CINÉTICA E REGULAÇÃO ENZIMÁTICA | ENZYMOLOGY IN EVOLUTION STUDIES

BERNARDO DUARTE

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Global seagrass distribution and diversity: A bioregional model

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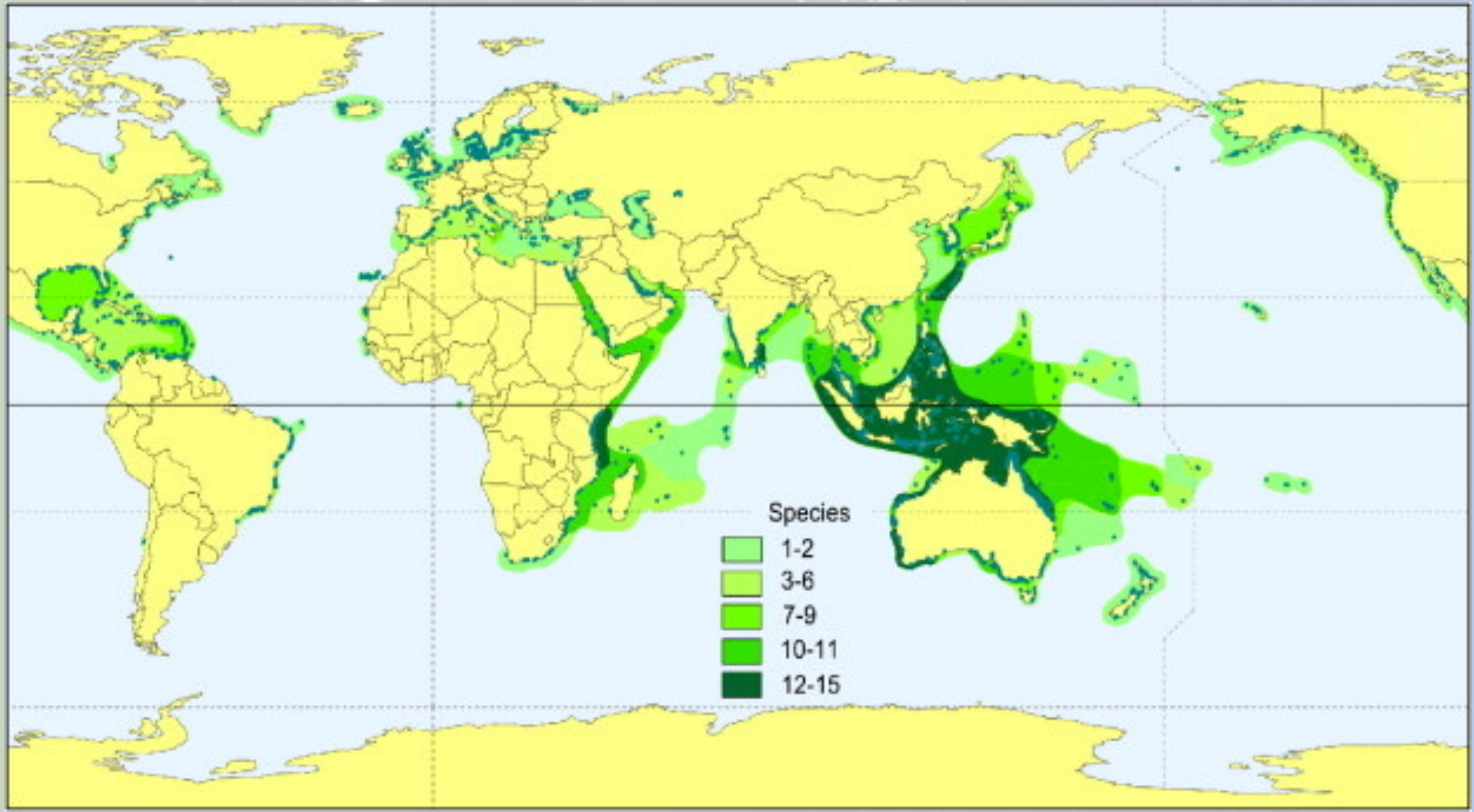

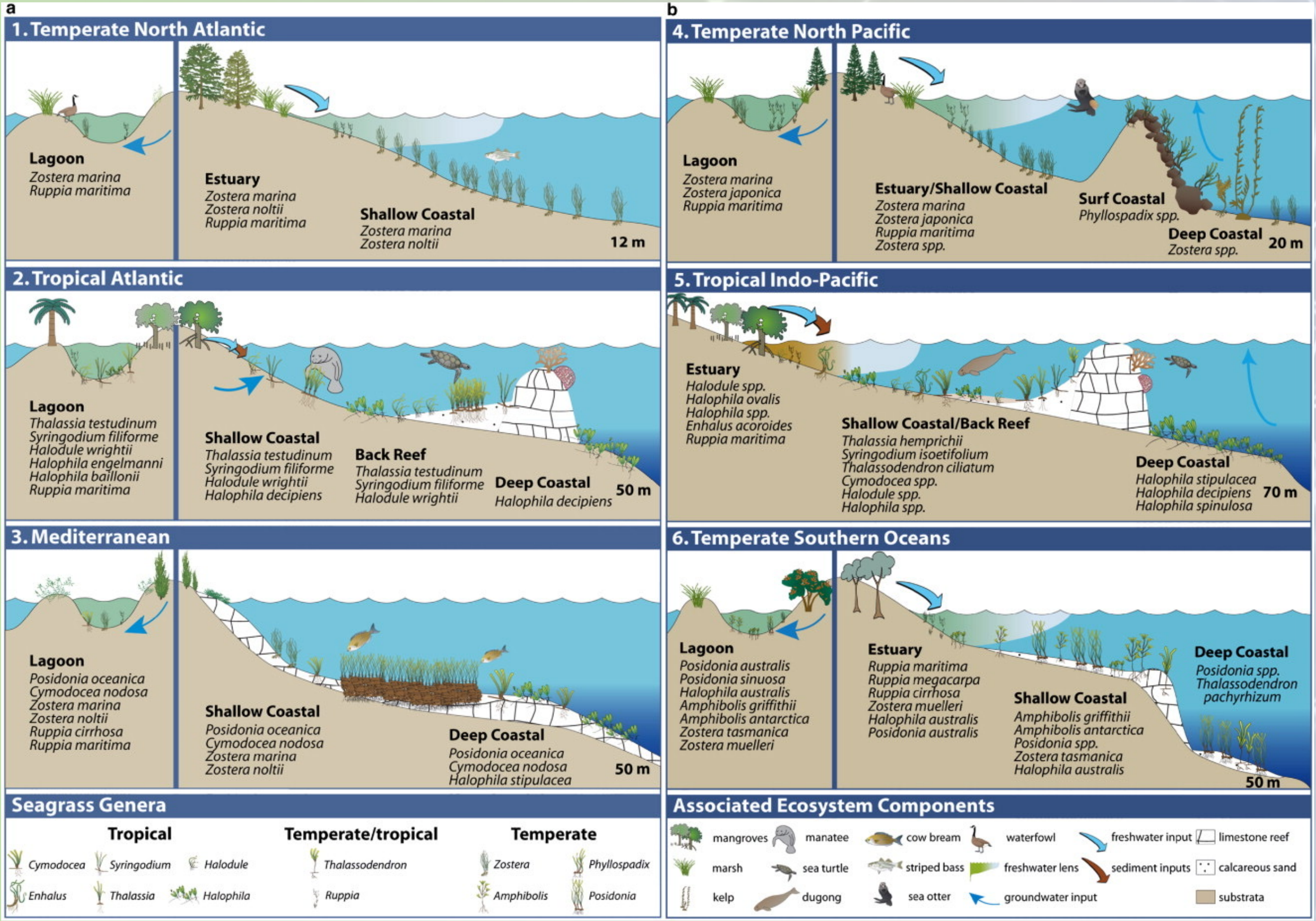

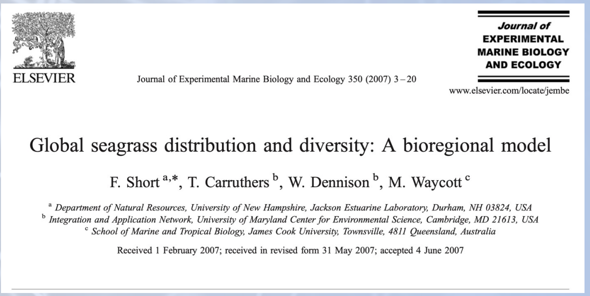
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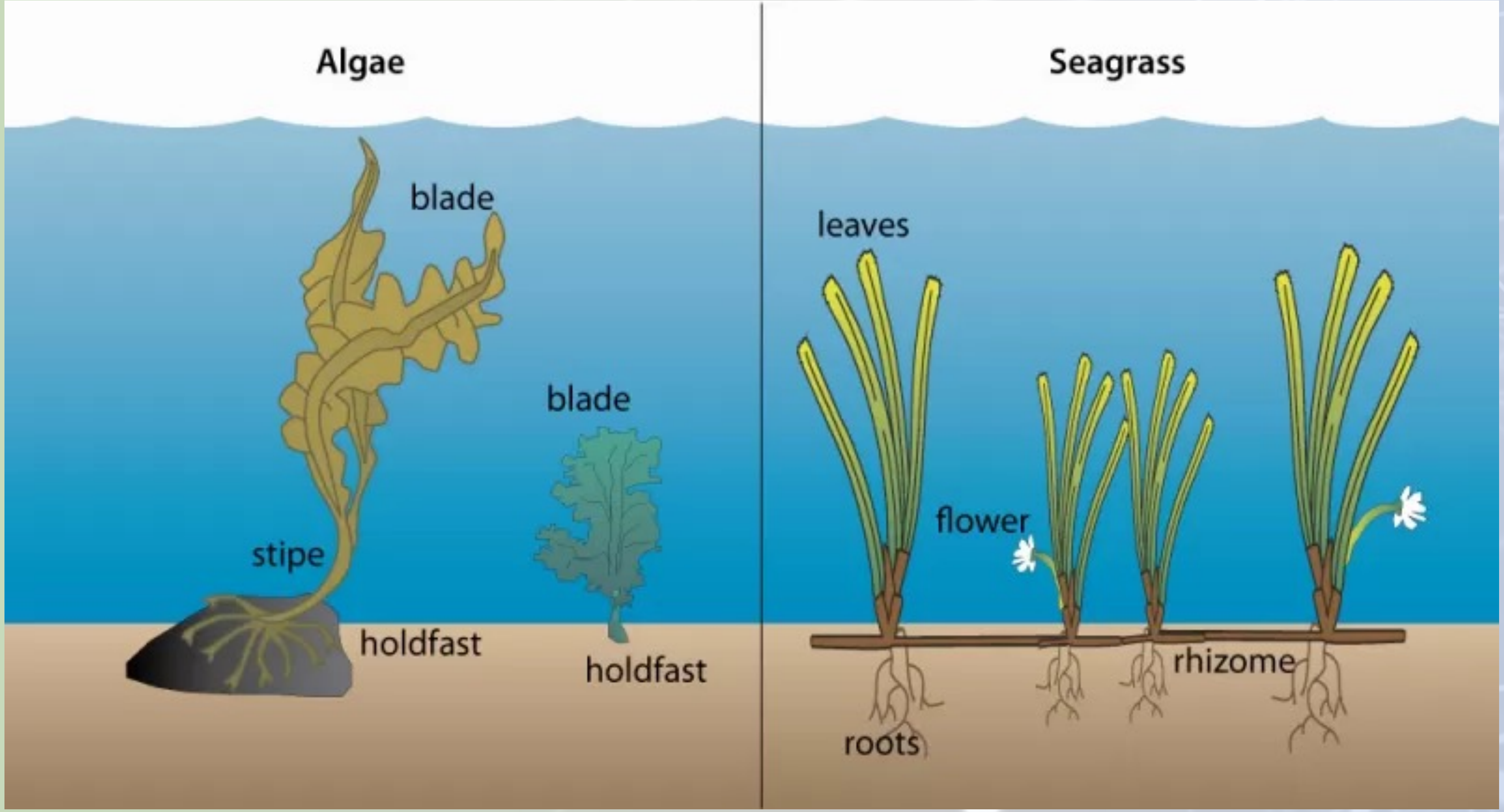
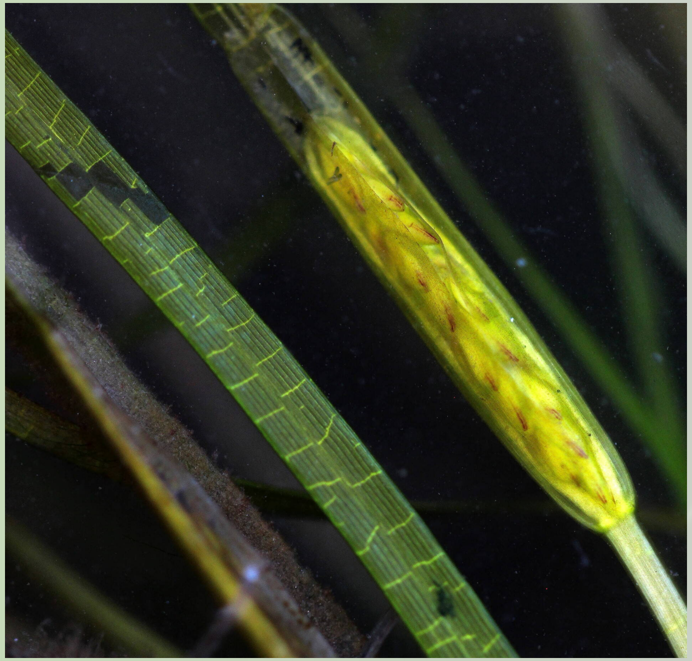
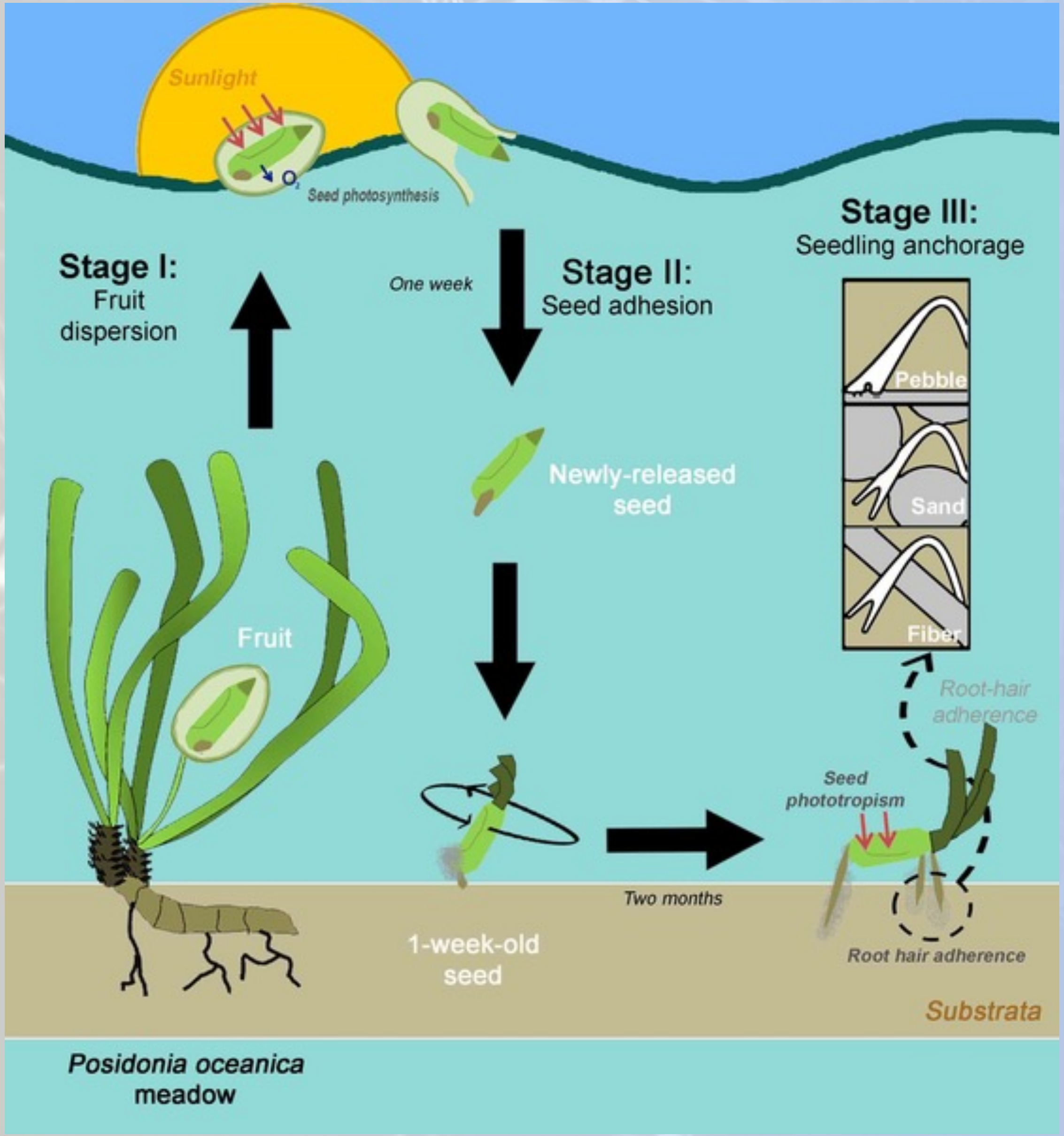
Seagrasses are NOT Algae



