Shifts in growth light optima among diatom species support their succession during the spring bloom in the Arctic

Croteau D., Lacour T., Schiffrine N., Morin P.-I., Forget M.-H., Bruyant F., Ferland J., Lafond A., Campbell D.A., Tremblay J.-E., Babin M., Lavaud J.

Supporting Information

Figure S1: Parameters used in this study with their definition and respective units

Parameters	Definition	Unit
α	The light-limited slope of a PE curve	mgC $m^{-3}h^{-1}$ (µmol photons m^{-2} s^{-1})$^{-1}$
α^*	The Chl *a*-specific light-limited slope of a PE curve	mgC mg Chl a^{-1} $m^{-3}h^{-1}$ (µmol photons m^{-2} s^{-1})$^{-1}$
α_μ	The light-limited slope of growth rate versus *gE*	d^{-1} m^2 mol $photons^{-1}$
β	The photoinhibition coefficient of the PE curves	mgC $m^{-3}h^{-1}$ (µmol photons m^{-2} s^{-1})$^{-1}$
η_g	The growth efficiency = μ_{gE}/P_{gE}	Dimensionless
σPSII	The apparent size of PSII antenna functional cross-section of PSII	$Å^2$ $quanta^{-1}$
μ	Growth rate	d^{-1}
μ_M	The maximum fitted growth rate	d^{-1}
C-to-Chl *a*	The carbon to chlorophyll *a* ratio	$g \cdot g^{-1}$
DES	Percentage of xanthophyll pigment de-epoxidized to diatoxanthin	%
E_K	The photoacclimation parameter = P_M/α	µmol photons m^{-2} s^{-1}
F_V/F_M	The dark-acclimated quantum yield of PSII	Dimensionless
gE	Growth light intensity	µmol photons m^{-2} s^{-1}
gEopt	Growth light intensity for maximal growth	µmol photons m^{-2} s^{-1}
P_0	The *y*-intercept of PE curves	mgC m^{-3} s^{-1}
P^*_M	The Chl *a*-specific saturated rate of the PE curves	mgC mg Chl a^{-1} $m^{-3}h^{-1}$
P^C_M	The carbon-specific saturated rate of photosynthesis	d^{-1}
P_{gE}	The C-specific 20 min ^{14}C-uptake under a given *gE* intensity extrapolated over 24 h	d^{-1}
P_M	The maximum carbon fixation rate at saturating light	mgC m^{-3} s^{-1}
P_S	The maximum carbon fixation rate in absence of photoinhibition	mgC m^{-3} s^{-1}

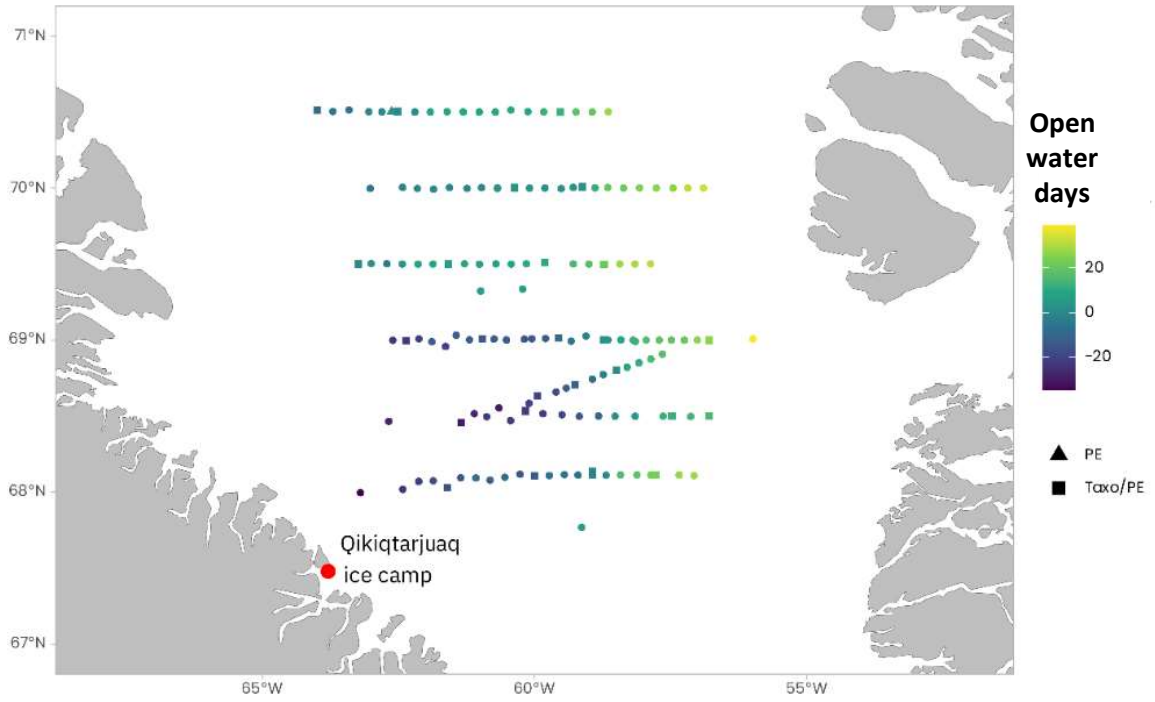


Figure S2: The Amundsen itinerary over the Green Edge 2016 oceanographic campaign in Baffin Bay and location of the 2015-2016 ice camp. Daily photosynthetically available radiation (PAR) was measured at all sampling stations, stations where ^{14}C-uptake photosynthesis response (PE) curves were conducted and diatom taxonomy was assessed are indicated by the symbols found in the legend and the "Open water days" as a proxy to reconstruct seasonal phenology relative to sea ice dynamics are indicated by the color scale in the legend. See Material and methods and Massicotte *et al.,* (2020) for more details on field measurements.

