i>Chordaria flagelliformis</i>	5.10	5.93	2.94	2.02	1.16	Nova Scotia	Probyn (1984)
<i>Dictyosiphon foeniculaceus</i>	4.34	63.79	34.15	1.87	14.70	Baltic	Wallentinus (1984)
<i>Elachista fucicola</i>	1.94	17.57	12.66	1.39	9.06	Baltic	Wallentinus (1984)
<i>Eudesme virescens</i>	2.23	10.29	7.11	1.45	4.61	Baltic	Wallentinus (1984)
<i>Fucus distichus</i>	3.50	20.00	11.76	1.70	5.71	British Columbia	Thomas et al. (1985)
<i>Fucus spiralis</i>	6.70	17.56	7.47	2.35	2.62	Massachusetts	Topinka (1978)
<i>Fucus vesiculosus</i>	24.69	9.29	2.08	4.47	0.65	Denmark	Wallentinus (1984), Pedersen & Borum (1997)
<i>Himantothallus grandifolius</i>	12.80			3.56		Antarctic	Korb & Gerard (2000)
<i>Kjellmaniella crassifolia</i>	4.48			1.90		Japan	Ozaki et al. (2001)
<i>Laminaria abyssalis</i>	14.00	5.00	1.32	3.80	0.36	Brazil	Braga & Yoneshigue- Valentin (1996)
<i>Laminaria japonica</i>	2.56			1.51		Japan	Ozaki et al. (2001)
<i>Laminaria longicruris</i>	4.67	9.66	4.97	1.94	2.11	Nova Scotia	Harlin & Craigie (1978), Espinoza & Chapman (1983)
<i>Laminaria groenlandica</i>	inf.		0.85	inf.		British Columbia	Harrison et al. (1986)
<i>Laminaria solidungula</i>	35.00			8.00		Canadian Arctic	Korb & Gerard (2000)
<i>Macrocystis pyrifera</i>	6.82	13.79	5.14	2.69	1.64	S. California	Haines & Wheeler (1978)
<i>Pilayella littoralis</i>	8.64	51.32	18.82	2.73	7.05	Baltic	Wallentinus (1984)
<i>Scytosiphon lomentaria</i>	6.92	59.36	24.90	2.38	8.58	Baltic	Wallentinus (1984)
<i>Scytothamnus australis</i>	17.74	10.26	2.26	4.55	0.58	New Zealand	Phillips (2001)
<i>Xiphophora chondrophylla</i>	9.99	2.92	0.97	3.00	0.29	New Zealand	Rees et al. (■ submitted)
<i>Xiphophora gladiata</i>	20.97	5.19	1.00	5.19	0.25	New Zealand	Phillips (2001)

Appendix 3. Summary of kinetic constants (K_m and V_{\max}) for phosphate uptake, calculated rates of uptake at 1 μM phosphate (V_1), calculated safety factors assuming a maximum ambient phosphate concentration of 1 μM [SF(1)] and $V_{\max}:K_m$ for phosphate uptake by seaweeds, together with location of each species

Species	K_m (μM)	V_{\max}	V_1	SF(1)	$V_{\max}:K_m$	Location	Source
Green							
<i>Acrosiphonia centralis</i>	1.43	3.32	1.37	2.43	2.33	Baltic	Wallentinus (1984)
<i>Chaetomorpha linum</i>	10.35	21.52	1.90	11.35	2.08	W. Australia	Lavery & McComb (1991)
<i>Cladophora sp.</i>	0.48	3.61	2.43	1.48	7.47	W. Australia	Gordon et al. (1981)
<i>Cladophora glomerata</i>	0.33	3.06	2.30	1.33	9.29	Baltic	Wallentinus (1984)
<i>Enteromorpha ahneriana</i>	1.51	4.59	1.48	3.09	4.65	Baltic	Wallentinus (1984)
<i>Enteromorpha compressa</i>	1.00	1.90	0.95	2.00	1.90	Baltic	Kautsky (1982)
<i>Monostroma grevillei</i>	2.71	2.79	0.75	3.71	1.03	Baltic	Wallentinus (1984)
<i>Ulva rigida</i>	3.65	8.77	1.89	4.65	2.40	W. Australia	Lavery & McComb (1991)
Red							
<i>Agardhiella subulata</i>	0.40	0.47	0.34	1.40	1.18	Massachusetts	DeBoer (1981)
<i>Ceramium tenuicorne</i>	1.00	0.78	0.51	1.55	1.56	Baltic	Wallentinus (1984)
<i>Furcellaria lumbricalis</i>	2.97	0.13	0.03	4.00	0.64	Baltic	Wallentinus (1984)
<i>Phyllophora truncata</i>	0.37	0.12	0.08	1.37	0.32	Baltic	Wallentinus (1984)
<i>Rhodomela confervoides</i>	1.03	0.64	0.31	2.03	0.62	Baltic	Wallentinus (1984)
Brown							
<i>Ascophyllum nodosum</i>	1.22	0.07	0.03	2.20	0.07	Ireland	Hurd & Dring (1990)
<i>Chorda filum</i>	0.62	1.38	0.85	1.62	2.22	Baltic	Wallentinus (1984)
<i>Dictyosiphon foeniculaceus</i>	2.12	11.13	3.56	3.12	5.24	Baltic	Wallentinus (1984)
<i>Ectocarpus siliculosus</i>	1.22	0.75	0.34	2.22	0.61	Baltic	Wallentinus (1984)
<i>Eudesme virescens</i>	0.67	3.55	2.12	1.67	5.26	Baltic	Wallentinus (1984)
<i>Fucus serratus</i>	6.95	0.39	0.05	7.17	0.07	Ireland	Hurd & Dring (1990), Hurd et al. (1993)
<i>Fucus spiralis</i>	5.34	0.75	0.14	5.39	0.18	Ireland	Hurd & Dring (1990), Hurd et al. (1993)
<i>Fucus vesiculosus</i>	7.58	0.38	0.06	6.58	0.07	Ireland	Hurd & Dring (1990)
<i>Fucus vesiculosus</i>	11.17	1.05	0.15	6.95	0.21	Baltic	Wallentinus (1984)
<i>Kjellmaniella crassifolia</i>	0.31			1.31		Japan	Ozaki et al. (2001)
<i>Laminaria abyssalis</i>	2.21	0.83	0.26	3.21	0.38	Brazil	Braga & Yoneshigue- Valentin (1996)
<i>Laminaria japonica</i>	0.14			1.14		Japan	Ozaki et al. (2001)
<i>Macrocystis pyrifera</i>	3.51			4.51		California	Manley (1985)
<i>Pelvetia canaliculata</i>	5.96	0.36	0.05	6.94	0.06	Ireland	Hurd & Dring (1990)
<i>Pilayella littoralis</i>	3.07	4.89	1.22	3.99	1.71	Baltic	Wallentinus (1984)
<i>Sargassum baccularia</i>	0.26	0.43	0.34	1.26	1.65	Great Barrier Reef	Schaffelke & Klumpp (1998)
<i>Scytosiphon lomentaria</i>	0.77	6.58	3.71	1.77	8.50	Baltic	Wallentinus (1984)