SEAGRASSES ARE ANGIOSPERMS

- **VASCULAR PLANTS**
- **PRODUCE FLOWERS, FRUITS AND SEEDS**





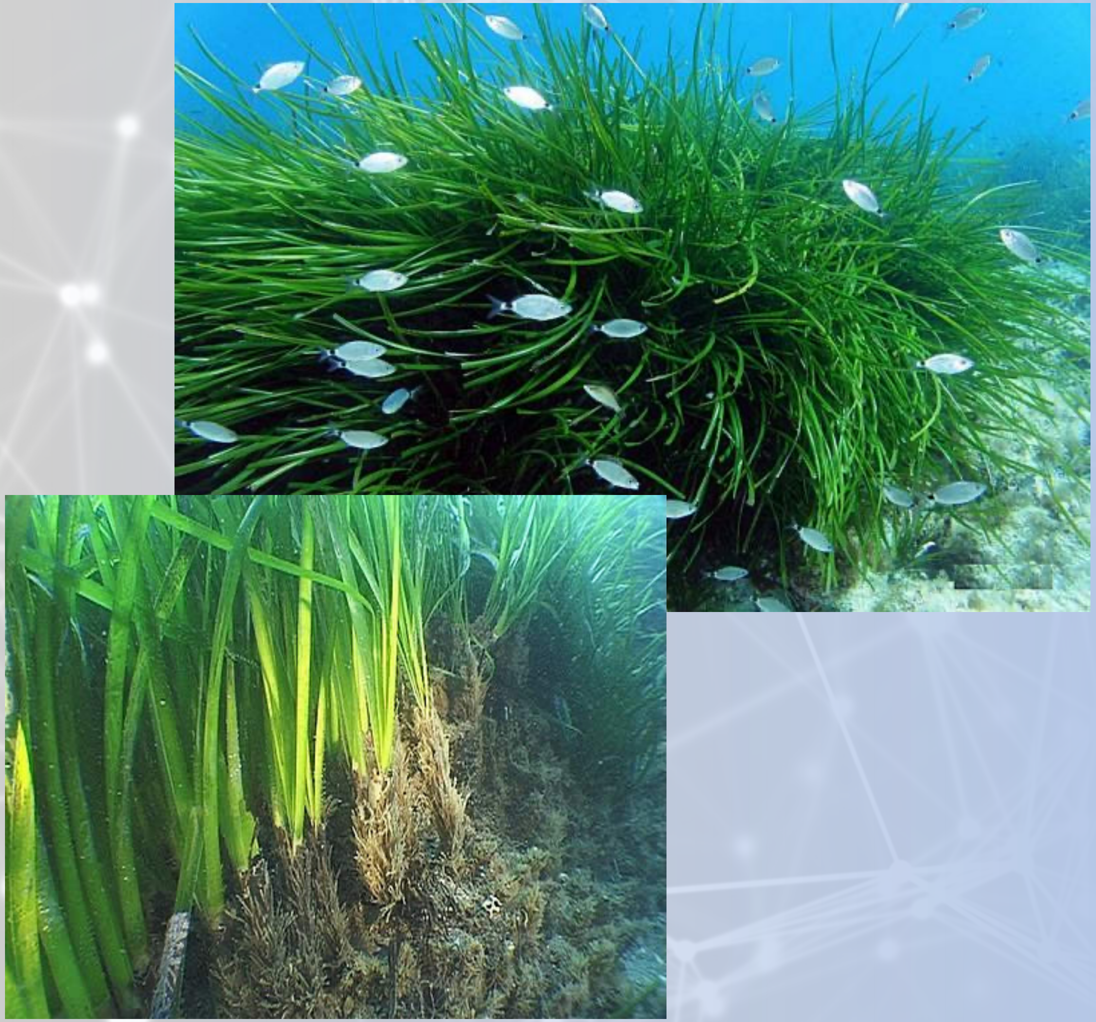
Seagrass species

Zostera noltii

Zostera marina

Seagrass species

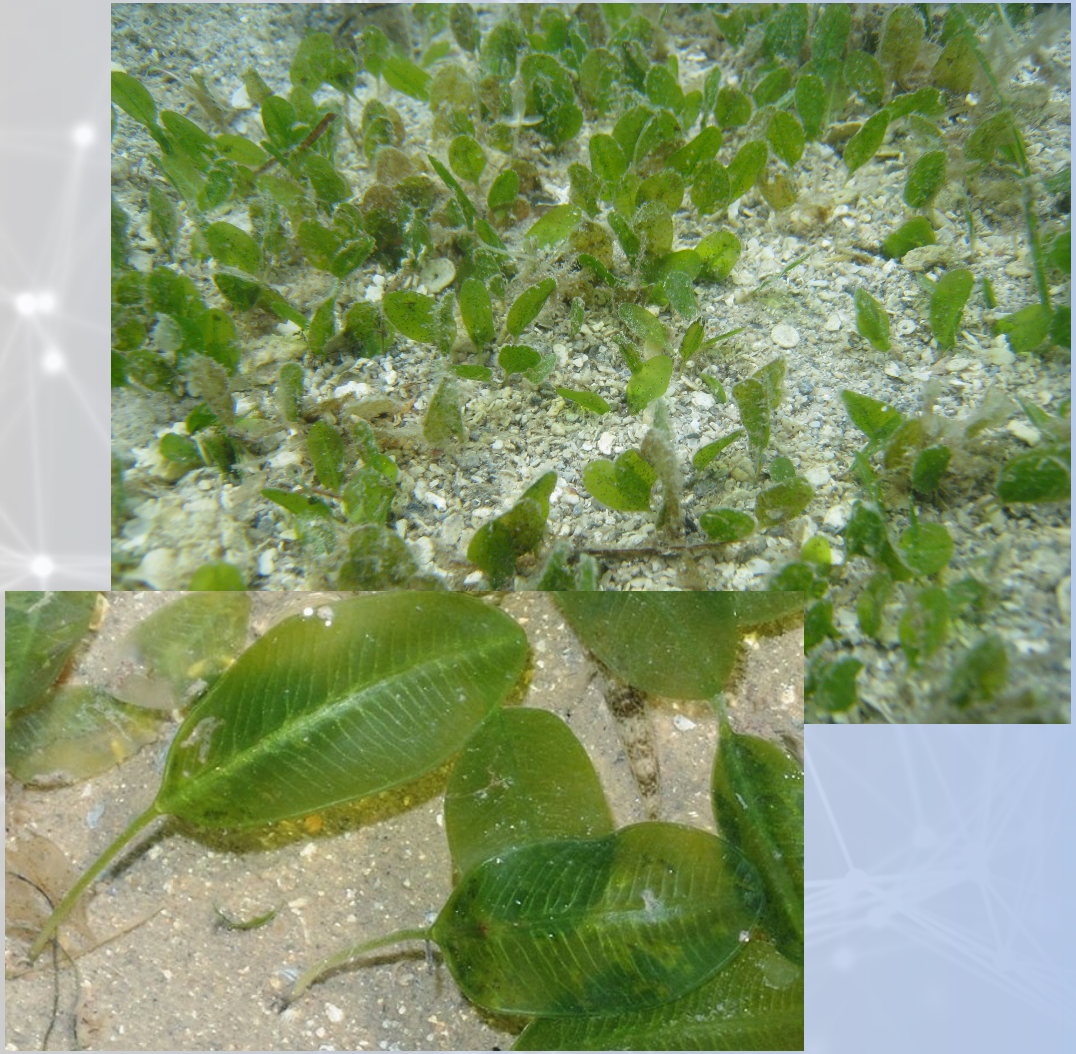
Cymodocea nodosa



Posidonia oceanica

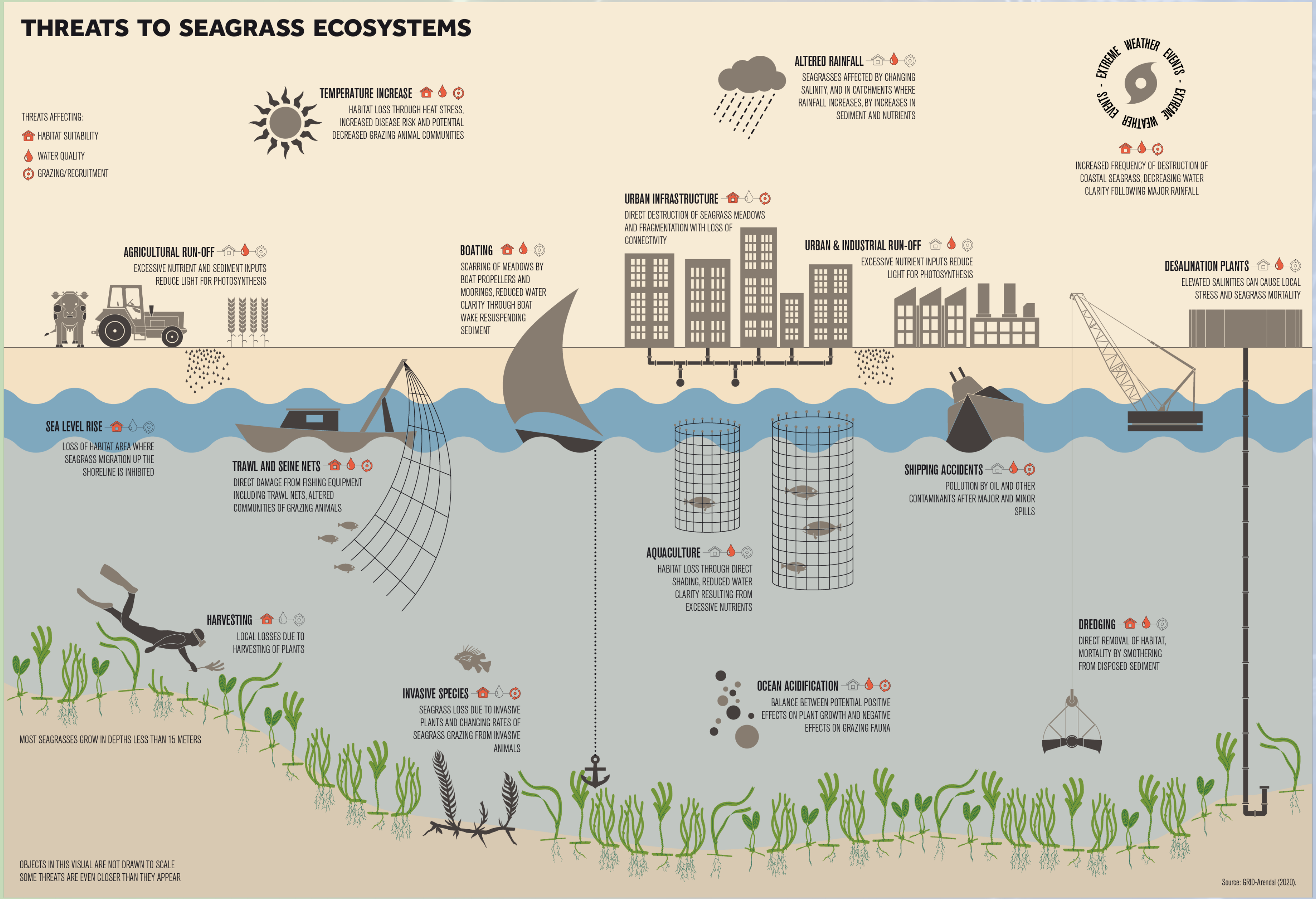
Seagrass species

Rupia maritima



Halophila ovalis

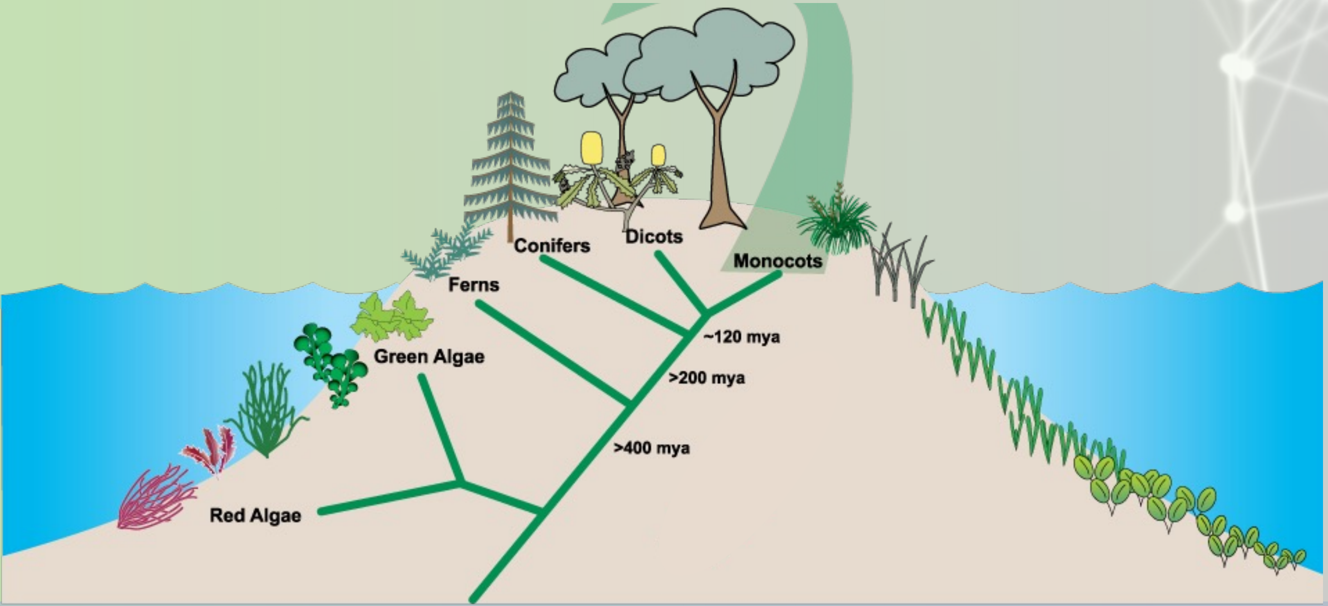
Threats to Seagrasses



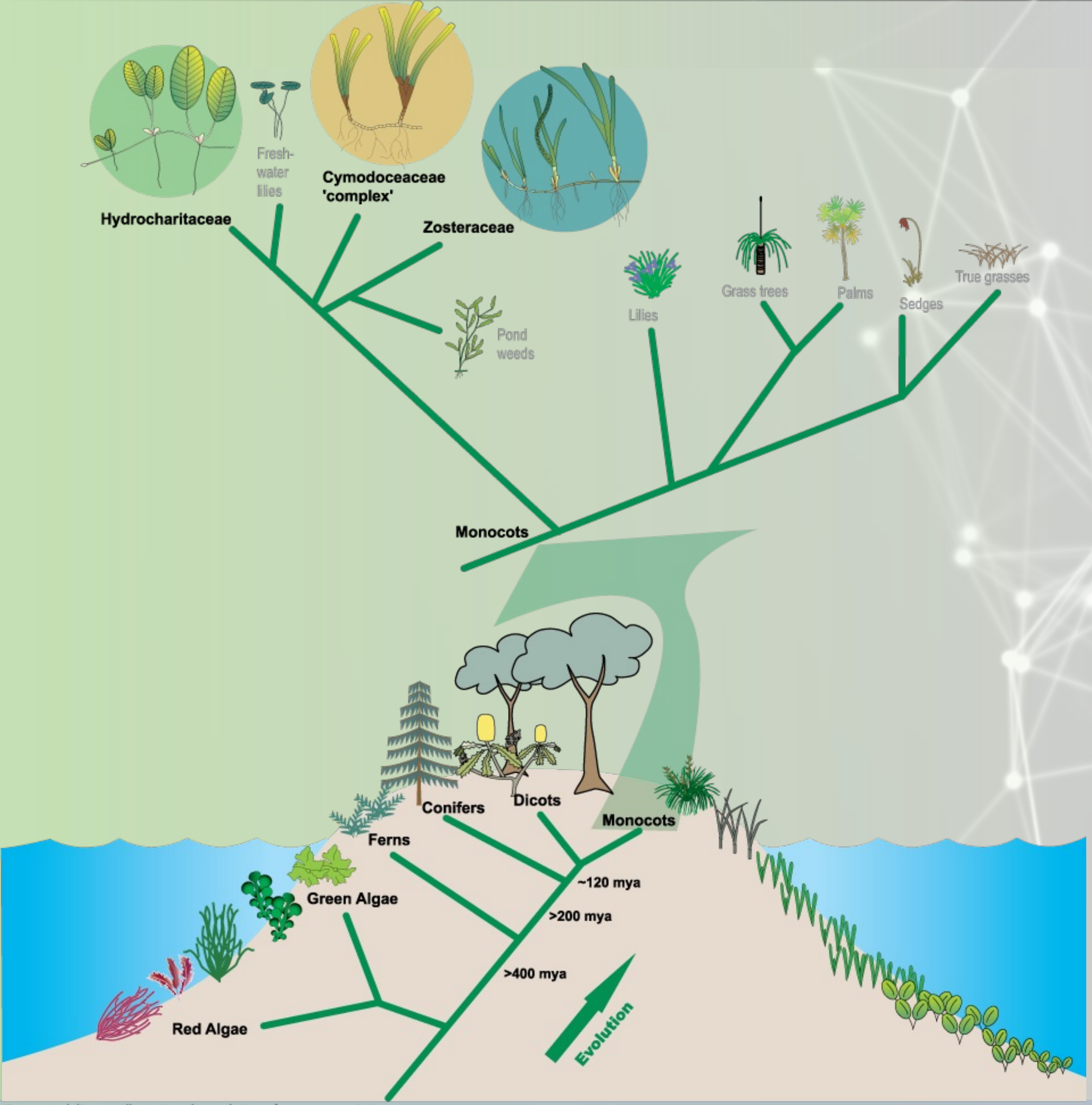
HOW DID SEAGRASSES EVOLVE?

HYPOTHESIS 1 – FROM ALGAE AT AN INTERMEDIATE STEP BEFORE THE EVOLUTION TO TERRESTRIAL VASCULAR PLANTS?

HYPOTHESIS 2 – FROM TERRESTRIAL VASCULAR PLANTS?



Conceptual diagram illustrating the evolution of seagrass species.
Diagram courtesy of James Cook University, Australia.



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HYPOTHESIS 2 – FROM TERRESTRIAL VASCULAR PLANTS?

The seagrass *Zostera marina*, or eelgrass, is widely distributed throughout the Northern Hemisphere. It is therefore of considerable ecological importance but — as with other seagrasses — its coastal habitats are among the world's most threatened ecosystems. Jeanine Olsen and colleagues report the whole-genome sequence of *Zostera*. Their analyses provide insights into the evolutionary changes associated with the **'back to the sea' reverse evolutionary trajectory** that has occurred in this angiosperm lineage.

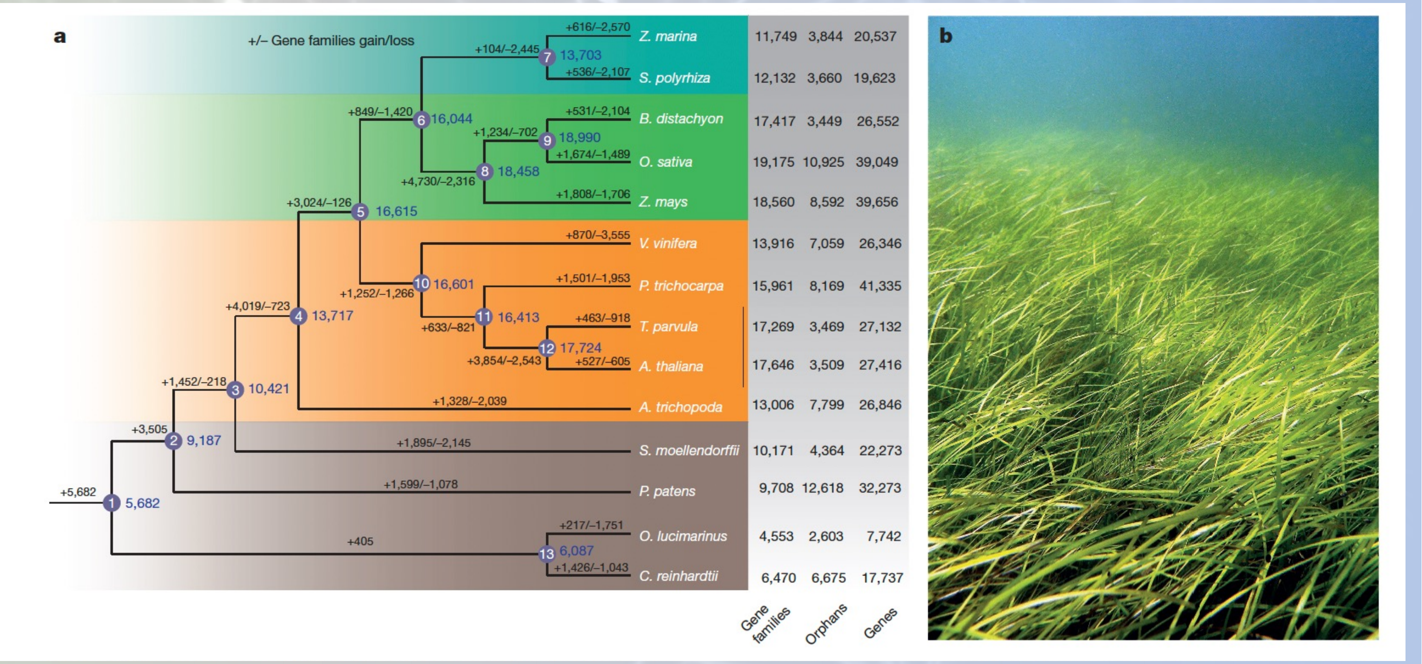
LETTER

OPEN