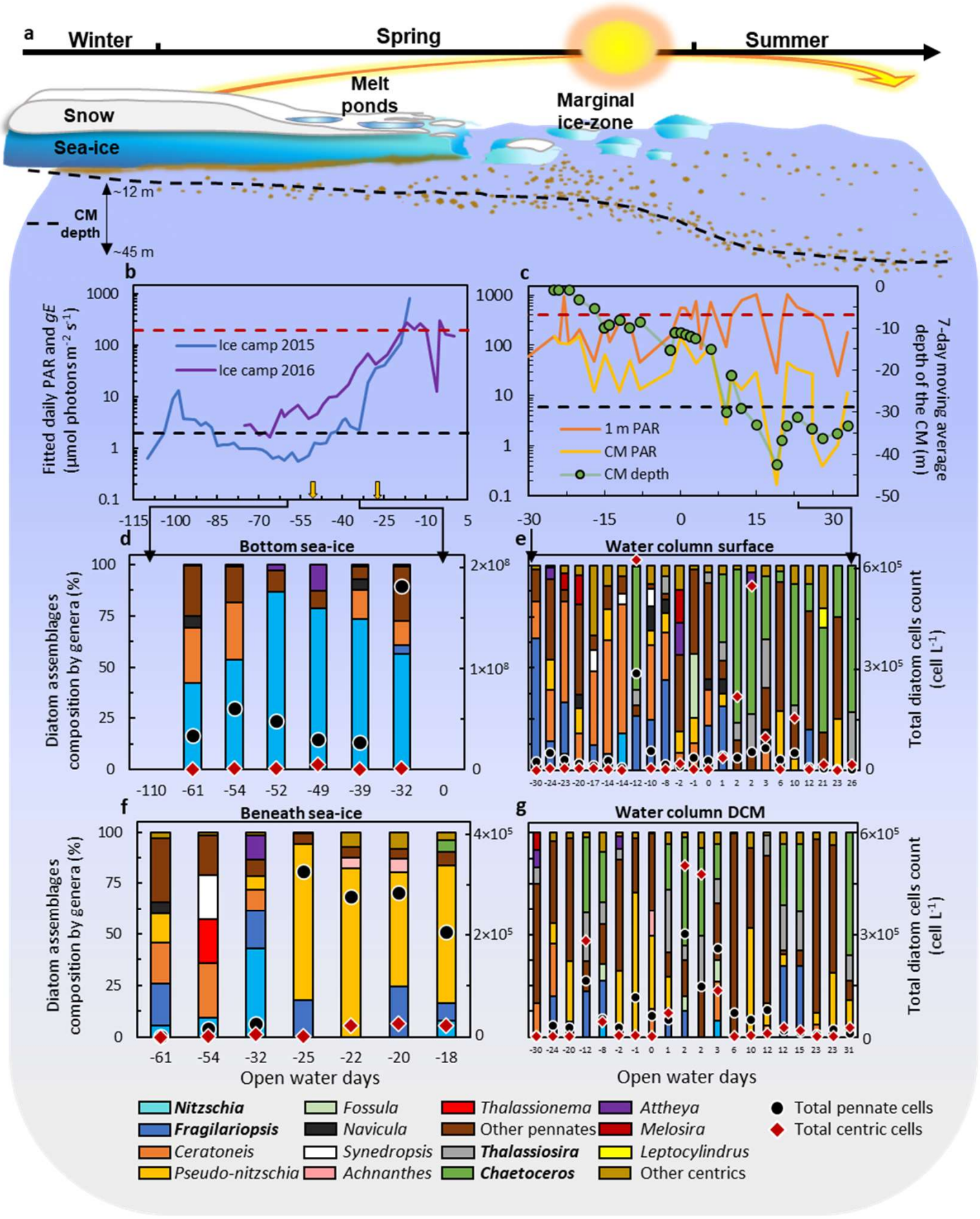

a
Winter
Spring
Summer
Melt ponds
Snow
Sea-ice
Marginal ice-zone
~12 m
CM depth
~45 m
b
Fitted daily PAR and gE (µmol photons m-2 s-1)
Ice camp 2015
Ice camp 2016
c
7-day moving average depth of the CM (m)
1 m PAR
CM PAR
CM depth
d
Bottom sea-ice
Diatom assemblages composition by genera (%)
e
Water column surface
Total diatom cells count (cell L-1)
f
Beneath sea-ice
g
Water column DCM
Open water days
Nitzschia
Fragilariopsis
Ceratoneis
Pseudo-nitzschia
Fossula
Navicula
Synedropsis
Achnanthes
Thalassionema
Other pennates
Thalassiosira
Chaetoceros
Attheya
Melosira
Leptocylindrus
Other centrics
Total pennate cells
Total centric cells

Figure S3: Schematic representation of a typical spring-to-summer Arctic diatom succession in Baffin Bay (where the Green Edge 2015-16 ice-camps (67.48N; 63.79W) and 2016 oceanographic campaigns were conducted) over the habitat transition from snow-covered sea-ice to open waters (a) combined with physical and biological parameters assessed during the Green Edge project. Daily averaged photosynthetically available radiation (PAR) in µmol photons m^{-2} s^{-1} at the sea-ice-water interface during the 2015 (solid blue line) and 2016 (solid orange line) ice-camps (b) , and at the water column surface at ≈1 m (solid green line) and at the chlorophyll maximum (CM) (solid yellow line) during the 2016 oceanographic campaign, with the 7-day moving average of the CM shown in green (c). PAR values are plotted versus open water days (OWD), where day 0 represents sea-ice break-up in (b, d and f) and the first three consecutive days of the season where roughly 50% of water is ice-covered in transient marginal ice zone at a given sample station in (c, e and g). Horizontal dotted lines represent the minimal (black) or maximal (red) *gE* used to grow either a sympagic (b) or a planktonic (c) diatom species in lab during our study. In (b) yellow vertical arrows represent the average chronological timing of snowmelt onset and melt ponds onset in that order. Time series of the taxonomic composition of diatom assemblages, at the genus level for genera amounting more than 5% of total cell counts, sampled over the 2016 Green Edge campaigns in sea-ice cores (d), at surface in the water column (f), in water beneath sea-ice from the ice camp (d) and at the CM in the water column (g), are plotted versus OWD, see Material and methods and Massicotte *et al.,* (2020) for details on *in situ* measurements.

