

Supplementary information for 'Vertical structure of phytoplankton in stratified oceans will shift in a warming climate'

February 1, 2026

This supplementary material contains the following supplemental Figures and Tables:

- Supplemental Figures: Figures S1–S14
- Supplemental Tables: Tables S1–S4

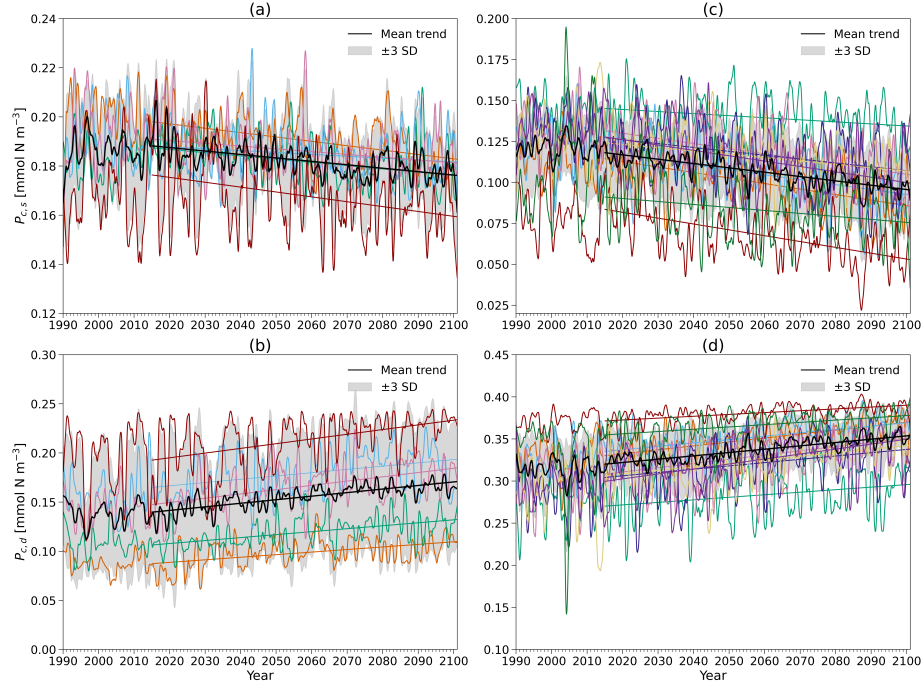


Figure S1: (a) Deseasonalized phytoplankton concentration averaged above the mixed layer (surface layer), 1990–2100, from the two-layer NPZ model at BATS, forced by historical records (1990–2014) and projected data (2015–2100) from BCC-CSM2-MR (orange), CESM2-WACCM (bluish green), CMCC-CM2-SR5 (blue), CMCC-ESM2 (pink), and GFDL-ESM4 (dark red) under the SSP5–8.5 scenario. Straight lines indicate linear regressions fitted to deseasonalized data from 2015 to 2100. The black line shows the five-model mean, and the grey shading represents ± 3 standard deviations around the mean. (b) As in (a), but for deseasonalized phytoplankton concentration averaged between the mixed layer and the euphotic zone (subsurface layer). (c) As in (a), but for phytoplankton surface concentration at HOT, with the input of the historical records (1990–2014) and projected data (2015–2100) from CanESM5 (orange), CESM2-WACCM (bluish green), CMCC-CM2-SR5 (light blue), CMCC-ESM2 (pink), GFDL-ESM4 (brown), EC-Earth3 (navy), EC-Earth3-Veg (gold), IPSL-CM6A-LR (purple), and NorESM-MM (forest green) under the SSP5–8.5 scenario. (d) As in (c), but for the subsurface phytoplankton concentration averaged between the mixed layer and the euphotic zone.

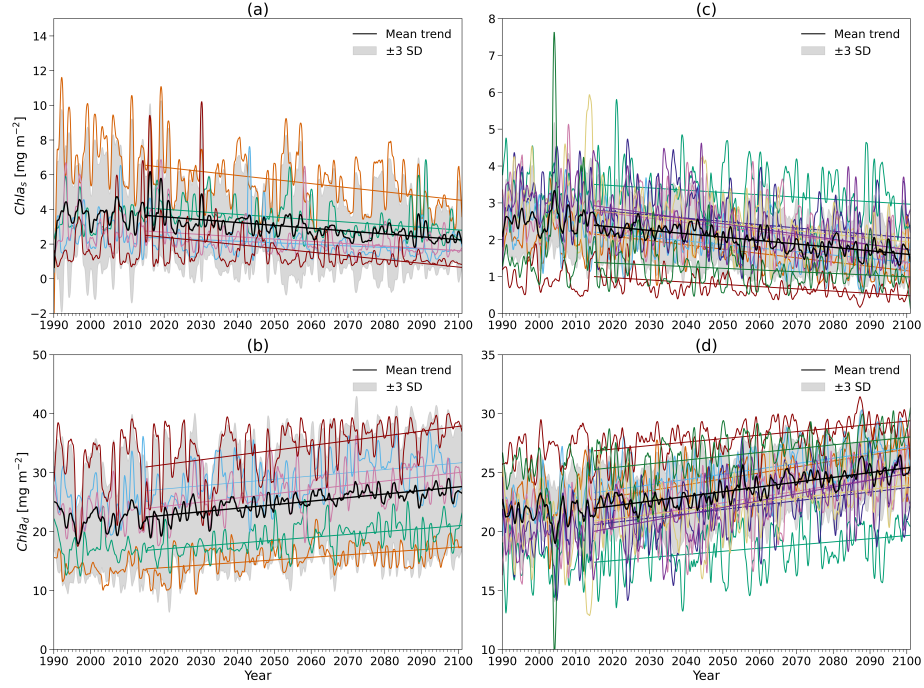


Figure S2: As in Fig. S1 but for chlorophyll-a integration.