doi:10.1038/nature16548

The genome of the seagrass *Zostera marina* reveals angiosperm adaptation to the sea

Jeanine L. Olsen[1]*, Pierre Rouzé[2], Bram Verhelst[2], Yao-Cheng Lin[2], Till Bayer[3], Jonas Collen[4], Emanuela Dattolo[5], Emanuele De Paoli[6], Simon Dittami[4], Florian Maumus[7], Gurvan Michel[4], Anna Kersting[8,9], Chiara Lauritano[5], Rolf Lohaus[2], Mats Töpel[10], Thierry Tonon[4], Kevin Vanneste[2], Mojgan Amirebrahimi[11], Janina Brakel[3], Christoffer Boström[12], Mansi Chovatia[11], Jane Grimwood[11,13], Jerry W. Jenkins[11,13], Alexander Jueterbock[14], Amy Mraz[15], Wytze T. Stam[1], Hope Tice[11], Erich Bornberg-Bauer[8], Pamela J. Green[16], Gareth A. Pearson[17], Gabriele Procaccini[5]*, Carlos M. Duarte[18], Jeremy Schmutz[11,13], Thorsten B. H. Reusch[3,19]* & Yves Van de Peer[2,20,21]*



Key angiosperm innovations that were **lost include the entire repertoire of stomatal genes, genes involved in the synthesis of terpenoids and ethylene signaling, and genes for ultraviolet protection and phytochromes for far-red sensing**. Seagrasses have also **regained functions enabling them to adjust to full salinity. Their cell walls contain all of the polysaccharides typical of land plants, but also contain polyanionic, low-methylated pectins and sulfated galactans, a feature shared with the cell walls of all macroalgae and that is important for ion homeostasis,** nutrient uptake and O2/CO2 exchange through leaf epidermal cells.