Figure S4: Fitted parameters estimates and statistics of the growth rate (μ) versus growth light intensities (a) and model information (b). The data was fitted according to Eilers and Peeters (1988) (αμ=initial slope of light-limited growth rate; μm=maximal growth rate; gEopt=growth light intensity for maximal growth) using the *nls.multstart* package in the R environment (Padfield *et al.,* 2021).

a)

Species	parameter	estimate	std.error	statistic	p.value
N. frigida	*αμ*	0.036	0.010	3.556	2.87E-03
N. frigida	*μm*	0.153	0.012	13.136	1.24E-09
N. frigida	*gEopt*	23.031	2.911	7.912	9.87E-07
F. cylindrus	*αμ*	0.017	0.005	3.318	4.68E-03
F. cylindrus	*μm*	0.293	0.023	12.953	1.51E-09
F. cylindrus	*gEopt*	46.269	5.751	8.045	8.04E-07
T. gravida	*αμ*	0.057	0.018	3.182	1.11E-02
T. gravida	*μm*	0.296	0.013	22.379	3.36E-09
T. gravida	*gEopt*	88.094	18.325	4.807	9.64E-04
C. neogracilis	*αμ*	0.043	0.006	6.839	5.61E-06
C. neogracilis	*μm*	0.658	0.017	37.680	2.84E-16
C. neogracilis	*gEopt*	206.447	52.287	3.948	1.29E-03
C. gelidus	*αμ*	0.022	0.004	5.111	6.35E-04
C. gelidus	*μm*	0.334	0.019	17.296	3.26E-08
C. gelidus	*gEopt*	75.129	9.202	8.164	1.88E-05

b)

Species	sigma	isConv	finTol	logLik	AIC	BIC	deviance	df.residual	nobs
N.f.	0.023	TRUE	1.49E-08	43.684	-79.369	-75.807	0.008	15	18
F.c.	0.053	TRUE	1.49E-08	29.011	-50.022	-46.460	0.042	15	18
T.g.	0.032	TRUE	1.49E-08	26.102	-44.204	-42.264	0.009	9	12
C.n.	0.048	TRUE	1.49E-08	30.639	-53.278	-49.716	0.035	15	18
C.g.	0.034	TRUE	1.49E-08	25.450	-42.900	-40.960	0.010	9	12

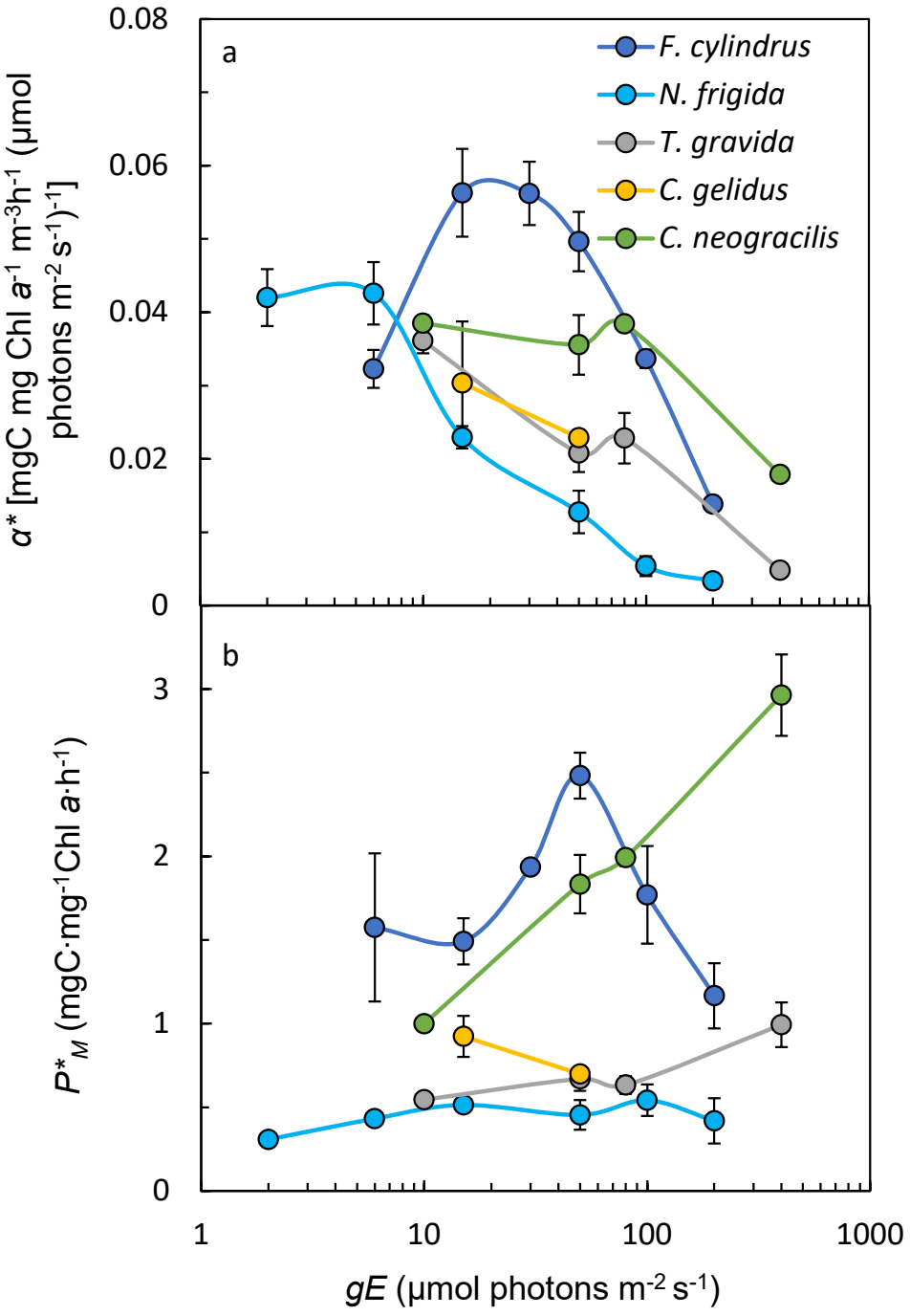
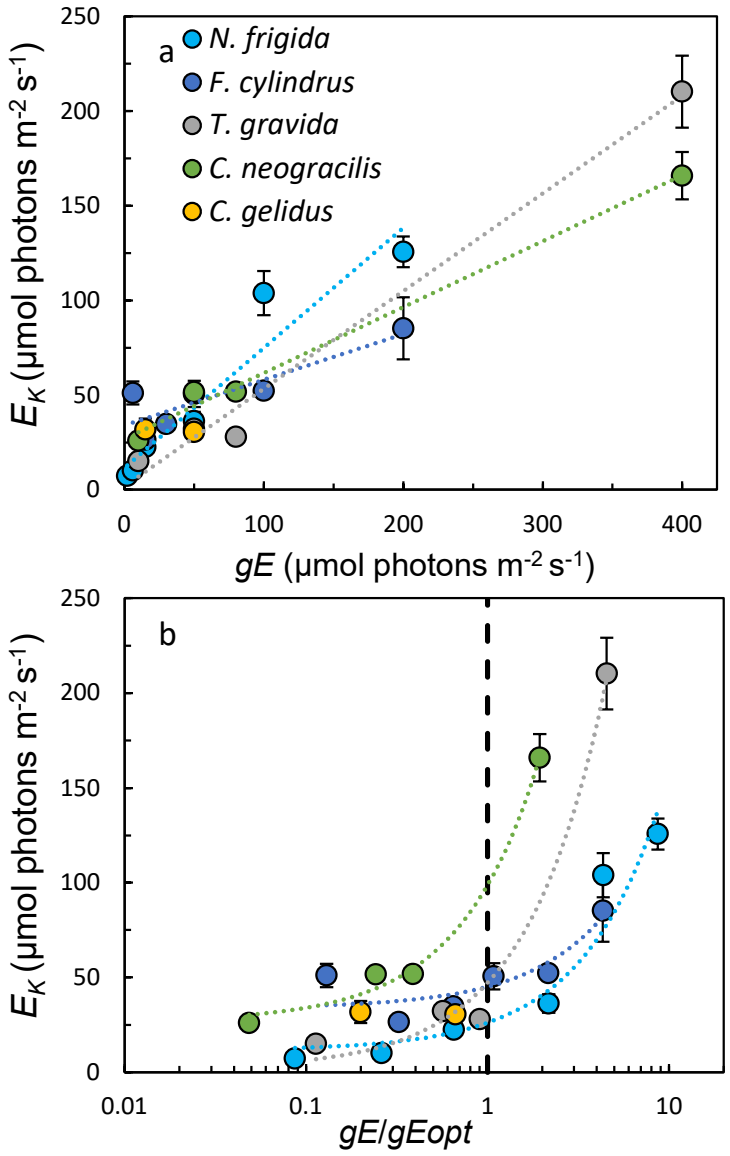