Table S1: Predicted surface and subsurface trend of deseasonalised phytoplankton concentration from 2015 to 2100 under scenarios SSP5–8.5 and SSP1–2.6 at BATS and HOT

Station	Input data	$P_{c,s}$ SSP5-8.5 [mmol N m ⁻³ yr ⁻¹]	$P_{c,d}$ SSP5-8.5 [mmol N m ⁻³ yr ⁻¹]	$P_{c,s}$ SSP1-2.6 [mmol N m ⁻³ yr ⁻¹]	$P_{c,d}$ SSP1-2.6 [mmol N m ⁻³ yr ⁻¹]
BATS	Mean	-0.00014 (p<< 0.05)	0.00036 (p<< 0.05)	-0.00003 (p<< 0.05)	0.00013 (p<< 0.05)
	BCC-CSM2-MR	-0.00018 (p<< 0.05)	0.00026 (p<< 0.05)	0.00009 (p<< 0.05)	0.00001 (p=0.32)
	CESM2-WACCM	-0.00013 (p<< 0.05)	0.00030 (p<< 0.05)	-0.00014 (p<< 0.05)	0.00033 (p<< 0.05)
	CMCC-CM2-SR5	-0.00008 (p<< 0.05)	0.00033 (p<< 0.05)	-0.00006 (p<< 0.05)	0.00020 (p<< 0.05)
	CMCC-ESM2	-0.00011 (p<< 0.05)	0.00044 (p<< 0.05)	0.00004 (p=0.01)	-0.00013 (p<< 0.05)
	GFDL-ESM4	-0.00020 (p<< 0.05)	0.00048 (p<< 0.05)	-0.00010 (p<< 0.05)	0.00024 (p<< 0.05)
HOTS	Mean	-0.00026 (p<< 0.05)	0.00040 (p<< 0.05)	-0.00006 (p<< 0.05)	0.00011 (p<< 0.05)
	CanESM5	-0.00034 (p<< 0.05)	0.00047 (p<< 0.05)	-0.00002 (p=0.35)	0.00006 (p=0.004)
	CESM2-WACCM	-0.00013 (p<< 0.05)	0.00030 (p<< 0.05)	0.00009 (p<< 0.05)	-0.00009 (p=0.003)
	CMCC-CM2-SR5	-0.00030 (p<< 0.05)	0.00040 (p<< 0.05)	-0.00017 (p<< 0.05)	0.00023 (p<< 0.05)
	CMCC-ESM2	-0.00031 (p<< 0.05)	0.00050 (p<< 0.05)	-0.00021 (p<< 0.05)	0.00034 (p<< 0.05)
	EC-Earth3	-0.00024 (p<< 0.05)	0.00039 (p<< 0.05)	0.00002 (p=0.32)	0.00010 (p=0.001)
	EC-Earth-Veg	-0.00020 (p<< 0.05)	0.00042 (p<< 0.05)	-0.00002 (p=0.15)	0.00006 (p=0.04)
	IPSL-CM6A	-0.00033 (p<< 0.05)	0.00059 (p<< 0.05)	-0.00013 (p<< 0.05)	0.00020 (p<< 0.05)
	NorESM-MM	-0.00018 (p<< 0.05)	0.00027 (p<< 0.05)	-0.00002 (p=0.30)	0.00008 (p<< 0.05)
	GFDL-ESM4	-0.00036 (p<< 0.05)	0.00022 (p<< 0.05)	-0.00005 (p=0.004)	0.00004 (p=0.000)