LETTER

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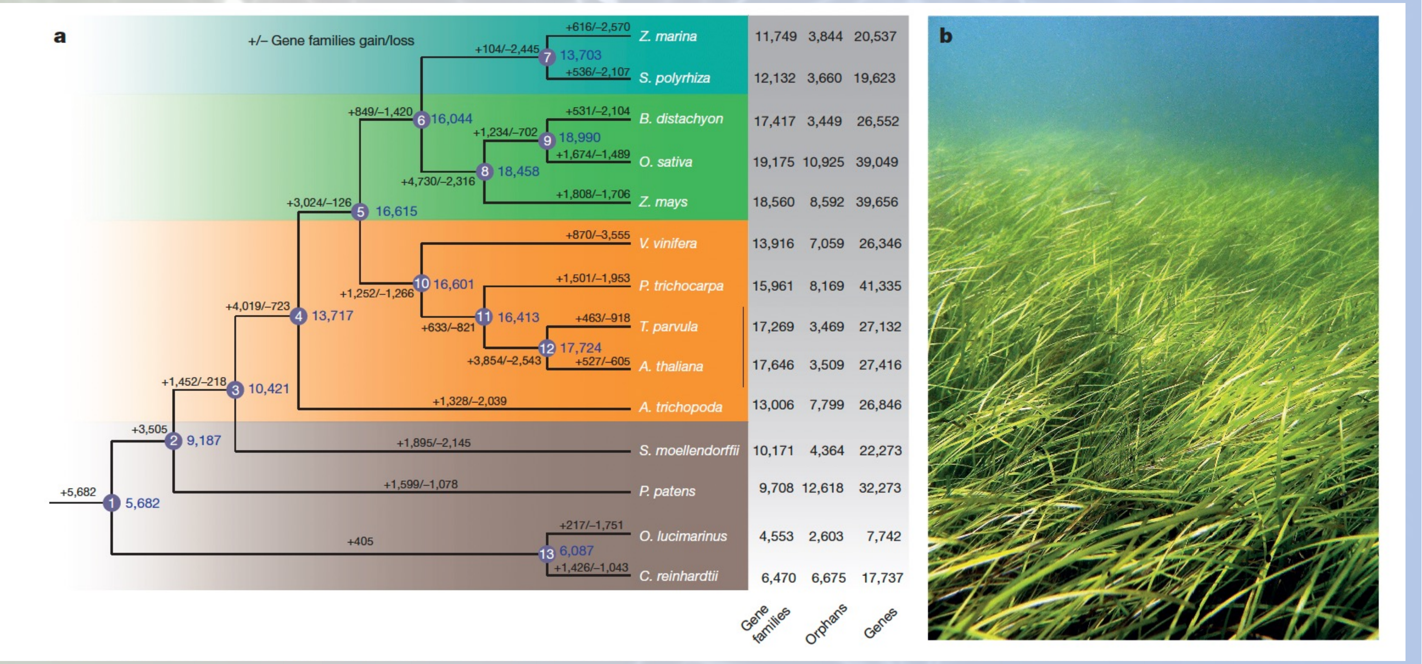
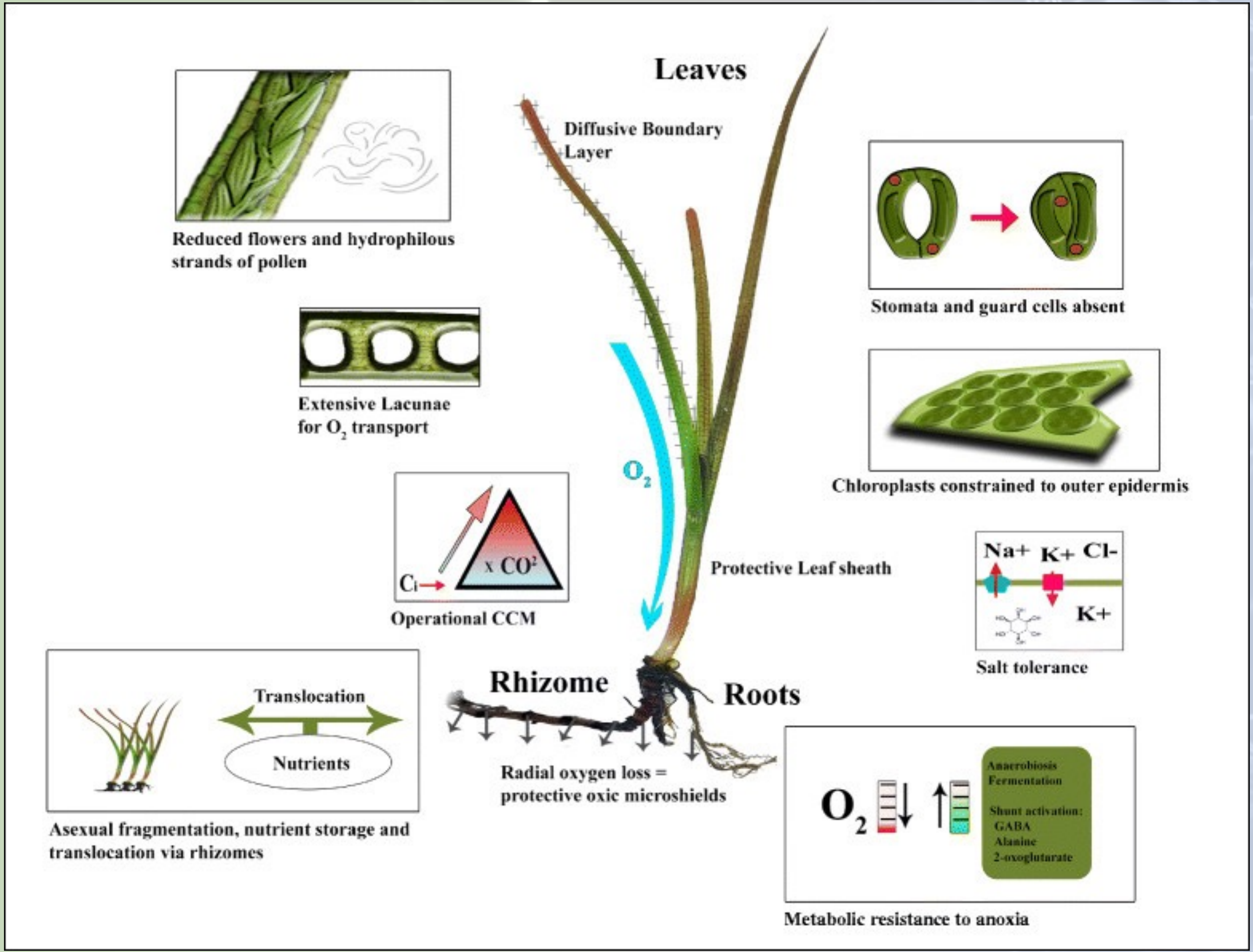
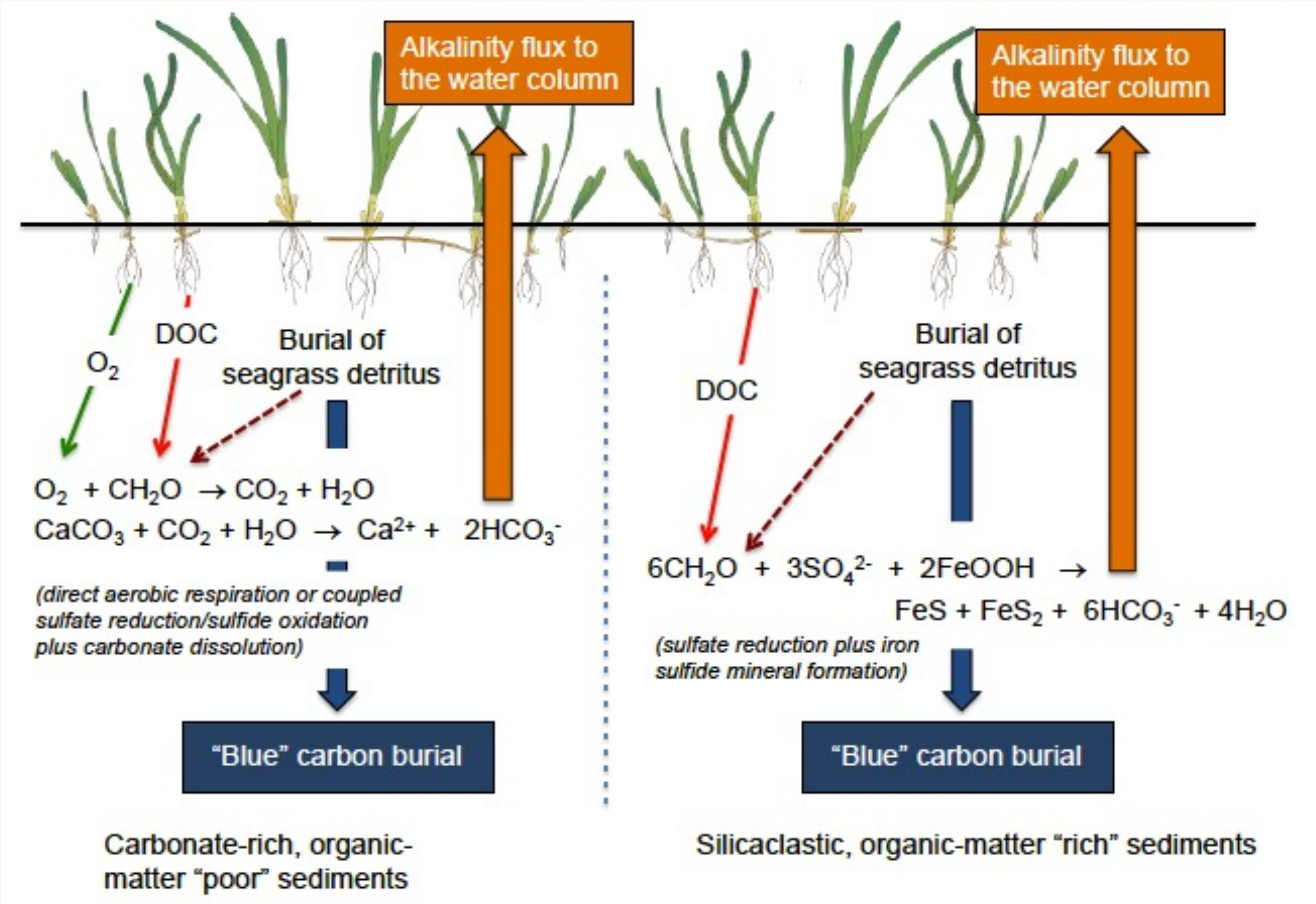
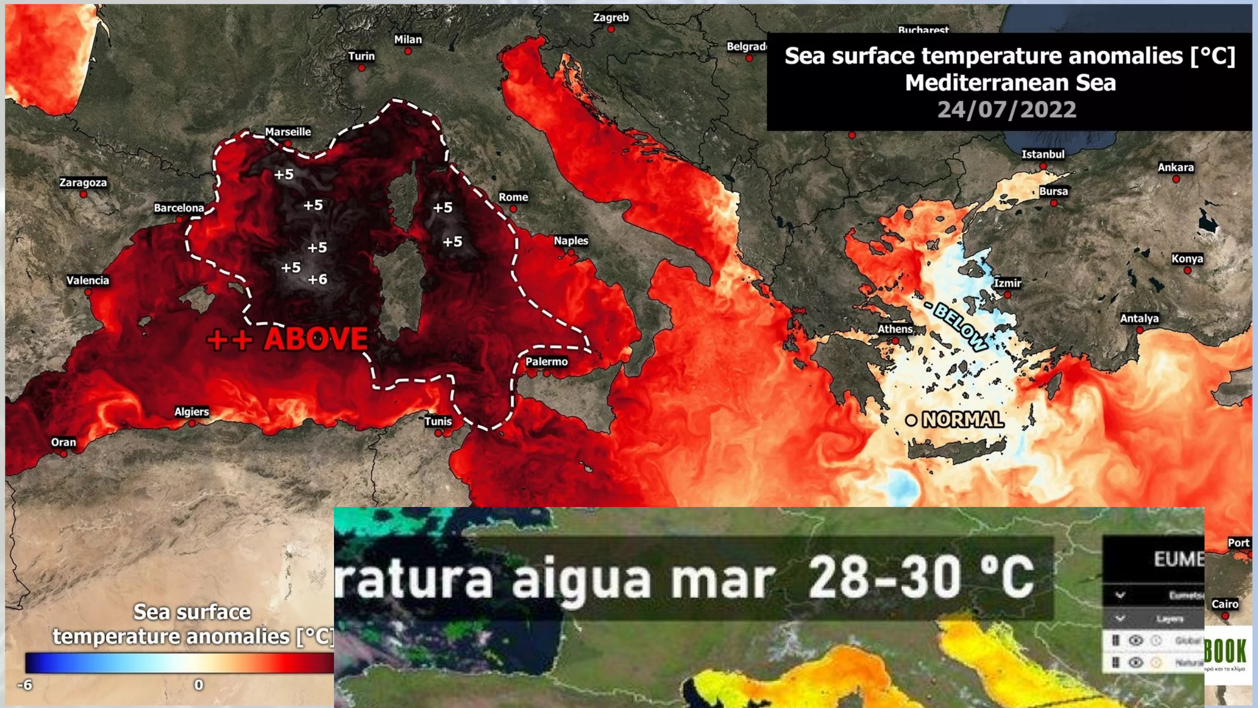


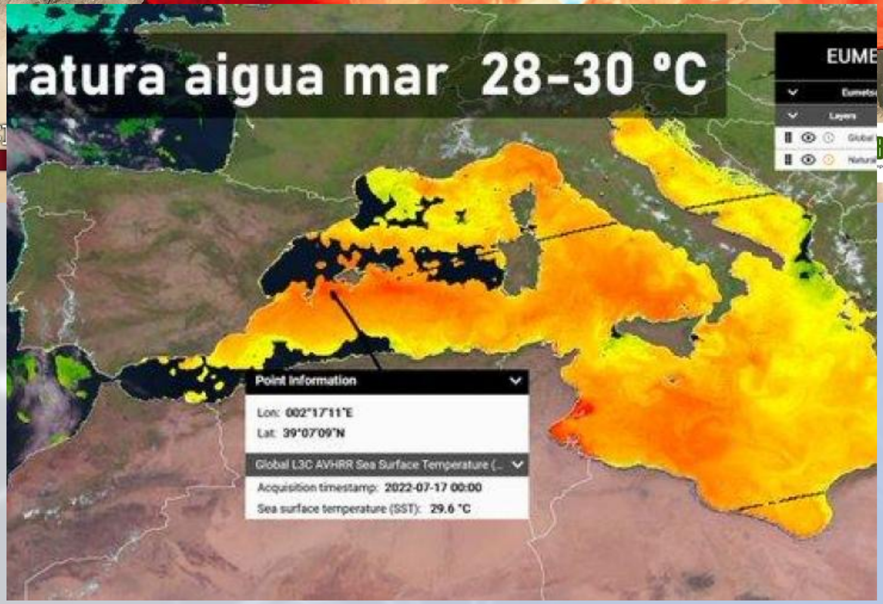
Seagrasses Photosynthetic Adaptations




Alkalinity flux to the water column
Alkalinity flux to the water column
DOC
O_2
Burial of seagrass detritus
$O_2 + CH_2O \rightarrow CO_2 + H_2O$
$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$
(direct aerobic respiration or coupled sulfate reduction/sulfide oxidation plus carbonate dissolution)
"Blue" carbon burial
DOC
Burial of seagrass detritus
$6CH_2O + 3SO_4^{2-} + 2FeOOH \rightarrow FeS + FeS_2 + 6HCO_3^- + 4H_2O$
(sulfate reduction plus iron sulfide mineral formation)
"Blue" carbon burial
Carbonate-rich, organic-matter "poor" sediments
Silicaclastic, organic-matter "rich" sediments


MENORCA
Mar Mediterráneo


Sea surface temperature anomalies [°C]
Mediterranean Sea
24/07/2022
++ ABOVE
- BELOW
O NORMAL
+5
+6
Marseille
Barcelona
Valencia
Zaragoza
Algiers
Oran
Tunis
Palermo
Naples
Rome
Milan
Turin
Zagreb
Athens
Izmir
Istanbul
Bursa
Ankara
Konya
Antalya
Sea surface temperature anomalies [°C]
-6
0


ratura aigua mar 28-30 °C
Point information
Lon: 002°17'11"E
Lat: 39°07'09"N
Global L3C AVHRR Sea Surface Temperature (...
Acquisition timestamp: 2022-07-17 00:00
Sea surface temperature (SST): 29.6 °C

WHY?