Fig. S5: The chlorophyll (Chl) *a* specific light-limited slope of photosynthesis (α^*) (a) and the light saturated rate of photosynthesis (P^*_M) (b) measured with ^{14}C-uptake photosynthesis response curves plotted versus the growth light (*gE*) intensitiy in the five Arctic diatom species studied. All data points are triplicate mean ± SD.



c

	E_K vs. *gE*			E_K vs. *gE/gEopt*		
Species	Slope	*y*-intercept	R2	Slope	*y*-intercept	R2
N.f.	0.63	11.6	0.91	14.59	11.6	0.91
F.c.	0.24	34	0.99	11.15	34	0.99
T.g.	0.52	1.8	0.99	45.42	1.8	0.99
C.n.	0.35	26.84	0.99	71.86	26.84	0.99

Fig. S6: The photoacclimation parameter (E_K) values plotted versus growth light (*gE*) intensity (a) and the dimensionless ratio between *gE* and *gE* for maximal growth rate (*gE/gEopt*), where the vertical dashed line represents *gE*/*gEopt* = 1, in the five Arctic diatom species studied, and the parameters of the linear relationships (unavailable in *C. gelidus*) (c).

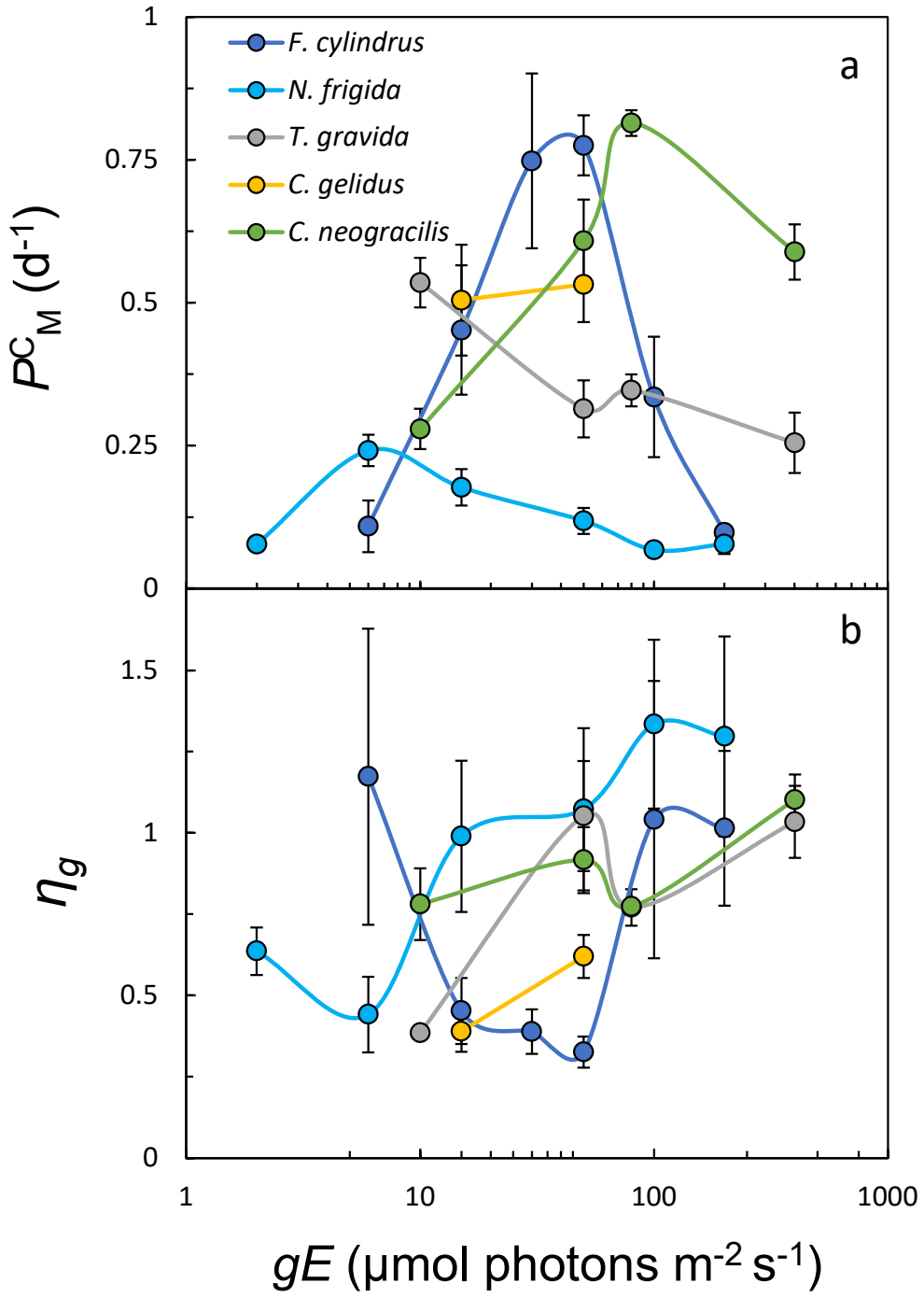


Figure S7 : The carbon specific maximal rate of photosynthesis (P^C_M) measured with ^{14}C-uptake photosynthesis response curves (a) and the growth efficiency (η_g) plotted versus gE (b) in the five Arctic diatom species studied. All data points are triplicate mean ± SD.

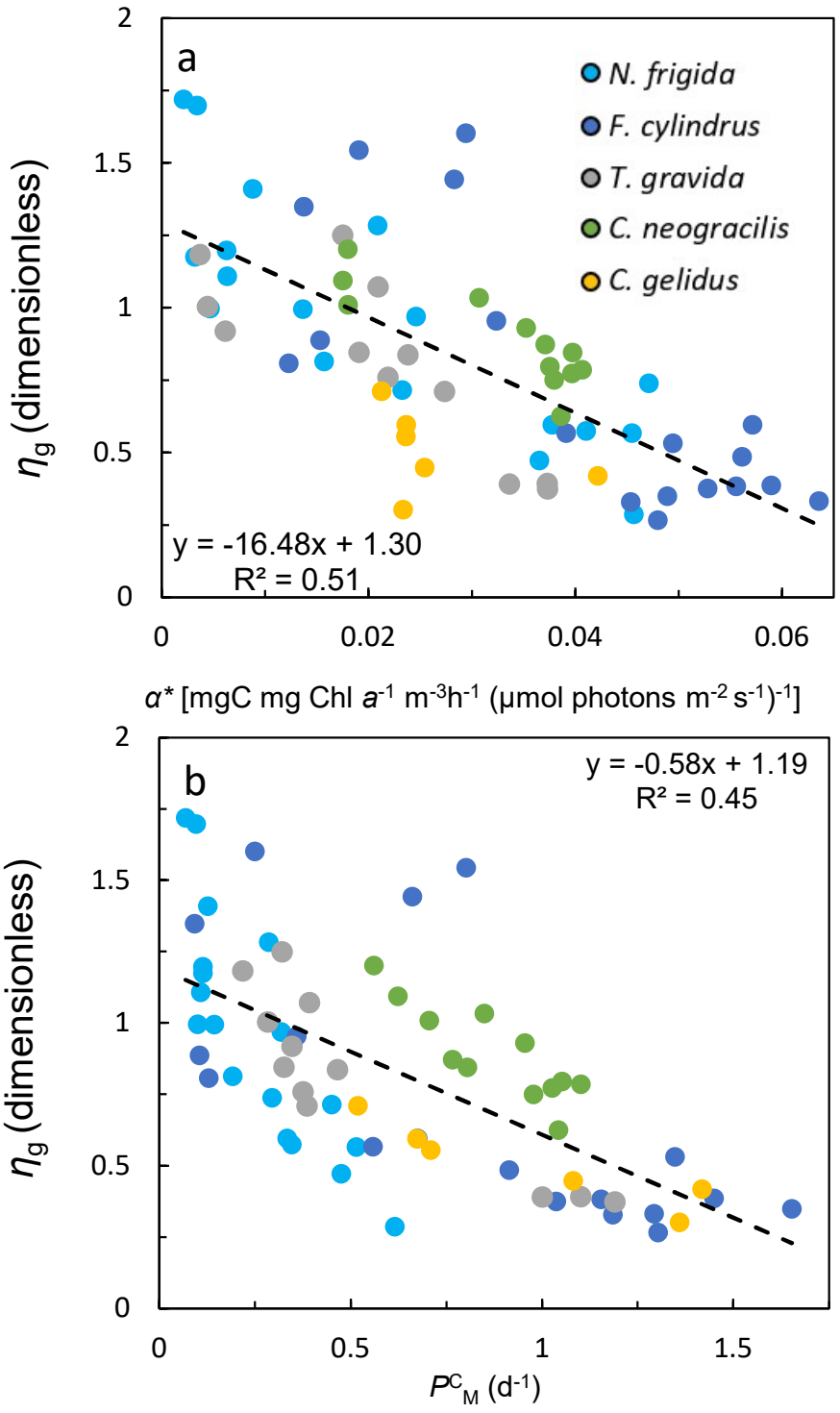


Figure S8: The linear regression of growth efficiency (η_g) as a function of the chlorophyll (Chl) *a*-specific light-limited slope of photosynthesis (α^*) (a) and the carbon specific maximal rate of photosynthesis (P^C_M) (b) in all species acclimated to every growth light.