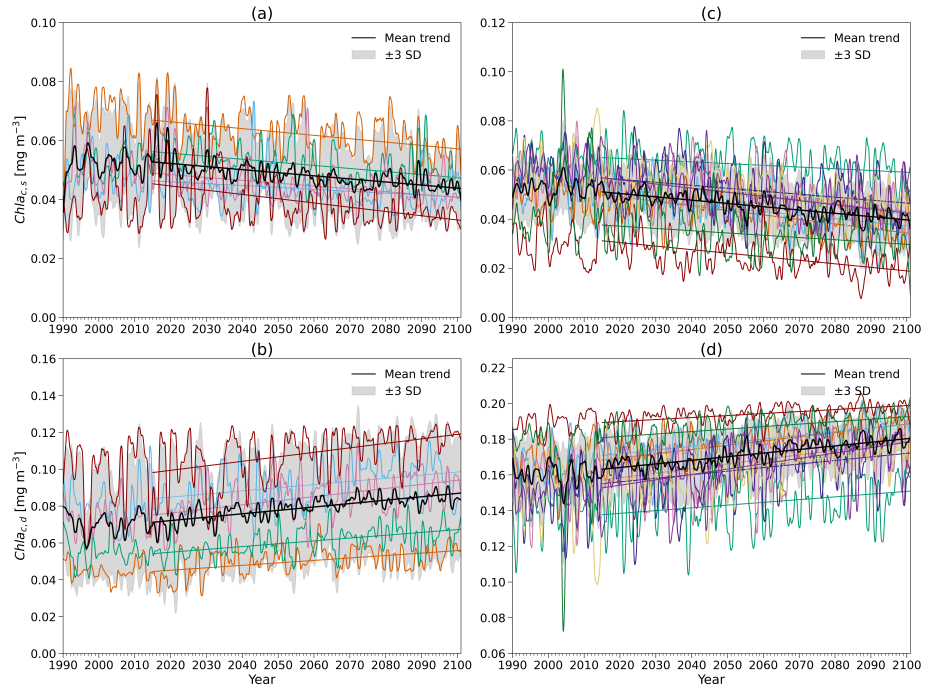


Figure S3: As in Fig S1 but for chlorophyll-a concentration

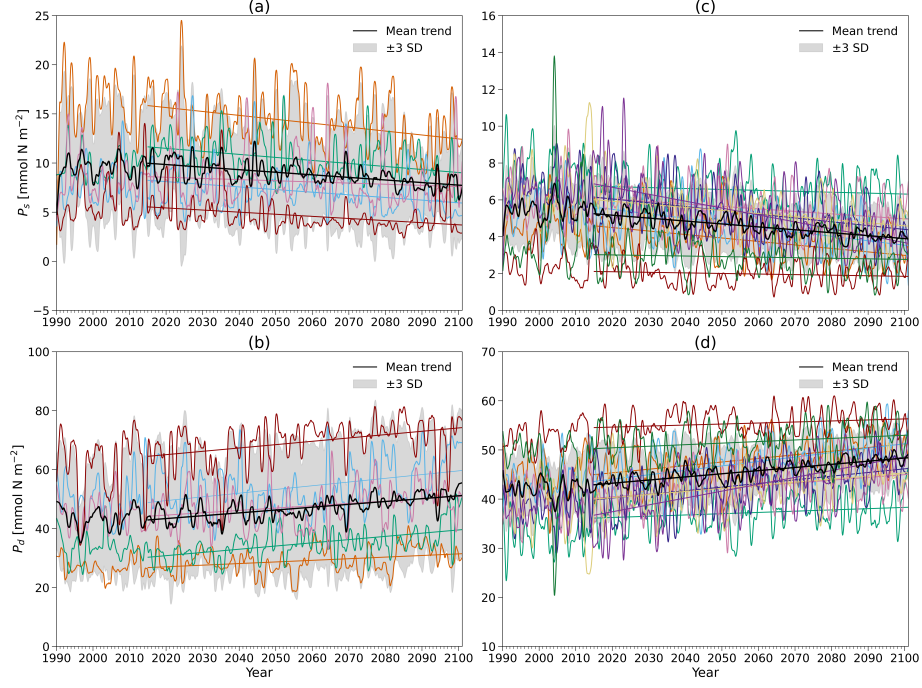


Figure S4: (a) Deseasonalized phytoplankton stocks above the mixed layer (surface layer), 1990–2100, from the two-layer NPZ model at BATS, forced by historical records (1990–2014) and projected data (2015–2100) from BCC-CSM2-MR (orange), CESM2-WACCM (bluish green), CMCC-CM2-SR5 (blue), CMCC-ESM2 (pink), and GFDL-ESM4 (dark red) under the SSP3–7.0 scenario. Straight lines indicate linear regressions fitted to deseasonalized data from 2015 to 2100. The black line shows the five-model mean, and the grey shading represents ± 3 standard deviations around the mean. (b) As in (a), but for deseasonalized phytoplankton stocks between the mixed layer and the euphotic zone (subsurface layer). (c) As in (a), but for phytoplankton surface stocks at HOT, with the input of the historical records (1990 – 2014) and projected data (2015 – 2100) from CanESM5 (orange), CESM2-WACCM (bluish green), CMCC-CM2-SR5 (light blue), CMCC-ESM2 (pink), GFDL-ESM4 (brown), EC-Earth3 (navy), EC-Earth3-Veg (gold), IPSL-CM6A-LR (purple), and NorESM-MM (forest green) under the SSP3–7.0 scenario. (d) As in (c), but for the subsurface layer between the mixed layer and the euphotic zone.

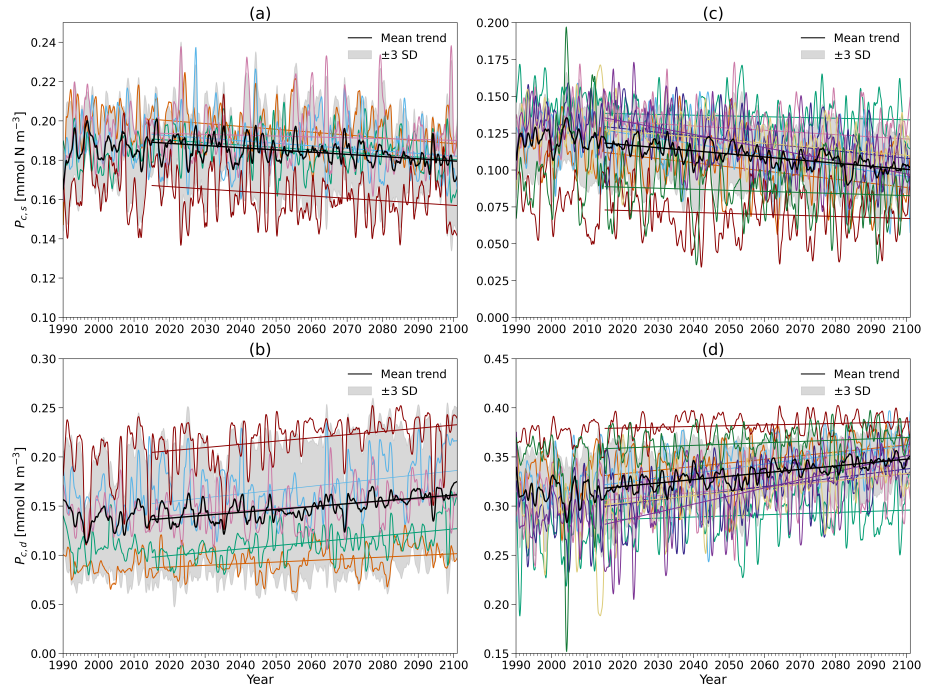


Figure S5: As in Fig S4 but for phytoplankton concentration.

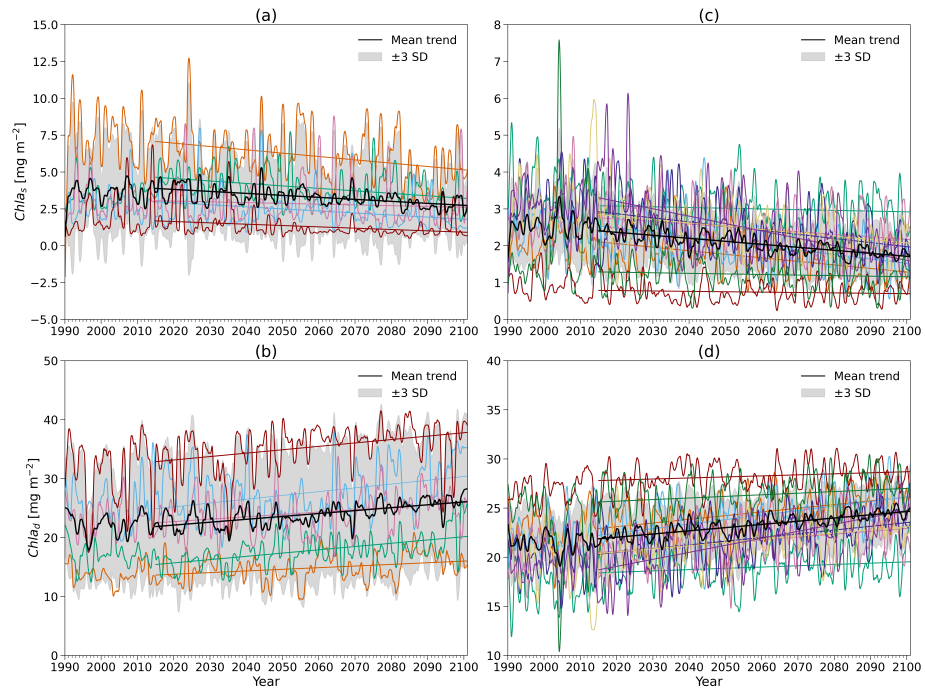


Figure S6: As in Fig. S4 but for chlorophyll-a stocks.

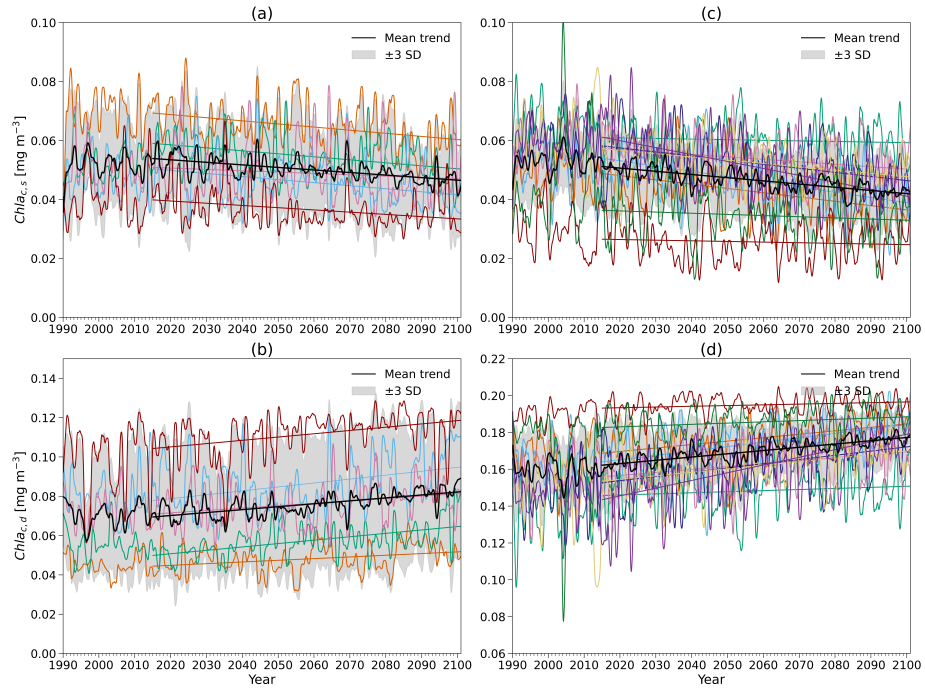


Figure S7: As in Fig. S4 but for chlorophyll-a concentration.