Posidonia oceanica massive death 2022

The lack of stomata makes these plants' leaf temperature prone to water temperature.

Increase temperature reduces CO2 dissolution in seawater, reducing its availability for photosynthesis.

https://doi.org/10.1093/plphys/kiac492 PLANT PHYSIOLOGY 2022: 00: 1–11

Plant Physiology®

Research Article

The trajectory in catalytic evolution of Rubisco in *Posidonia* seagrass species differs from terrestrial plants

Sebastià Capó-Bauçà[1,*] **Spencer Whitney**[2] **Concepción Iñiguez**[1] **Oscar Serrano**[3,4] **Timothy Rhodes**[2] **and Jeroni Galmés**[1]

1 Research Group on Plant Biology under Mediterranean Conditions. Universitat de les Illes Balears-INAGEA, Palma 07122, Spain
2 Research School of Biology, Australian National University, Canberra, ACT 2601, Australia
3 Centro de Estudios Avanzados de Blanes, Consejo Superior de Investigaciones Cientificas (CEAB-CISC), Blanes 17300, Spain
4 School of Science, Centre for Marine Ecosystems Research, Edith Cowan University, Joondalup, WA 6027, Australia

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C.I. and J.G. conceived the study. S.C.-B. and S.W. measured the Rubisco biochemistry and S.C.-B. carried out the rest of experiments, analyzed the data, and produced the figures with help from all authors. T.R. performed the rbcL sequencing and O.S. collected the Australian *Posidonia* species. S.C.-B. drafted the manuscript with editing contributions from all authors.
The author responsible for distribution of materials integral to the findings presented in this article in accordance with the policy described in the Instructions for Authors (https://academic.oup.com/plphys/pages/general-instructions) is: Sebastià Capó-Bauçà (sebastia.capo@uib.cat).

Abstract

The CO_2-fixing enzyme Ribulose bisphosphate carboxylase-oxygenase (Rubisco) links the inorganic and organic phases of the global carbon cycle. In aquatic systems, the catalytic adaptation of algae Rubiscos has been more expansive and followed an evolutionary pathway that appears distinct to terrestrial plant Rubisco. Here, we extend this survey to differing seagrass species of the genus *Posidonia* to reveal how their disjunctive geographical distribution and diverged phylogeny, along with their CO_2 concentrating mechanisms (CCMs) effectiveness, have impacted their Rubisco kinetic properties. The Rubisco from *Posidonia* species showed lower carboxylation efficiencies and lower sensitivity to O_2 inhibition than those measured for terrestrial C_3 and C_4-plant Rubiscos. Compared with the Australian *Posidonia* species, Rubisco from the Mediterranean *Posidonia oceanica* had 1.5–2-fold lower carboxylation and oxygenation efficiencies, coinciding with effective CCMs and five Rubisco large subunit amino acid substitutions. Among the Australian *Posidonia* species, CCM effectiveness was higher in *Posidonia sinuosa* and lower in the deep-living *Posidonia angustifolia*, likely related to the 20%–35% lower Rubisco carboxylation efficiency in *P. sinuosa* and the two-fold higher Rubisco content in *P. angustifolia*. Our results suggest that the catalytic evolution of *Posidonia* Rubisco has been impacted by the low CO_2 availability and gas exchange properties of marine environments, but with contrasting Rubisco kinetics according to the time of diversification among the species. As a result, the relationships between maximum carboxylation rate and CO_2- and O_2-affinities of *Posidonia* Rubiscos follow an alternative path to that characteristic of terrestrial angiosperm Rubiscos.

The genus Posidonia is one of the most relevant genera among seagrasses and contains relevant species in terms of biomass and carbon sequestration capacity (Duarte and Chiscano, 1999), being distributed in ***seven species along the Australian coastlines*** *and* ***a single Posidonia oceanica species endemic to the Mediterranean Sea*** *(Campey et al., 2000).*

This ***disjunct species distribut****ion suggests there may have been a* ***loss of Posidonia species from those that originally connected the Mediterranean and Australian populations during Pangea*** *(Larkum et al., 2006).*

Within these phylogenetically separate clades of Posidonia species *it is unclear the extent to which* ***growth habitat differences*** *within and between both geographical locations have* ***impacted the adaptative evolution of their CCM and Rubisco****.*

Here, we ***examine the ecophysiology and Rubisco biochemistry at 25 °C*** *among the Mediterranean* ***P. oceanica and four distinct lineages of Posidonia species from the seven morphologically described species found in Australia*** *(Aires et al., 2011).*

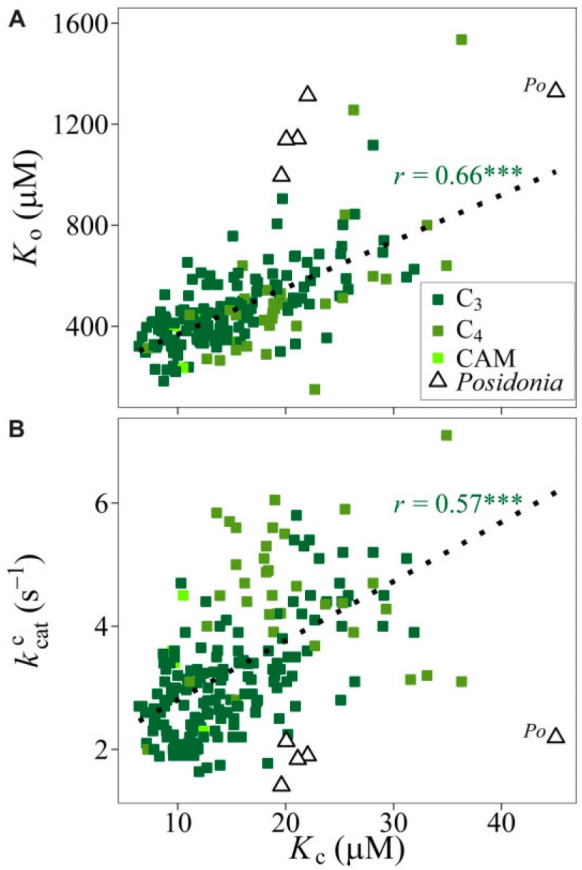
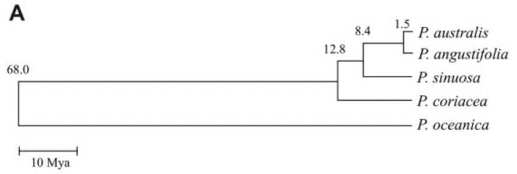


Figure 1 Diversity in the catalytic properties of *Posidonia* Rubisco relative to C_3, C_4, and CAM plants. A, Correlation between the Michaelis–Menten constant for CO_2 (K_c) and the Michaelis–Menten constant for O_2 (K_o); (B) and between K_c and the maximum carboxylation rate (k_{cat}^c). Empty triangles are the species of *Posidonia* measured in this study ($n = 5$) and *Po* indicates the Mediterranean endemic *P. oceanica*. Light and dark green squares belongs to terrestrial plants compiled by Iñiguez et al. (2020) ($n = 178$ in A and 203 in B). r is the reported Pearson's regression coefficient of terrestrial plants and asterisks show the significance of the correlation test (***$P < 0.001$).



B

	251	279	375	429	449
P. australis	M	S	L	Q	T
P. angustifolia	M	S	L	Q	T
P. sinuosa	M	S	L	Q	T
P. coriacea	M	S	L	Q	T
P. oceanica	L	T	F	K	S

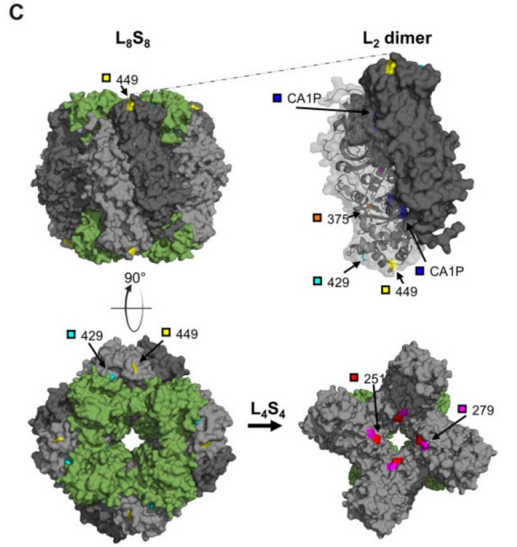
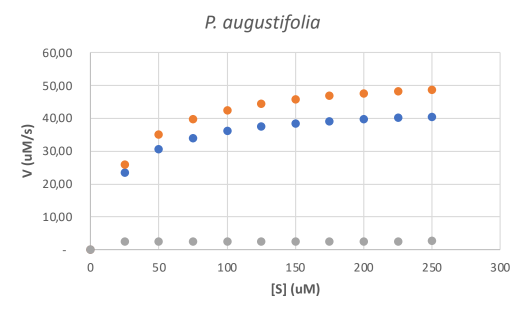
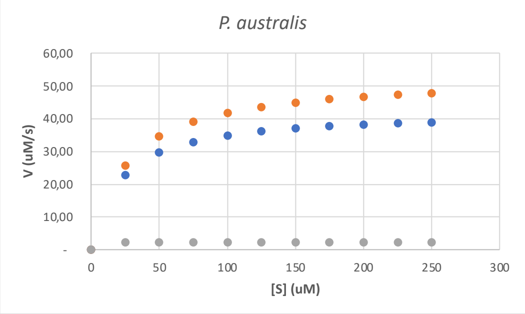


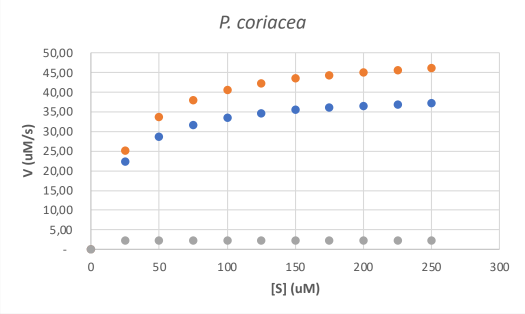
Figure 2 Phylogenetic and Rubisco molecular diversity across *Posidonia* species. A, Phylogenetic tree of *Posidonia* species analyzed in the study abbreviated from that derived by Aires et al. (2011) from mapping the rRNA-internal transcribed spacer (ITS) region; numbers above branches are the divergence dates (in Mya) estimated on the maximum-likelihood topology derived from the ITS data set; B, amino acid changes among *rbcL* of *Posidonia* species; C, location of the variable amino acid positions of *P. oceanica* RbcL mapped onto the crystal structure of spinach Rubisco (8RUC) using Pymol V1.8.x. Residues 251, 279, 375, 429, and 449, and the inhibitor CA1P are highlighted.