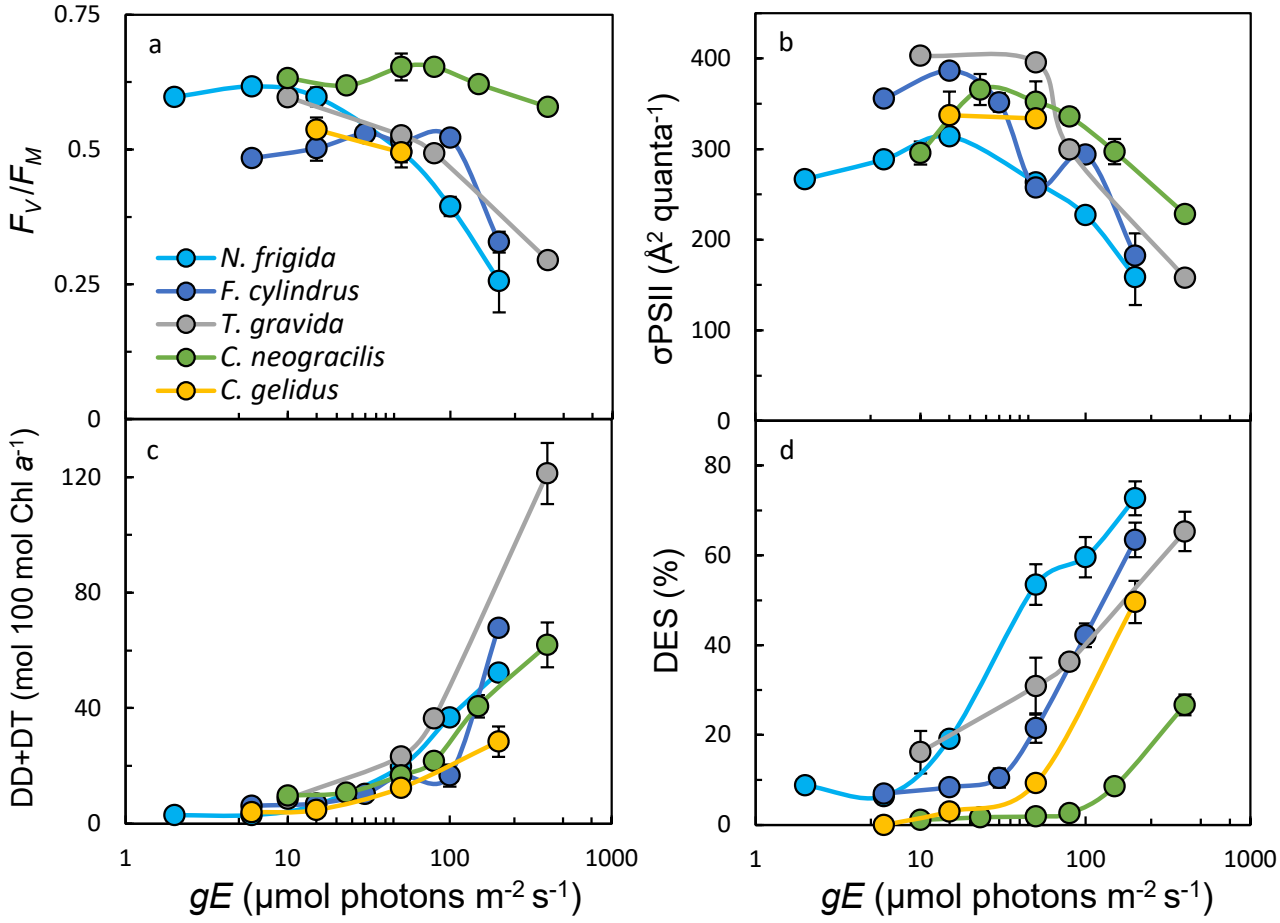


Figure S9: The dark-acclimated quantum yield of photosystem (PS) II (F_V/F_M) (a), the apparent size of PSII antenna functional cross-section (σPSII) (b), the sum of xanthophyll pigments diadinoxanthin (DD) and diatoxanthin (DT) (c) and the de-epoxidation state (DES) of the xanthophyll pool (d) plotted versus growth light (*gE*) intensity in the five Arctic diatom species studied. All data points are triplicate mean ± SD.