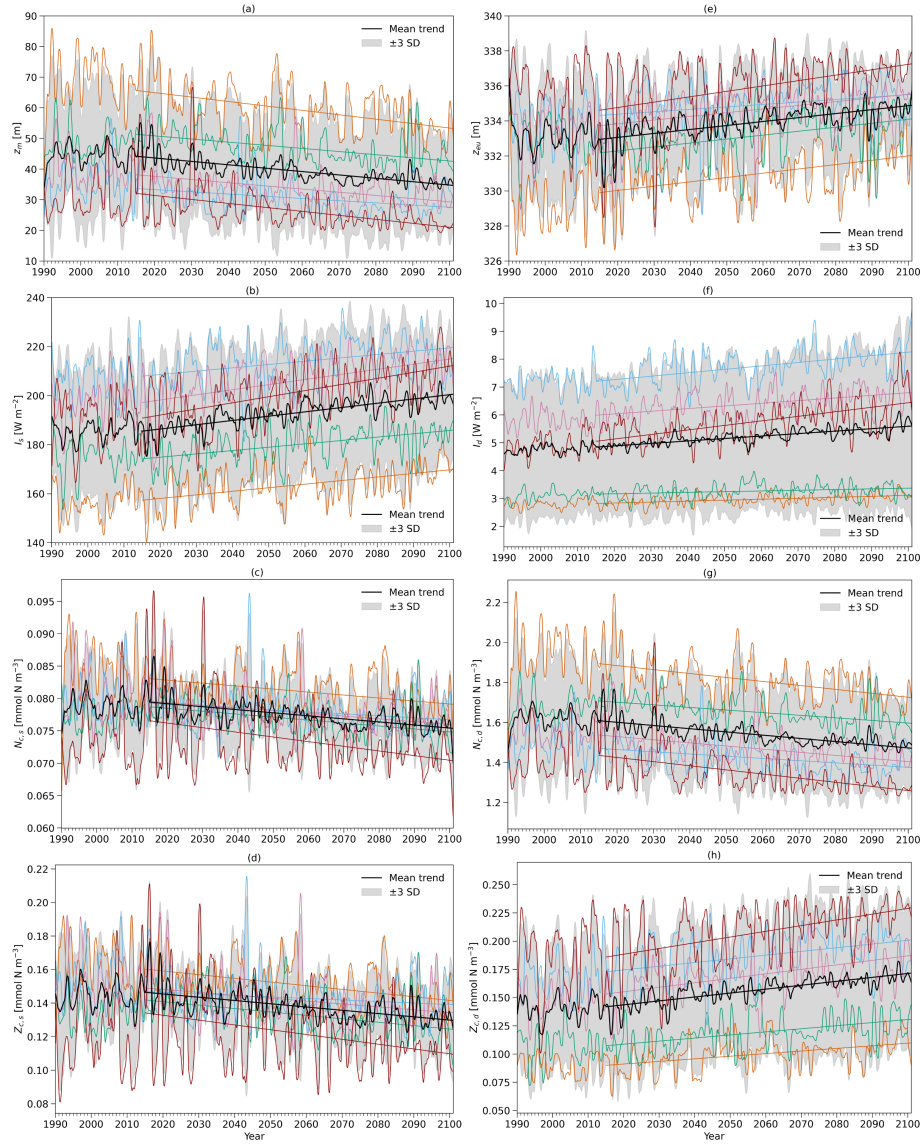


Figure S8: (a) Deseasonalized historical (1990–2014) and projected (2015–2100) mixed layer depth (z_m) from BCC-CSM2-MR (orange), CESM2-WACCM (bluish green), CMCC-CM2-SR5 (blue), CMCC-ESM2 (pink), and GFDL-ESM4 (dark red) SSP5–8.5 scenario at BATS. Straight lines indicate linear regressions fitted to deseasonalized data from 2015 to 2100. The black line shows the five-model mean, and the grey shading represents ± 3 standard deviations around the mean. (b) As in (a), but for simulated vertical-averaged light across z_m running with the input of the historical records (1990–2014) and projected data (2015–2100) from BCC-CSM2-MR (orange), CESM2-WACCM (bluish green), CMCC-CM2-SR5 (blue), CMCC-ESM2 (pink), and GFDL-ESM4 (dark red) under the SSP 5–8.5 scenario. (c) As in (b) but for surface vertical-averaged nutrient concentration. (d) As in (b) but for surface vertical-averaged zooplankton concentration. (e) As in (b) but for the simulated euphotic zone (bottom boundary, z_{eu}). (f) As in (b) but for simulated subsurface (from z_m to z_{eu}) vertical-averaged light. (g) As in (f) but for subsurface vertical-averaged nutrient concentration. (h) As in (f) but for subsurface vertical-averaged zooplankton concentration.