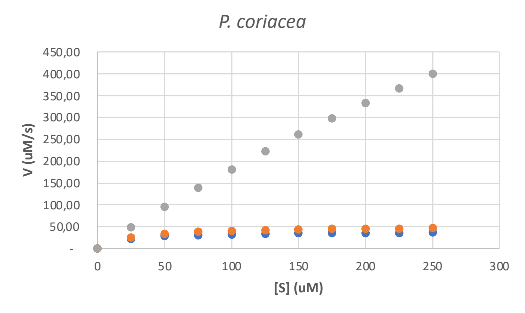
Rubisco Kinetic Parameters

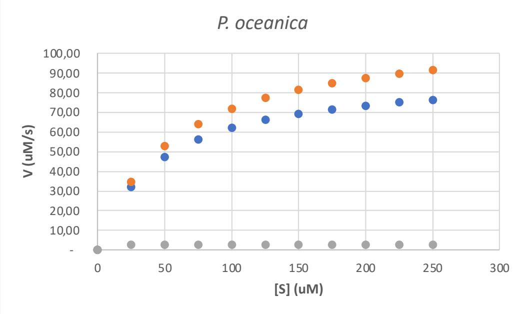
	P. augustifolia	*P. australis*	*P. coriacea*	*P. sinuosa*	*P. oceanica*	*T. aestivum*	*Z. mays*
[S] µM	**v (Carboxylase) µM/s**						
0	-	-	-	-	-	-	-
25	23,40	22,89	22,28	21,97	32,14	15,56	25,15
50	30,56	29,68	28,67	28,16	47,37	18,43	33,60
75	34,02	32,93	31,70	31,08	56,25	19,64	37,84
100	36,07	34,85	33,47	32,78	62,07	20,31	40,38
125	37,41	36,11	34,63	33,89	66,18	20,73	42,08
150	38,37	37,00	35,45	34,67	69,23	21,02	43,30
175	39,09	37,66	36,06	35,25	71,59	21,23	44,21
200	39,64	38,17	36,53	35,70	73,47	21,39	44,92
225	40,08	38,58	36,90	36,06	75,00	21,52	45,49
250	40,44	38,92	37,21	36,35	76,27	21,62	45,95
	v (Carboxylase+Oxygenase) µM/s						
0	-	-	-	-	-	-	-
25	25,96	25,68	25,20	25,35	34,57	19,59	31,03
50	35,06	34,55	33,69	33,95	52,83	24,36	44,99
75	39,71	39,05	37,95	38,28	64,12	26,51	52,93
100	42,52	41,77	40,51	40,89	71,79	27,73	58,06
125	44,41	43,59	42,22	42,63	77,35	28,53	61,63
150	45,76	44,90	43,44	43,88	81,55	29,08	64,27
175	46,78	45,88	44,36	44,82	84,85	29,49	66,30
200	47,58	46,64	45,08	45,55	87,50	29,80	67,91
225	48,21	47,26	45,65	46,13	89,68	30,05	69,22
250	48,74	47,76	46,11	46,61	91,50	30,25	70,30
	v (Oxygenase) µM/s						
0	-	-	-	-	-	-	-
25	2,49	2,18	2,18	48,77	2,52	47,20	47,67
50	2,56	2,23	2,23	95,22	2,59	89,41	91,10
75	2,58	2,25	2,24	139,49	2,61	127,36	130,83
100	2,59	2,26	2,25	181,74	2,62	161,69	167,32
125	2,60	2,26	2,26	222,10	2,63	192,87	200,94
150	2,60	2,27	2,26	260,70	2,63	221,33	232,02
175	2,61	2,27	2,26	297,65	2,64	247,40	260,84
200	2,61	2,27	2,27	333,05	2,64	271,38	287,64
225	2,61	2,27	2,27	367,01	2,64	293,51	312,62
250	2,61	2,27	2,27	399,60	2,64	313,99	335,96

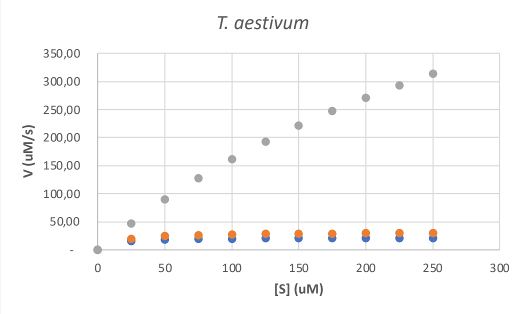


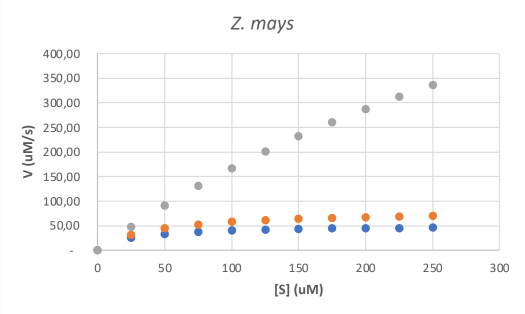












Rubisco Kinetic Parameters

[S] µM	*P. augustifolia*	*P. australis*	*P. coriacea*	*P. sinuosa*	*P. oceanica*	*T. aestivum*	*Z. mays*
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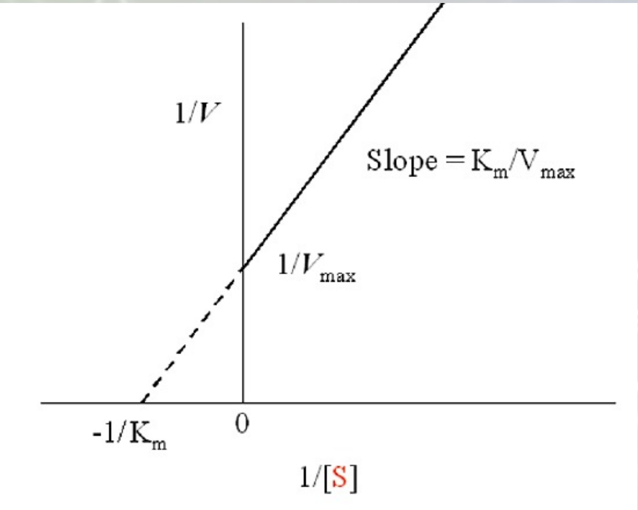
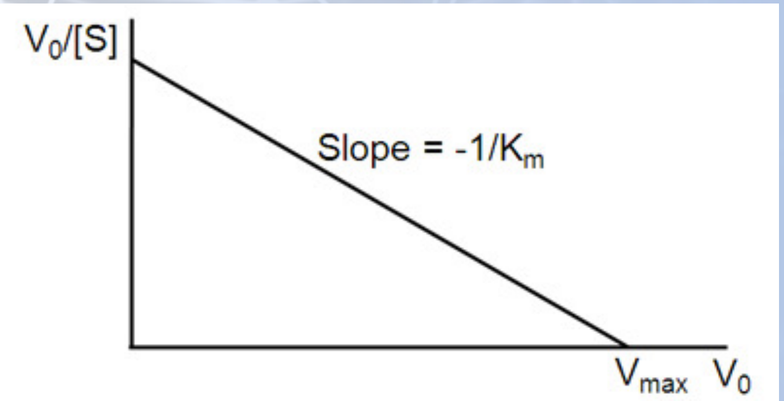
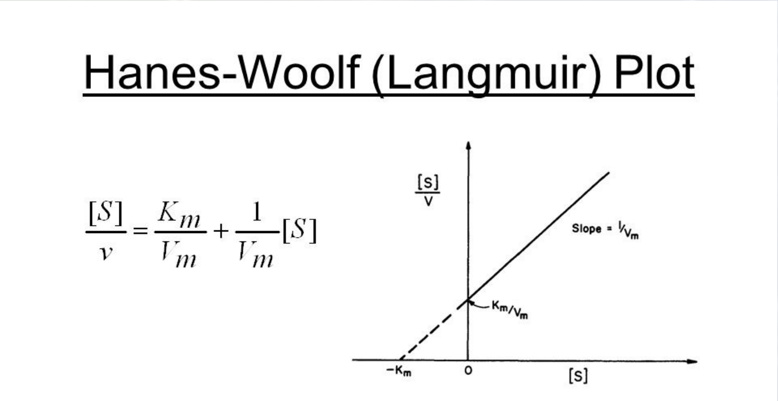
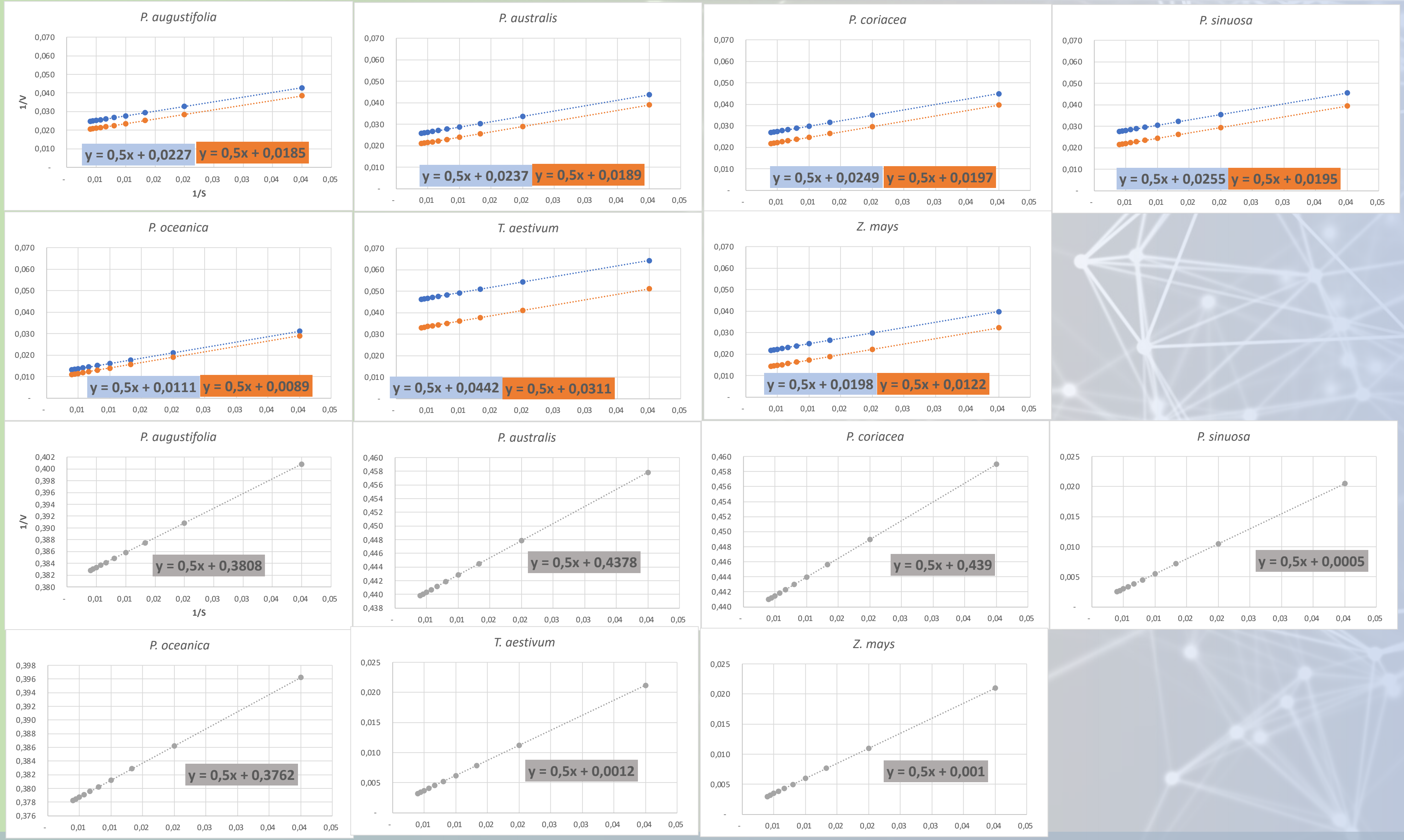
250	40,44	38,92	37,21	36,35	76,27	21,62	45,95
	v (Carboxylase+Oxygenase) µM/s						
0	-	-	-	-	-	-	-
25	25,96	25,68	25,20	25,35	34,57	19,59	31,03
50	35,06	34,55	33,69	33,95	52,83	24,36	44,99
75	39,71	39,05	37,95	38,28	64,12	26,51	52,93
100	42,52	41,77	40,51	40,89	71,79	27,73	58,06
125	44,41	43,59	42,22	42,63	77,35	28,53	61,63
150	45,76	44,90	43,44	43,88	81,55	29,08	64,27
175	46,78	45,88	44,36	44,82	84,85	29,49	66,30
200	47,58	46,64	45,08	45,55	87,50	29,80	67,91
225	48,21	47,26	45,65	46,13	89,68	30,05	69,22
250	48,74	47,76	46,11	46,61	91,50	30,25	70,30
	v (Oxygenase) µM/s						
0	-	-	-	-	-	-	-
25	2,49	2,18	2,18	48,77	2,52	47,20	47,67
50	2,56	2,23	2,23	95,22	2,59	89,41	91,10
75	2,58	2,25	2,24	139,49	2,61	127,36	130,83
100	2,59	2,26	2,25	181,74	2,62	161,69	167,32
125	2,60	2,26	2,26	222,10	2,63	192,87	200,94
150	2,60	2,27	2,26	260,70	2,63	221,33	232,02
175	2,61	2,27	2,26	297,65	2,64	247,40	260,84
200	2,61	2,27	2,27	333,05	2,64	271,38	287,64
225	2,61	2,27	2,27	367,01	2,64	293,51	312,62
250	2,61	2,27	2,27	399,60	2,64	313,99	335,96





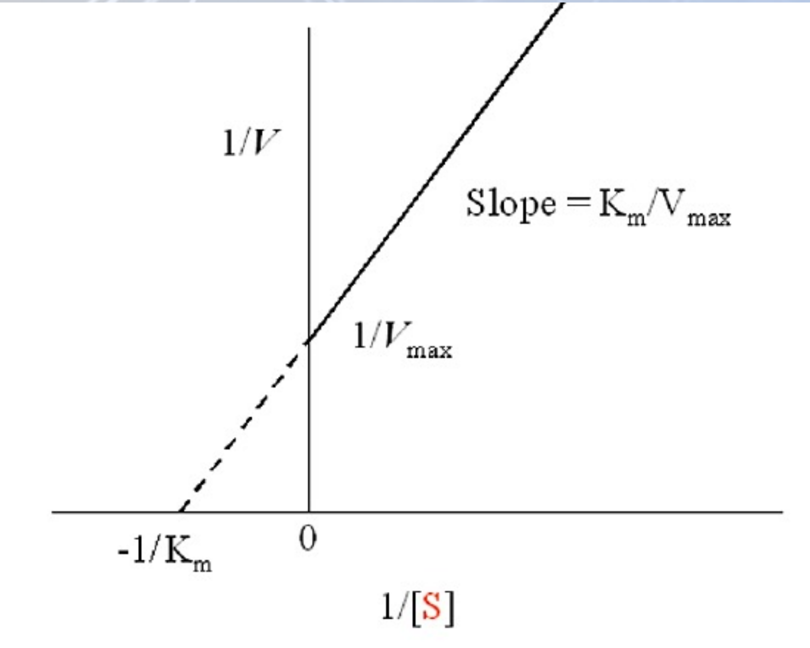


Rubisco Kinetic Parameters - Lineweaver-Burke

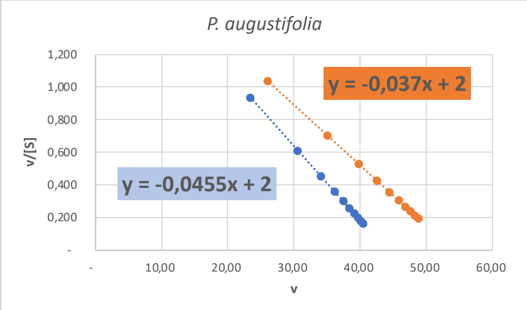


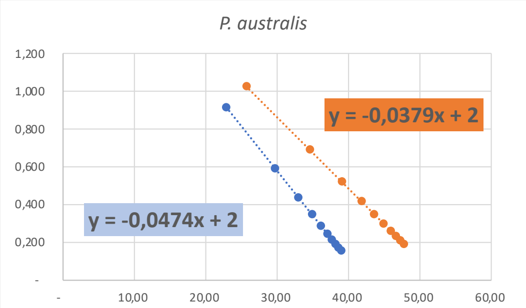
Rubisco Kinetic Parameters - Lineweaver-Burke