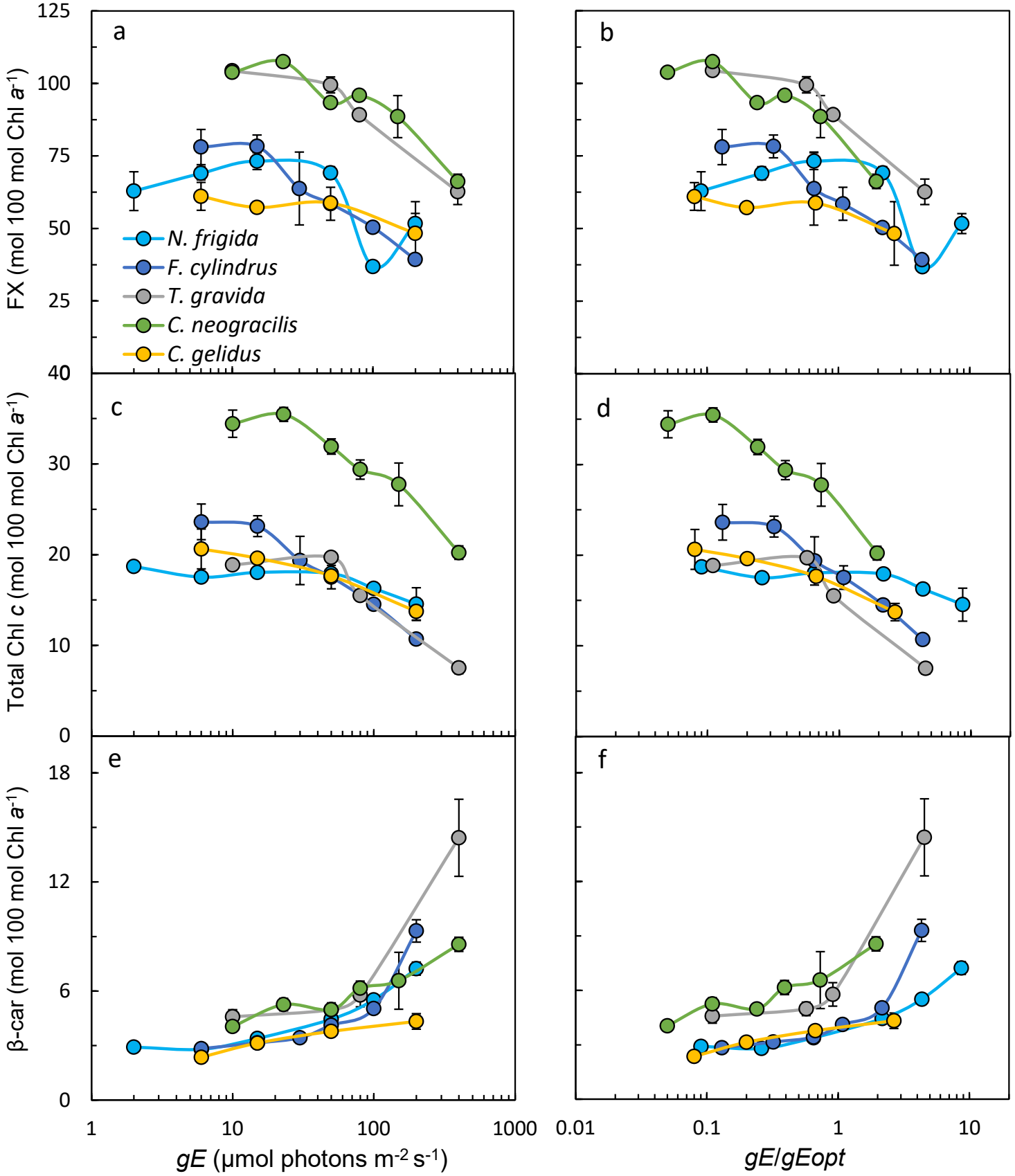
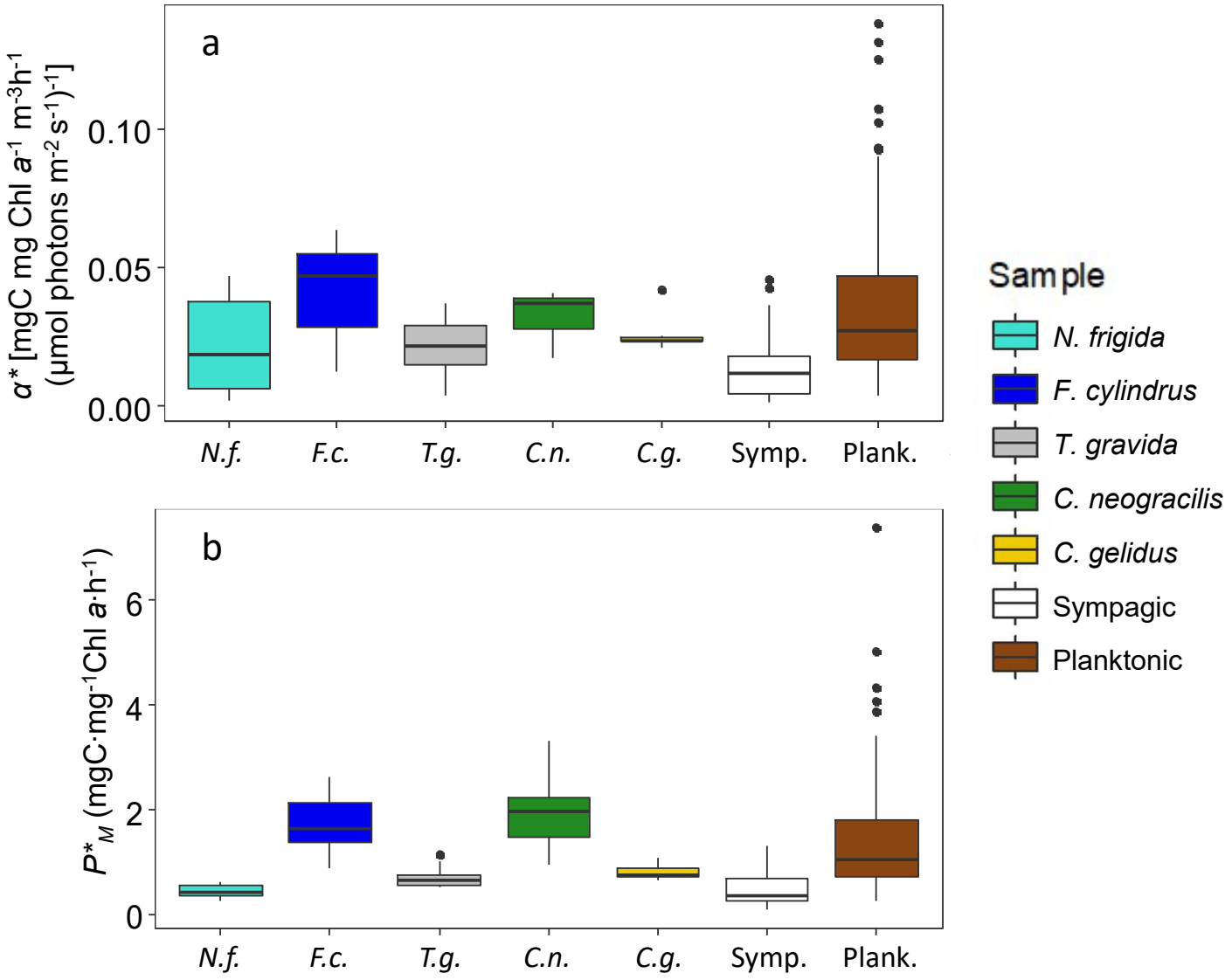