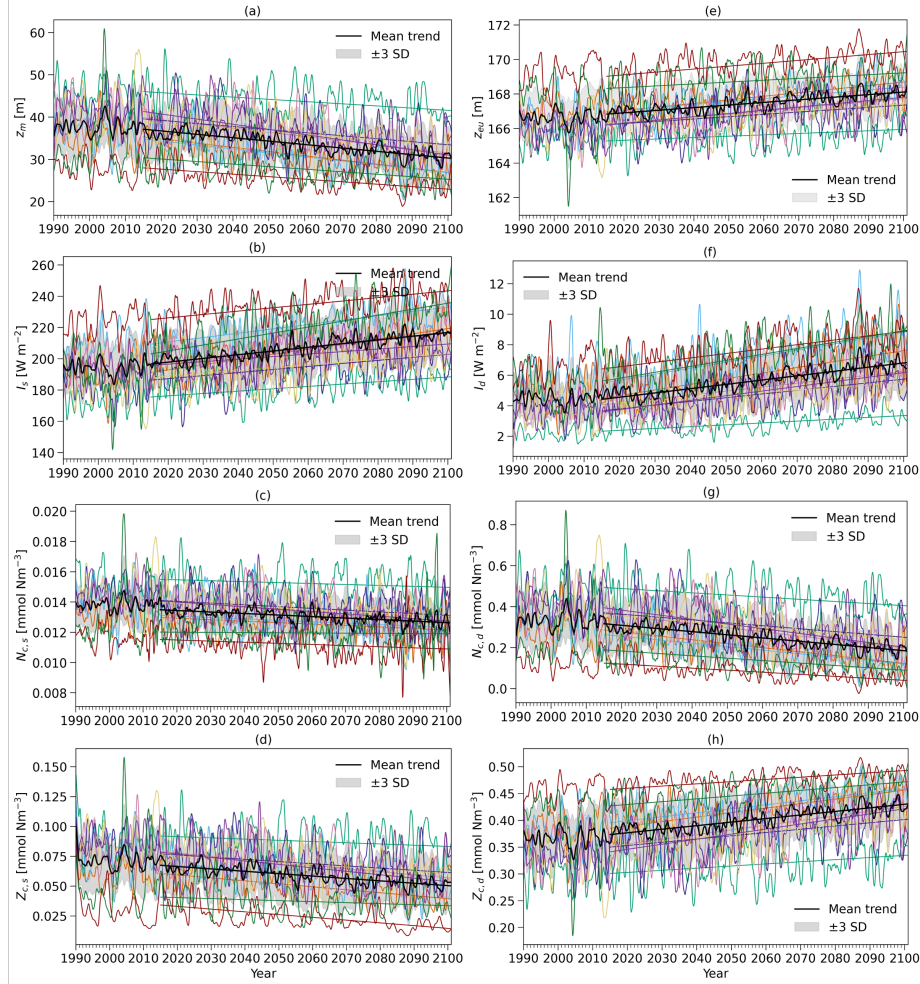


Figure S9: (a) Deseasonalized historical (1990–2014) and projected (2015–2100) mixed layer depth (z_m) from CanESM5 (orange), CESM2-WACCM (bluish green), CMCC-CM2-SR5 (light blue), CMCC-ESM2 (pink), GFDL-ESM4 (brown), EC-Earth3 (navy), EC-Earth-Veg (gold), IPSL-CM6A (purple), and NorESM-MM (forest green) SSP5–8.5 scenario at HOT. Straight lines indicate linear regressions fitted to deseasonalized data from 2015 to 2100. The black line shows the nine-model mean, and the grey shading represents ± 3 standard deviations around the mean. (b) As in (a), but for simulated vertical-averaged light across z_m running with the input of the historical records (1990–2014) and projected data (2015–2100) from CanESM5 (orange), CESM2-WACCM (bluish green), CMCC-CM2-SR5 (light blue), CMCC-ESM2 (pink), GFDL-ESM4 (brown), EC-Earth3 (navy), EC-Earth3-Veg (gold), IPSL-CM6A-LR (purple), and NorESM-MM (forest green) under the SSP5–8.5 scenario. (c) As in (b) but for surface vertical-averaged nutrient concentration. (d) As in (b) but for surface vertical-averaged zooplankton concentration. (e) As in (b) but for the simulated euphotic zone (bottom boundary, z_{eu}). (f) As in (b) but for simulated subsurface (from z_m to z_{eu}) vertical-averaged light. (g) As in (f) but for subsurface vertical-averaged nutrient concentration. (h) As in (f) but for subsurface vertical-averaged zooplankton concentration.

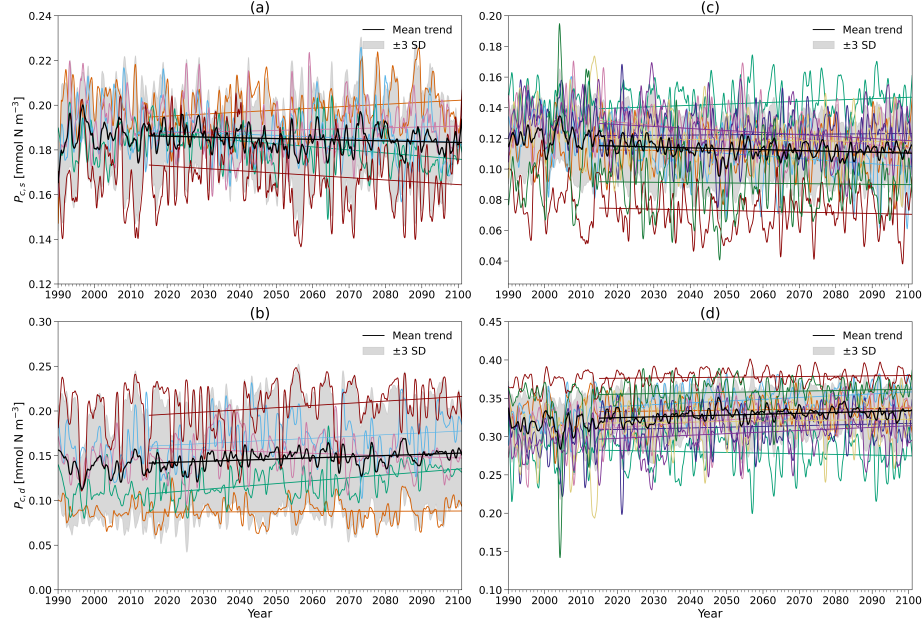


Figure S10: (a) Deseasonalized phytoplankton concentration averaged above the mixed layer (surface layer), 1990–2100, from the two-layer NPZ model at BATS, forced by historical records (1990–2014) and projected data (2015–2100) from BCC-CSM2-MR (orange), CESM2-WACCM (bluish green), CMCC-CM2-SR5 (blue), CMCC-ESM2 (pink), and GFDL-ESM4 (dark red) under the SSP1–2.6 scenario. Straight lines indicate linear regressions fitted to deseasonalized data from 2015 to 2100. The black line shows the model mean, and the grey shading represents ± 3 standard deviations around the mean. (b) As in (a), but for deseasonalized phytoplankton concentration averaged between the mixed layer and the euphotic zone (subsurface layer). (c) As in (a), but for phytoplankton surface concentration at HOT, with the input of the historical records (1990–2014) and projected data (2015–2100) from CanESM5 (orange), CESM2-WACCM (bluish green), CMCC-CM2-SR5 (light blue), CMCC-ESM2 (pink), GFDL-ESM4 (brown), EC-Earth3 (navy), EC-Earth-Veg (gold), IPSL-CM6A (purple), and NorESM-MM (forest green) under the SSP1–2.6 scenario. (d) As in (c), but for the subsurface phytoplankton concentration averaged between the mixed layer and the euphotic zone.