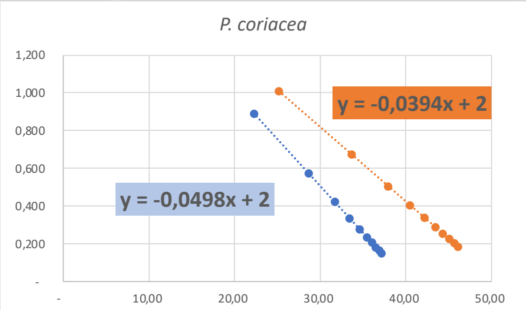
	P. augustifol	*P. australis*	*P. coriacea*	*P. sinuosa*	*P. oceanica*	*T. aestivum*	*Z. mays*
Km (c)	22,03	21,10	20,08	19,61	45,05	11,31	25,25
Km (c+o)	27,03	26,46	25,38	25,64	56,18	16,08	40,98
Km (o)	1,31	1,14	1,14	1 000,00	1,33	416,67	500,00
Vmax (c)	44,05	42,19	40,16	39,22	90,09	22,62	50,51
Vmax (c+o)	54,05	52,91	50,76	51,28	112,36	32,15	81,97
Vmax (o)	2,63	2,28	2,28	2 000,00	2,66	833,33	1 000,00

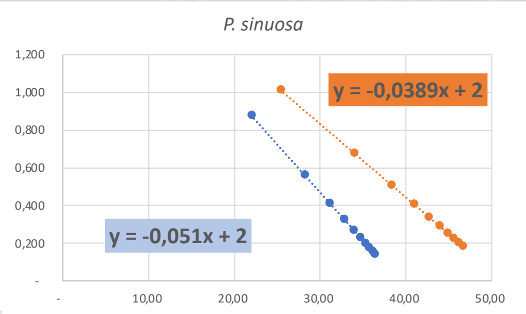


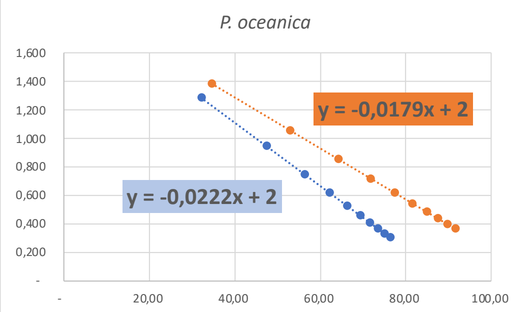
Rubisco Kinetic Parameters - Eadie–Hofstee

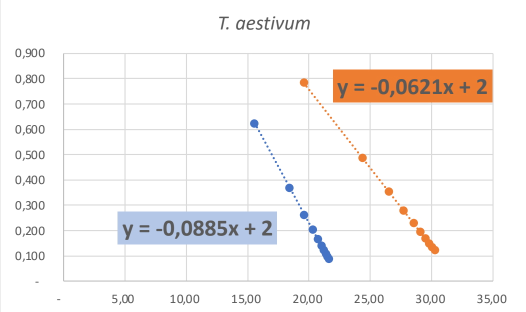


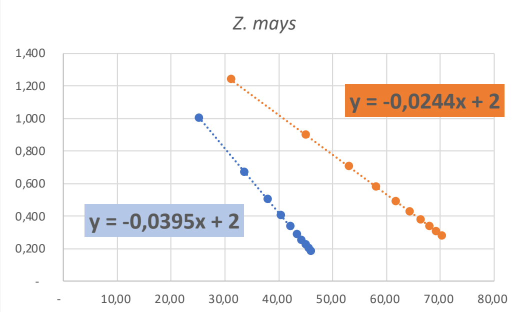


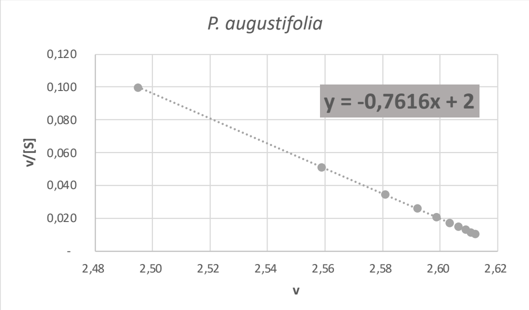


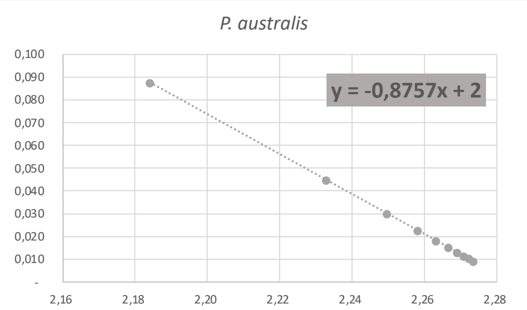


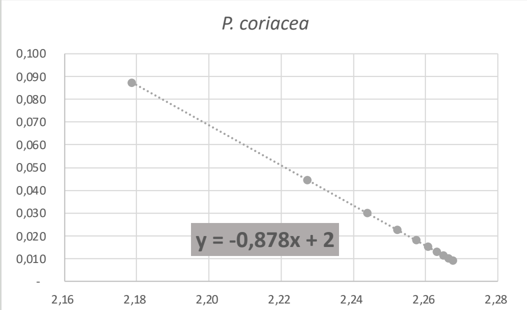


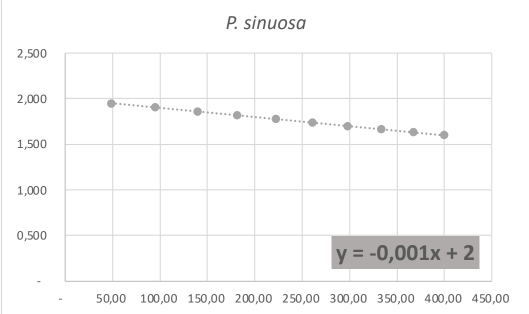


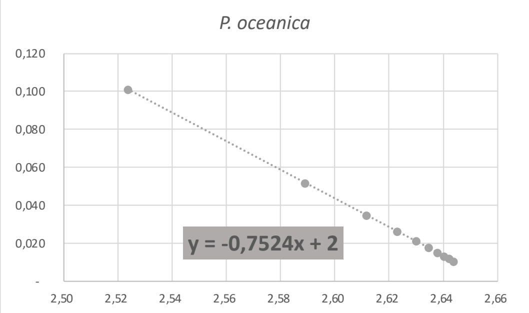


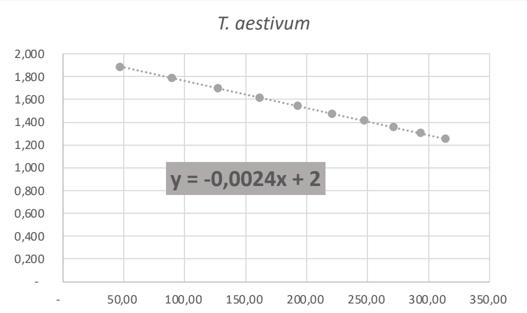


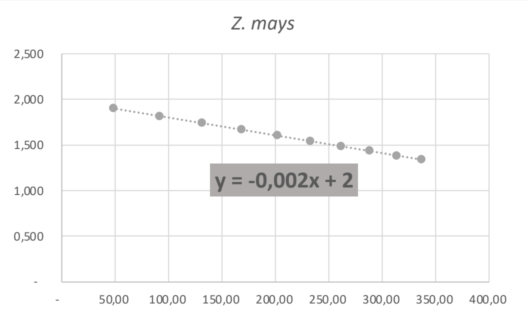






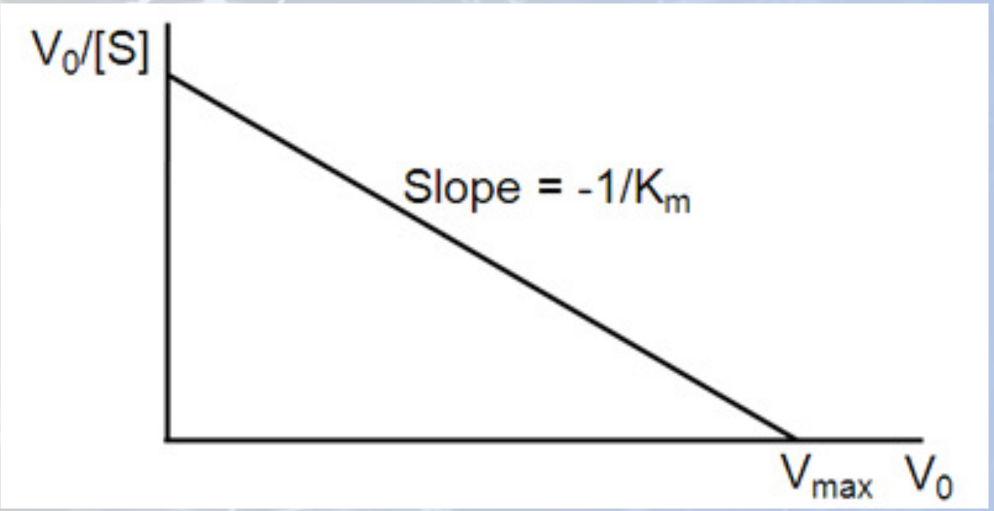




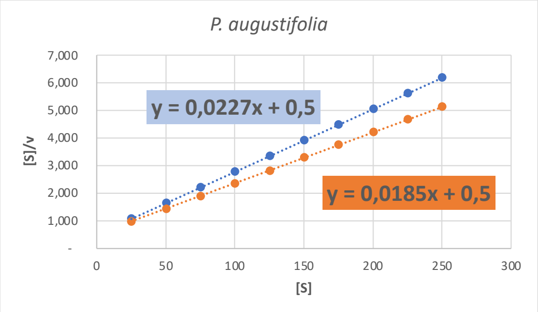


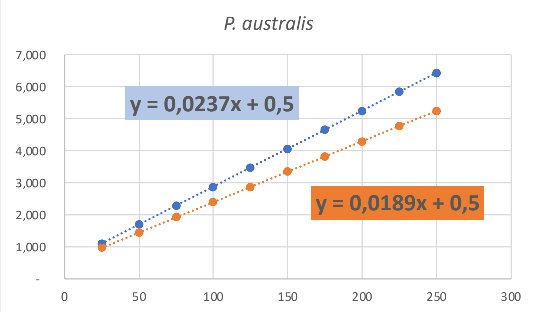
Rubisco Kinetic Parameters - Eadie–Hofstee

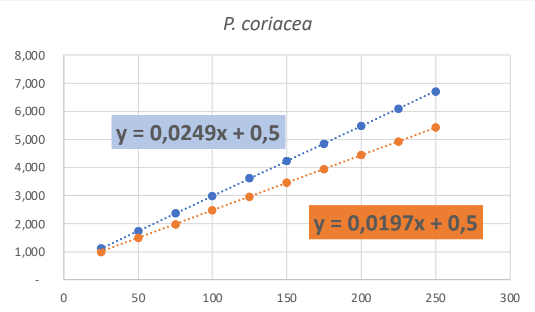
	P. augustifol.	*P. australis*	*P. coriacea*	*P. sinuosa*	*P. oceanica*	*T. aestivum*	*Z. mays*
Km (c)	21,98	21,10	20,08	19,61	45,05	11,30	25,32
Km (c+o)	27,03	26,39	25,38	25,71	55,87	16,10	40,98
Km (o)	1,31	1,14	1,14	1 000,00	1,33	416,67	500,00
Vmax (c)	43,96	42,19	40,16	39,22	90,09	22,60	50,63
Vmax (c+o)	54,05	52,77	50,76	51,41	111,73	32,21	81,97
Vmax (o)	2,63	2,28	2,28	2 000,00	2,66	833,33	1 000,00

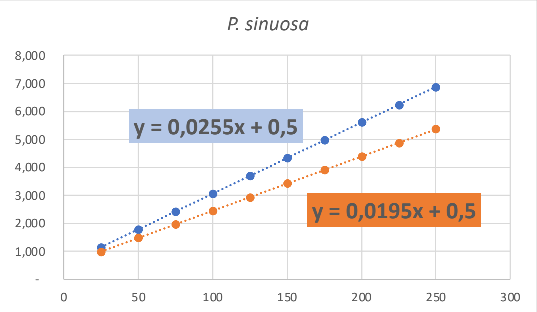


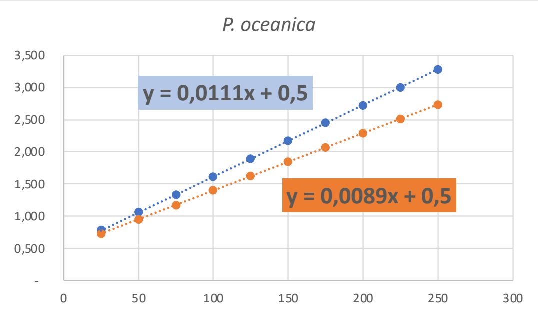
Rubisco Kinetic Parameters - Hanes-Woolf