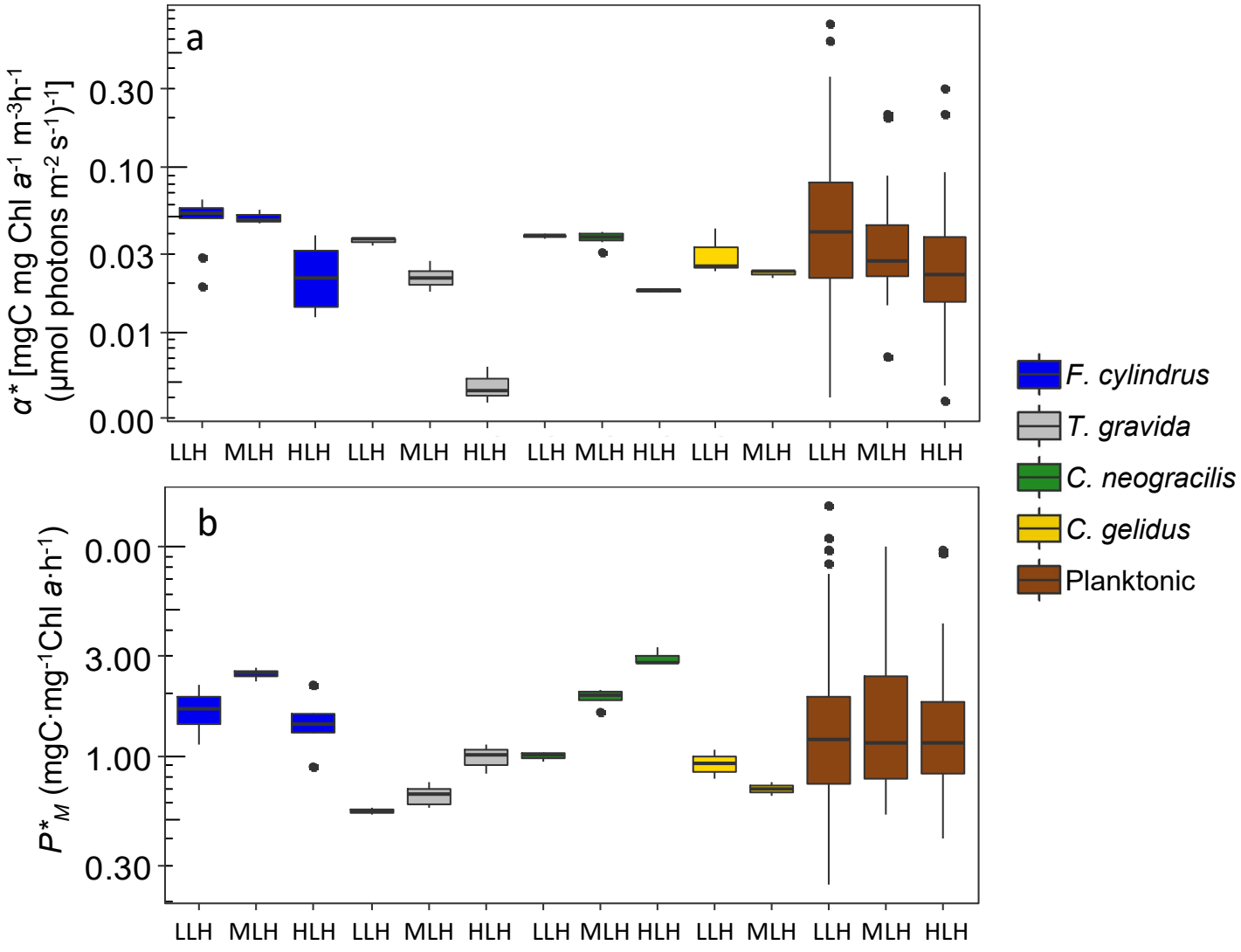
Figure S10: Fucoxanthin (FX) (a-b), total chlorophyll (Chl) *c* (c-d) and β-carotene (β-car) (e-f) contents plotted versus growth light (*gE*) intensity (a, c and e) and the dimensionless ratio between *gE* and *gE* for maximal growth rate (*gE/gEopt*), (b, d, and f) in the five Arctic diatom species studied. All data points are triplicate mean ± SD.



c

Params	Df1	Df2	Df3	Fvalue Sample	Pvalue Sample	Fvalue LH	Pvalue LH	Fvalue interaction	Pvalue interaction	*N.f.*	*F.c.*	*T.g.*	*C.n.*	*C.g.*	Sympagic	Planktonic	LLH	MLH	HLH
α*	6	2	11	6.909	1.09E-06	14.913	9.10E-07	0.436	0.938	ab	a	ab	ab	ab	b	a	a	ab	b
P*m	6	2	11	10.314	7.10E-10	0.225	0.799	1.159	0.318	c	a	bc	a	abc	c	ab	a	a	a

Figure S11: Boxplots comparing data distribution of chlorophyll (Chl) *a* specific light-limited slope of photosynthesis (α^*) (a) and light saturated rate of photosynthesis (P^*_M) measured on lab monocultures and sympagic communities sampled during the Green-Edge 2016 ice-camp and planktonic communities sampled during the 2016 Amundsen expedition. In (c), results of the 2-way ANOVA and Tukey's HSD test used to identify significant difference with sample (species and communities from each habitat) and light history (LH) as factors. LH refers to growth light intensity (*gE*) for lab cultures or daily *in situ* photosynthetically available radiation (PAR) for natural communities. Low LH (LLH), medium LH (MLH) and high LH (HLH) are assigned to daily average *gE* or PAR of < 40, between 40 and 80 and > 80 µmol photons m^{-2} s^{-1} respectively. Different letters indicate significantly different groups by Tukey's HSD test.



c

params	Df1	Df2	F-value	p-value
α*	13	205	0.894	0.561
P^*_M	13	203	0.585	0.864

Figure S12: Boxplots comparing data distribution of chlorophyll (Chl) *a* specific light-limited slope of photosynthesis (α^*) (a) and light-saturated rate of photosynthesis (P^*_M) measured on lab monocultures of species abundant in the Arctic Ocean water column and planktonic communities sampled during the Green-Edge 2016 Amundsen expedition. Samples (species or *in situ* planktonic samples) are sub-grouped by light history (LH) which refers to growth light intensity (*gE*) for cultures or daily *in situ* photosynthetically available radiation (PAR). Low LH (LLH), medium LH (MLH) and high LH (HLH) are assigned to daily average *gE* or PAR of < 40, between 40 and 80 and > 80 µmol photons m^{-2} s^{-1} respectively. In (c), results of the ANOVA used to show no significant differences between groups of sample*LH.