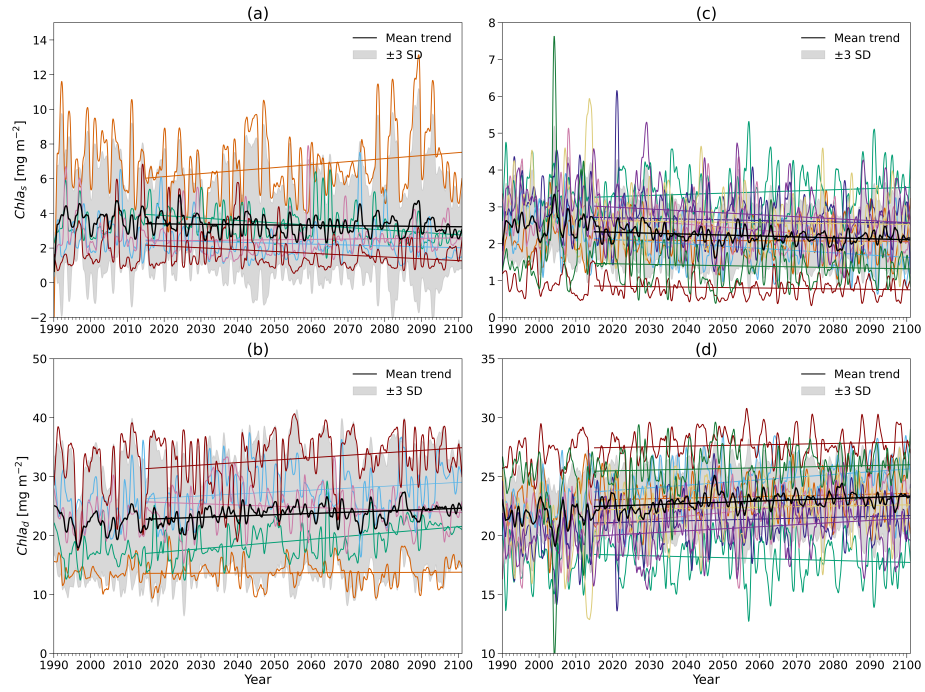


Figure S11: As in Fig. S10 but for chlorophyll-a stocks.

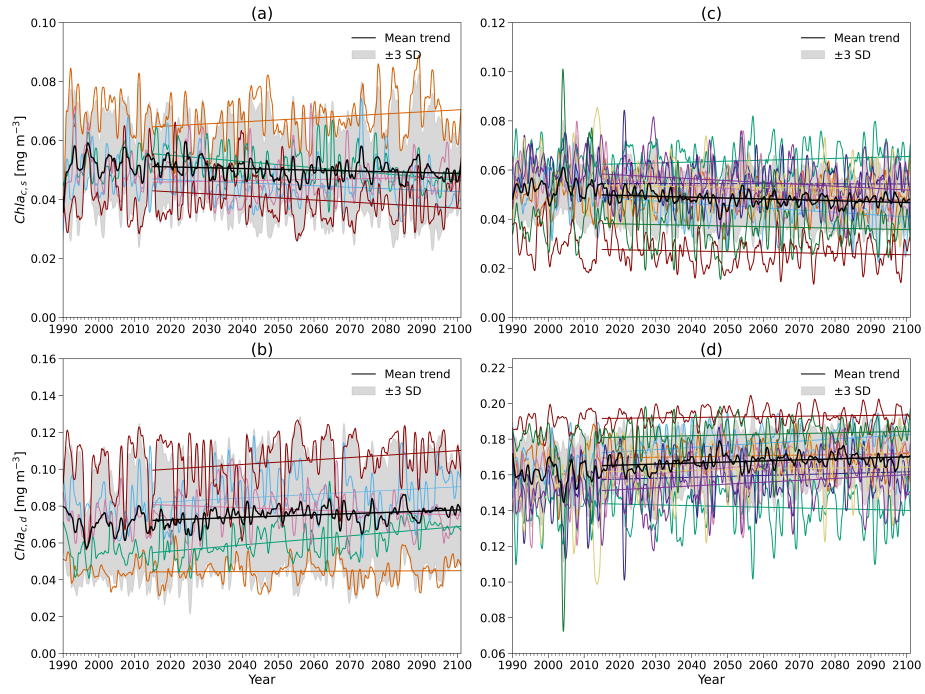


Figure S12: As in Fig. S10 but for chlorophyll-a concentration.

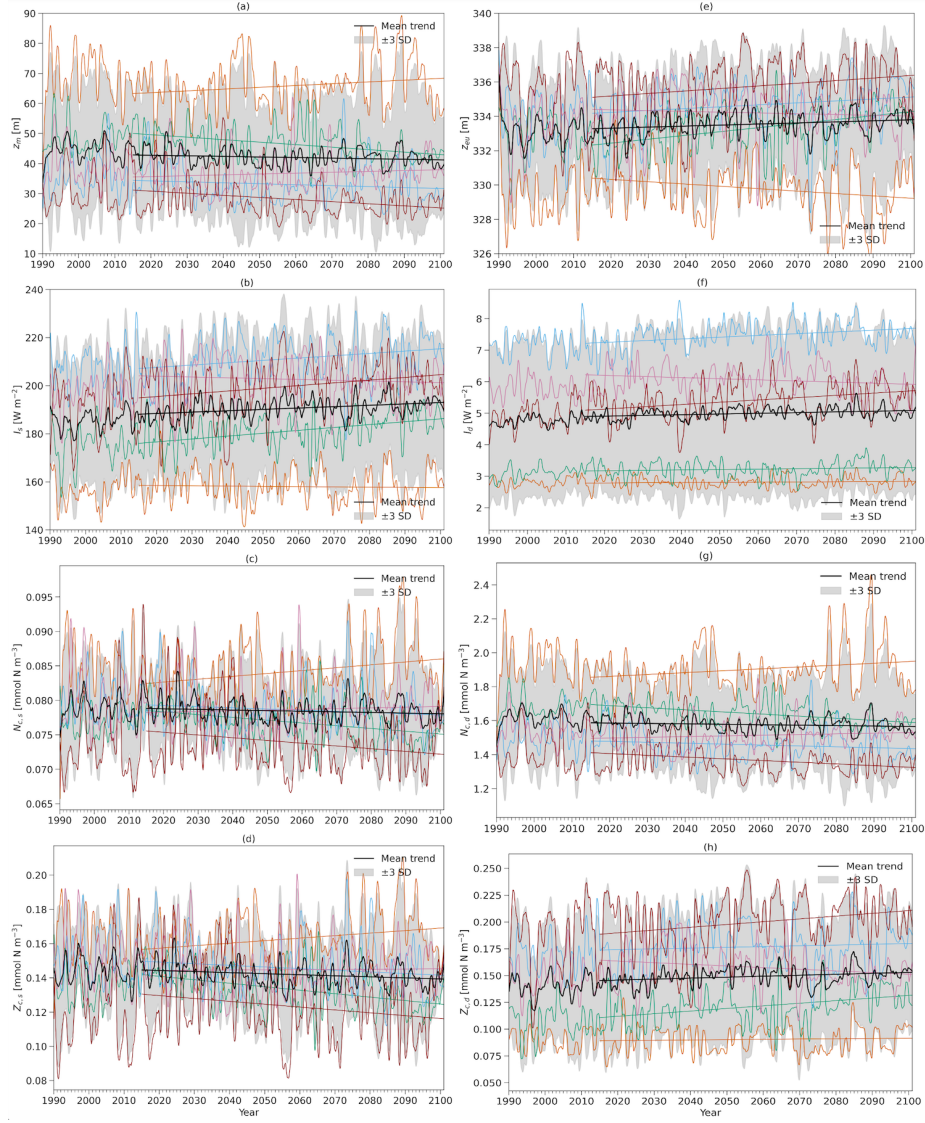


Figure S13: As in Fig. S11 but for results under SSP1-2.6 scenarios.