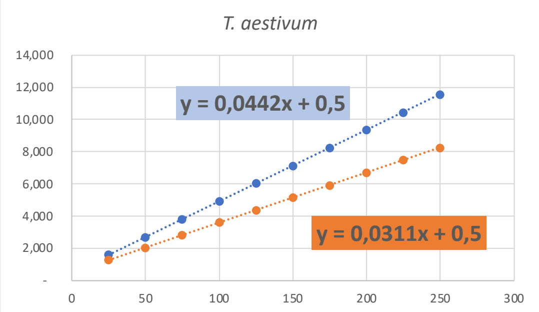


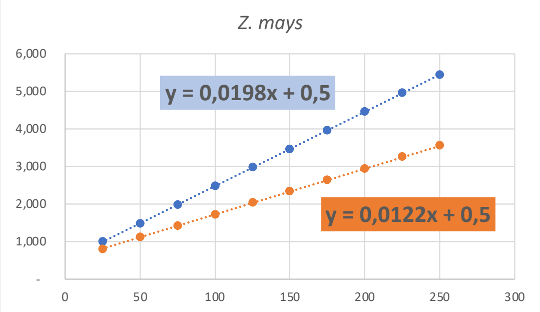


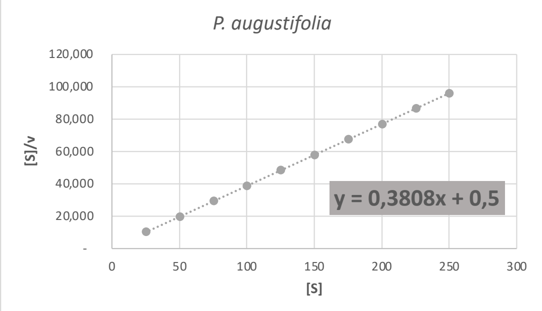


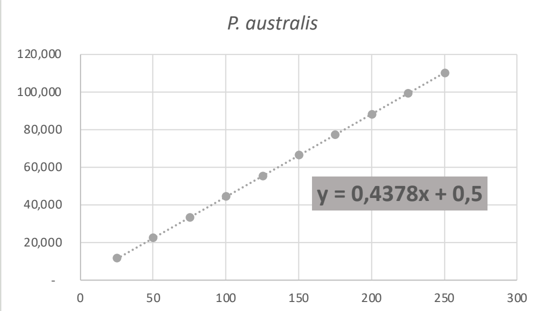


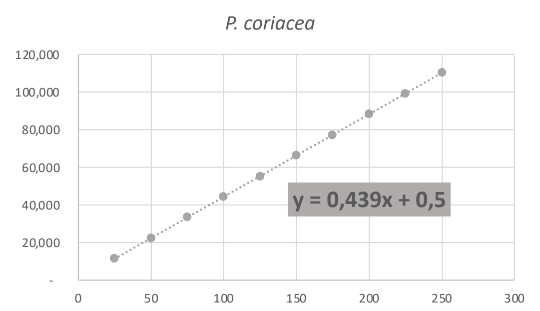


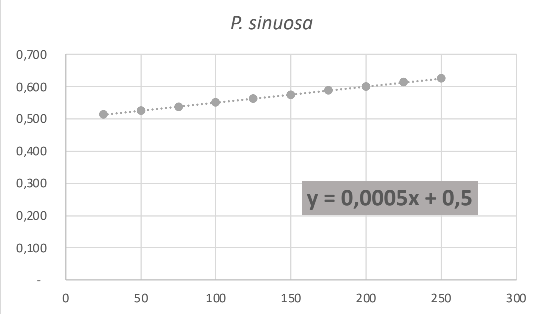


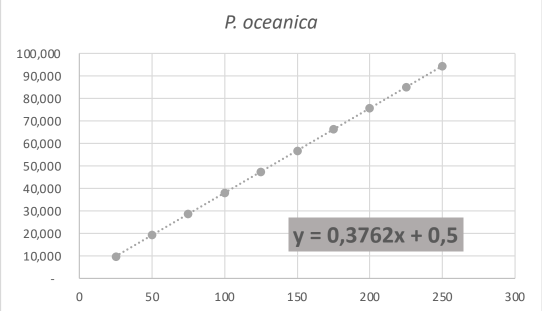


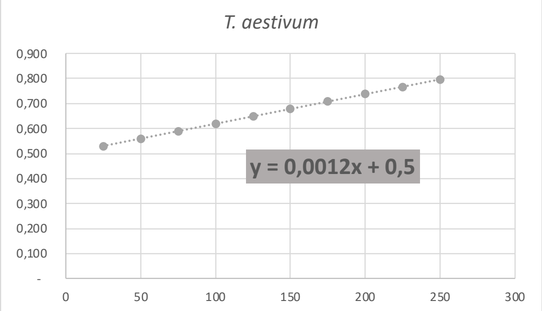


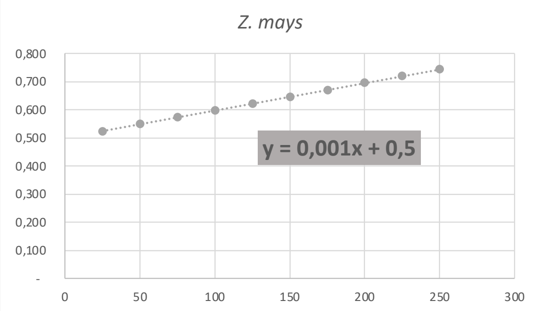






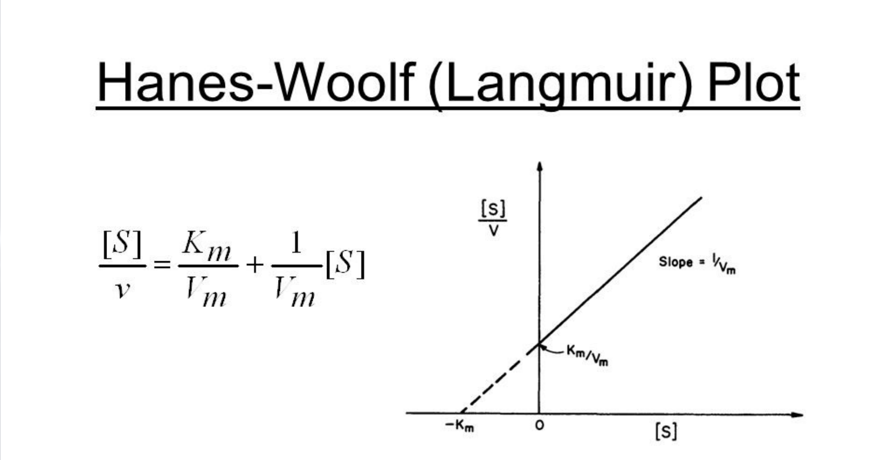






Rubisco Kinetic Parameters - Hanes-Woolf

	P. augustifol	*P. australis*	*P. coriacea*	*P. sinuosa*	*P. oceanica*	*T. aestivum*	*Z. mays*
Km (c)	22,03	21,10	20,08	22,22	45,05	11,31	25,25
Km (c+o)	27,03	26,46	25,38	25,64	56,18	16,08	40,98
Km (o)	1,31	1,14	1,14	1 000,00	1,33	416,67	500,00
Vmax (c)	44,05	42,19	40,16	44,44	90,09	22,62	50,51
Vmax (c+o)	54,05	52,91	50,76	51,28	112,36	32,15	81,97
Vmax (o)	2,63	2,28	2,28	2 000,00	2,66	833,33	1 000,00



Rubisco Kinetic Parameters - Hanes-Woolf

		P. augustifol	*P. australis*	*P. coriacea*	*P. sinuosa*	*P. oceanica*	*T. aestivum*	*Z. mays*
MM	Km (c)	22,00	21,10	20,10	19,60	45,00	11,30	25,30
	Km (c+o)	27,00	26,40	25,40	25,70	56,00	16,10	40,90
	Km (o)	1,31	1,14	1,14	995,00	1,33	422,00	512,00
	Vmax (c)	44,00	42,20	40,20	39,20	90,00	22,60	50,60
	Vmax (c+o)	54,00	52,80	50,80	51,40	112,00	32,20	81,80
	Vmax (o)	2,63	2,28	2,28	1 990,00	2,66	844,00	1 024,00
LB	Km (c)	22,03	21,10	20,08	19,61	45,05	11,31	25,25
	Km (c+o)	27,03	26,46	25,38	25,64	56,18	16,08	40,98
	Km (o)	1,31	1,14	1,14	1 000,00	1,33	416,67	500,00
	Vmax (c)	44,05	42,19	40,16	39,22	90,09	22,62	50,51
	Vmax (c+o)	54,05	52,91	50,76	51,28	112,36	32,15	81,97
	Vmax (o)	2,63	2,28	2,28	2 000,00	2,66	833,33	1 000,00
EH	Km (c)	21,98	21,10	20,08	19,61	45,05	11,30	25,32
	Km (c+o)	27,03	26,39	25,38	25,71	55,87	16,10	40,98
	Km (o)	1,31	1,14	1,14	1 000,00	1,33	416,67	500,00
	Vmax (c)	43,96	42,19	40,16	39,22	90,09	22,60	50,63
	Vmax (c+o)	54,05	52,77	50,76	51,41	111,73	32,21	81,97
	Vmax (o)	2,63	2,28	2,28	2 000,00	2,66	833,33	1 000,00
HW	Km (c)	22,03	21,10	20,08	22,22	45,05	11,31	25,25
	Km (c+o)	27,03	26,46	25,38	25,64	56,18	16,08	40,98
	Km (o)	1,31	1,14	1,14	1 000,00	1,33	416,67	500,00
	Vmax (c)	44,05	42,19	40,16	44,44	90,09	22,62	50,51
	Vmax (c+o)	54,05	52,91	50,76	51,28	112,36	32,15	81,97
	Vmax (o)	2,63	2,28	2,28	2 000,00	2,66	833,33	1 000,00

Lower Km(carboxylase) than Z. mays (C4) -> Higher affinity to CO2.

Higher Vmax than C3 and lower than C4.

Rubisco Kinetic Parameters - Hanes-Woolf

		P. augustifol	*P. australis*	*P. coriacea*	*P. sinuosa*	*P. oceanica*	*T. aestivum*	*Z. mays*
	Km (c)	22,00	21,10	20,10	19,60	45,00	11,30	25,30
	Km (c+o)	27,00	26,40	25,40	25,70	56,00	16,10	40,90
	Km (o)	1,31	1,14	1,14	995,00	1,33	422,00	512,00
	Vmax (c)	44,00	42,20	40,20	39,20	90,00	22,60	50,60
	Vmax (c+o)	54,00	52,80	50,80	51,40	112,00	32,20	81,80
MM	Vmax (o)	2,63	2,28	2,28	1 990,00	2,66	844,00	1 024,00
	Km (c)	22,03	21,10	20,08	19,61	45,05	11,31	25,25
	Km (c+o)	27,03	26,46	25,38	25,64	56,18	16,08	40,98
	Km (o)	1,31	1,14	1,14	1 000,00	1,33	416,67	500,00
	Vmax (c)	44,05	42,19	40,16	39,22	90,09	22,62	50,51
	Vmax (c+o)	54,05	52,91	50,76	51,28	112,36	32,15	81,97
LB	Vmax (o)	2,63	2,28	2,28	2 000,00	2,66	833,33	1 000,00
	Km (c)	21,98	21,10	20,08	19,61	45,05	11,30	25,32
	Km (c+o)	27,03	26,39	25,38	25,71	55,87	16,10	40,98
	Km (o)	1,31	1,14	1,14	1 000,00	1,33	416,67	500,00
	Vmax (c)	43,96	42,19	40,16	39,22	90,09	22,60	50,63
	Vmax (c+o)	54,05	52,77	50,76	51,41	111,73	32,21	81,97
EH	Vmax (o)	2,63	2,28	2,28	2 000,00	2,66	833,33	1 000,00
	Km (c)	22,03	21,10	20,08	22,22	45,05	11,31	25,25
	Km (c+o)	27,03	26,46	25,38	25,64	56,18	16,08	40,98
	Km (o)	1,31	1,14	1,14	1 000,00	1,33	416,67	500,00
	Vmax (c)	44,05	42,19	40,16	44,44	90,09	22,62	50,51
	Vmax (c+o)	54,05	52,91	50,76	51,28	112,36	32,15	81,97
HW	Vmax (o)	2,63	2,28	2,28	2 000,00	2,66	833,33	1 000,00

Lower Km(oxygenase) than Z. mays (C4) -> Higher affinity to O2.

Very low Vmax compared to C3 or C4.

Rubisco Kinetic Parameters - Hanes-Woolf

This study revealed differences in the kinetic evolution of Rubisco among Posidonia species consistent with their disjunct geographic distribution and phylogenetic divergence, leading to five unique amino acid substitutions in the RbcL of P. oceanica that possibly account for its two-fold poorer Rubisco CO_2-affinity.

Among Australian Posidonia species, we can attribute some of the Rubisco kinetics and quantity variation with differences in their CCM efficiency, as the 40% slower kcat c and 20%–35% lower carboxylation efficiency in P. sinuosa or the two-fold higher Rubisco content in the deep-living P. angustifolia.

Nevertheless, the distinctly slower kcat c, lower CO_2 and O_2 affinities, and lower carboxylation efficiency shared by Posidonia Rubiscos compared with those of their distant terrestrial angiosperm relatives show how the enzyme in these seagrasses have clearly followed an alternative pathway in their kinetic evolution.

However, further refined experiments are needed to accurately map evidence of correlations in the adaptive evolution of Posidonia Rubisco kinetics and their photosynthetic adaptation. Such analyses necessitate an assessment of the contrasting temperature, nutrient, CO_2 concentration, and irradiance characteristics of the habitats of each species, as well as an appreciation of their adaptive Rubisco temperature kinetic response and intracellular O_2 concentration.