Appendix 4. Summary of surface area:volume (SA:V) ratios for seaweeds

Species	SA:V	Source
Green		
<i>Codium fragile</i>	8.9	Rosenberg & Ramus (1984)
<i>Chaetomorpha linum</i>	237	Nielsen & Sand-Jensen (1990)
<i>Enteromorpha intestinalis</i>	315	Taylor et al. (1998)
<i>Ulva lactuca</i>	400	Odum et al. (1958)
<i>Enteromorpha ahlneriana</i>	529	Hein et al. (1995)
<i>Enteromorpha prolifera</i>	529	Hein et al. (1995)
<i>Cladophora glomerata</i>	569	Hein et al. (1995)
<i>Cladophora serica</i>	645	Nielsen & Sand-Jensen (1990)
Red		
<i>Phyllophora truncata</i>	8.9	Hein et al. (1995)
<i>Apophlaea lyallii</i>	14.9	Phillips (2001)
<i>Furcellaria lumbricalis</i>	20.5	Hein et al. (1995)
<i>Gracilaria foliifera</i>	30	Hein et al. (1995)
<i>Gracilaria pacifica</i>	30	Hein et al. (1995)
<i>Stictosiphonia arbuscula</i>	41.59	Phillips (2001)
<i>Pterocladia capillacea</i>	80	Taylor et al. (1998)
<i>Ceramium tenuicorne</i>	191	Hein et al. (1995)
<i>Rhodomela confervoides</i>	207.9	Hein et al. (1995)
Brown		
<i>Xiphophora gladiata</i>	15.6	Phillips (2001)
<i>Chorda filum</i>	17	Odum et al. (1958)
<i>Scytothamnus australis</i>	19.2	Phillips (2001)
<i>Xiphophora chondrophylla</i>	21	Taylor et al. (1998)
<i>Fucus distichus</i>	30	Hein et al. (1995)
<i>Fucus vesiculosus</i>	33.7	Odum et al. (1958), Nielsen & Sand-Jensen (1990)
<i>Fucus spiralis</i>	34	Nielsen & Sand-Jensen (1990)
<i>Chordaria flagelliformis</i>	100	Hein et al. (1995)
<i>Dictyosiphon foeniculaceus</i>	408.5	Hein et al. (1995)
<i>Elachista fucicola</i>	1042.3	Hein et al. (1995)
<i>Pilayella littoralis</i>	1694	Hein et al. (1995)

Appendix 5. Summary of K_m for ammonium uptake and calculated safety factors assuming a maximum ambient ammonium concentration of 1.5 μM [SF(1.5)] for coastal clones of phytoplankton

Species	K_m (μM)	SF(1.5)	Source
<i>Asterionella japonica</i>	1.05	1.70	Eppley et al. (1969)
<i>Chaetoceros debilis</i>	0.50	1.33	Conway & Harrison (1977)
<i>Coscinodiscus lineatus</i>	2.00	2.33	Eppley et al. (1969)
<i>Coscinodiscus wailesii</i>	4.90	4.27	Eppley et al. (1969)
<i>Ditylum brightwellii</i>	1.10	1.73	Eppley et al. (1969)
<i>Dunaliella tertiolecta</i>	0.10	1.07	Eppley et al. (1969)
<i>Gonyaulax polyedra</i>	5.50	4.67	Eppley et al. (1969)
<i>Gymnodinium splendens</i>	1.10	1.73	Eppley et al. (1969)
<i>Leptocylindricus danicus</i>	1.60	2.07	Eppley et al. (1969)
<i>Monochrysis lutheri</i>	0.50	1.33	Eppley et al. (1969)
<i>Phaeodactylum tricorutum</i>	1.47	1.98	Grant (2002)
<i>Rhizosolenia robusta</i>	7.45	5.97	Eppley et al. (1969)
<i>Rhizosolenia stolterfothii</i>	0.50	1.33	Eppley et al. (1969)
<i>Skeletonema costatum</i>	1.23	1.82	Conway et al. (1976), Conway & Harrison (1977)
<i>Thalassiosira gravida</i>	0.50	1.33	Conway & Harrison (1977)

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