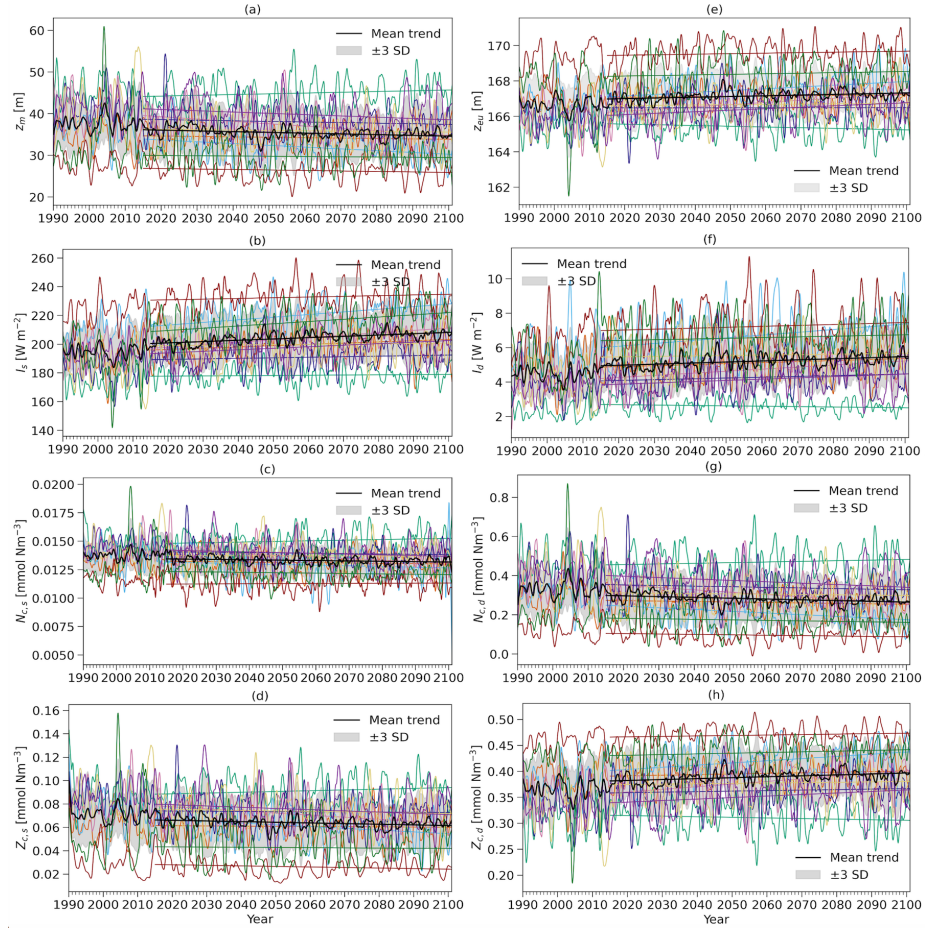


Figure S14: As in Fig. S12 but for results under SSP1-2.6 scenarios.

Table S2: Predicted surface and subsurface trend of deseasonalised phytoplankton integration from 2015 to 2100 under scenarios SSP585 and SSP126 at BATS and HOT.

Station	Input data	$Chla_s$ SSP5-8.5	$Chla_d$ SSP5-8.5	$Chla_s$ SSP1-2.6	$Chla_d$ SSP1-2.6	$Chla_{c,s}$ SSP5-8.5	$Chla_{c,d}$ SSP5-8.5	$Chla_{c,s}$ SSP1-2.6	$Chla_{c,d}$ SSP1-2.6
		[mg m ⁻² yr ⁻¹]	[mg m ⁻² yr ⁻¹]	[mg m ⁻² yr ⁻¹]	[mg m ⁻² yr ⁻¹]	[mg m ⁻³ yr ⁻¹]	[mg m ⁻³ yr ⁻¹]	[mg m ⁻³ yr ⁻¹]	[mg m ⁻³ yr ⁻¹]
BATS	Mean	-0.016 (p<<0.05)	0.060 (p<<0.05)	-0.002 (p=0.002)	0.022 (p<<0.05)	-0.00010 (p<<0.05)	0.00018 (p<<0.05)	-0.00003 (p<<0.05)	0.00007 (p<<0.05)
	BCC-CSM2-MR	-0.023 (p<<0.05)	0.044 (p<<0.05)	0.017 (p<<0.05)	0.002 (p=0.37)	-0.00011 (p<<0.05)	0.00013 (p<<0.05)	0.00007 (p<<0.05)	0.00008 (p=0.32)
	CESM2-WACCM	-0.015 (p<<0.05)	0.049 (p<<0.05)	-0.014 (p<<0.05)	0.053 (p<<0.05)	-0.00010 (p<<0.05)	0.00015 (p<<0.05)	-0.00011 (p<<0.05)	0.00017 (p<<0.05)
	CMCC-CM2-SR5	-0.009 (p<<0.05)	0.055 (p<<0.05)	-0.005 (p<<0.05)	0.033 (p<<0.05)	-0.00006 (p<<0.05)	0.00017 (p<<0.05)	-0.00005 (p<<0.05)	0.00010 (p<<0.05)
	CMCC-ESM2	-0.013 (p<<0.05)	0.072 (p<<0.05)	0.002 (p=0.09)	-0.021 (p<<0.05)	-0.00010 (p<<0.05)	0.00022 (p<<0.05)	0.00002 (p=0.01)	-0.00007 (p<<0.05)
	GFDL-ESM4	-0.021 (p<<0.05)	0.081 (p<<0.05)	-0.011 (p<<0.05)	0.041 (p<<0.05)	-0.00014 (p<<0.05)	0.00024 (p<<0.05)	-0.00007 (p<<0.05)	0.00012 (p<<0.05)
HOTS	Mean	-0.009 (p<<0.05)	0.040 (p<<0.05)	-0.003 (p<<0.05)	0.010 (p<<0.05)	-0.00013 (p<<0.05)	0.00020 (p<<0.05)	-0.00004 (p<<0.05)	0.00006 (p<<0.05)
	CanESM5	-0.012 (p<<0.05)	0.051 (p<<0.05)	-0.000 (p=0.41)	0.006 (p=0.0003)	-0.00018 (p<<0.05)	0.00024 (p<<0.05)	-0.00001 (p=0.08)	0.00003 (p=0.004)
	CESM2-WACCM	-0.006 (p<<0.05)	0.027 (p<<0.05)	0.003 (p<<0.05)	-0.008 (p=0.0002)	-0.00007 (p<<0.05)	0.00015 (p<<0.05)	0.00004 (p<<0.05)	-0.00004 (p=0.003)
	CMCC-CM2-SR5	-0.010 (p<<0.05)	0.045 (p<<0.05)	-0.006 (p<<0.05)	0.023 (p<<0.05)	-0.00014 (p<<0.05)	0.00020 (p<<0.05)	-0.00009 (p<<0.05)	0.00012 (p<<0.05)
	CMCC-ESM2	-0.012 (p<<0.05)	0.049 (p<<0.05)	-0.008 (p<<0.05)	0.030 (p<<0.05)	-0.00016 (p<<0.05)	0.00026 (p<<0.05)	-0.00011 (p<<0.05)	0.00017 (p<<0.05)
	EC-Earth3	-0.009 (p<<0.05)	0.037 (p<<0.05)	-0.002 (p=0.02)	0.007 (p=0.002)	-0.00012 (p<<0.05)	0.00020 (p<<0.05)	-0.00000 (p=0.80)	0.00005 (p=0.001)
	EC-Earth-Veg	-0.010 (p<<0.05)	0.036 (p<<0.05)	-0.001 (p=0.13)	0.005 (p=0.03)	-0.00012 (p<<0.05)	0.00021 (p<<0.05)	-0.00002 (p=0.09)	0.00003 (p=0.04)
	IPSL-CM6A	-0.014 (p<<0.05)	0.058 (p<<0.05)	-0.005 (p<<0.05)	0.018 (p<<0.05)	-0.00017 (p<<0.05)	0.00030 (p<<0.05)	-0.00008 (p<<0.05)	0.00010 (p<<0.05)
	NorESM-MM	-0.005 (p<<0.05)	0.032 (p<<0.05)	-0.002 (p=0.01)	0.006 (p=0.002)	-0.00009 (p<<0.05)	0.00014 (p<<0.05)	-0.00003 (p=0.004)	0.00004 (p<<0.05)
	GFDL-ESM4	-0.006 (p<<0.05)	0.030 (p<<0.05)	-0.001 (p=0.0002)	0.006 (p=0.0002)	-0.00014 (p<<0.05)	0.00011 (p<<0.05)	-0.00003 (p=0.0004)	0.00002 (p=0.0002)

Table S3: Predicted surface and subsurface slopes of phytoplankton and chlorophyll timeseries from 2015 to 2100 under scenarios SSP3-7.0 at BATS and HOT.

Station	Input data	P_s [mmol N m ⁻² yr ⁻¹]	$P_{c,s}$ [mmol N m ⁻³ yr ⁻¹]	$Chla_s$ [mg m ⁻² yr ⁻¹]	$Chla_{c,s}$ [mg m ⁻³ yr ⁻¹]	P_d [mmol N m ⁻² yr ⁻¹]	$P_{c,d}$ [mmol N m ⁻³ yr ⁻¹]	$Chla_d$ [mg m ⁻² yr ⁻¹]	$Chla_{c,d}$ [mg m ⁻³ yr ⁻¹]
BATS	Mean	-0.027(p<0.05)	-0.00011 (p<0.05)	-0.015(p<0.05)	-0.00009(p<0.05)	0.096 (p<0.05)	0.00028(p<0.05)	0.047 (p<0.05)	0.00014(p<0.05)
	BCC-CSM2-MR	-0.040 (p<0.05)	-0.00015(p<0.05)	-0.023(p<0.05)	-0.00011(p<0.05)	0.055(p<0.05)	0.00017(p<0.05)	0.028(p<0.05)	0.00009(p<0.05)
	CESM2-WACCM	-0.031 (p<0.05)	-0.00012(p<0.05)	-0.017(p<0.05)	-0.0001(p<0.05)	0.11(p<0.05)	0.00034(p<0.05)	0.056(p<0.05)	0.00017(p<0.05)
	CMCC-CM2-SR5	-0.027(p<0.05)	-0.00013(p<0.05)	-0.014(p<0.05)	-0.0001 (p<0.05)	0.126(p<0.05)	0.00039(p<0.05)	0.064(p<0.05)	0.0002(p<0.05)
	CMCC-ESM2	-0.012(p<0.05)	-0.00004(p=0.01)	-0.005(p=0.005)	-0.00005(p<0.05)	0.079(p<0.05)	0.00024(p<0.05)	0.04(p<0.05)	0.00012(p<0.05)
	GFDL-ESM4	-0.021(p<0.05)	-0.00012(p<0.05)	-0.009(p<0.05)	-0.00008(p<0.05)	0.113(p<0.05)	0.00033(p<0.05)	0.058(p<0.05)	0.00017(p<0.05)
HOTS	Mean	-0.015(p<0.05)	-0.00020(p<0.05)	-0.0076(p<0.05)	-0.00010(p<0.05)	0.063(p<0.05)	0.00033(p<0.05)	0.032(p<0.05)	0.00017(p<0.05)
	CanESM5	-0.019(p<0.05)	-0.00028(p<0.05)	-0.0096(p<0.05)	-0.00015(p<0.05)	0.074(p<0.05)	0.00037(p<0.05)	0.037(p<0.05)	0.00019(p<0.05)
	CESM2-WACCM	-0.005(p<0.05)	-0.00005(p=0.0004)	-0.0020(p=0.008)	-0.00002(p<0.05)	0.027(p<0.05)	0.00012(p<0.05)	0.013(p<0.05)	0.00006(p<0.05)
	CMCC-CM2-SR5	-0.024(p<0.05)	-0.00037(p<0.05)	-0.0120(p<0.05)	-0.00018(p<0.05)	0.090(p<0.05)	0.00047(p<0.05)	0.046(p<0.05)	0.00024(p<0.05)
	CMCC-ESM2	-0.014(p<0.05)(p<0.05)	-0.00015(p<0.05)	-0.0069(p<0.05)	-0.00008(p<0.05)	0.057(p<0.05)	0.00032(p<0.05)	0.028(p<0.05)	0.00016(p<0.05)
	EC-Earth3	-0.021(p<0.05)	-0.00025(p<0.05)	-0.0112(p<0.05)	-0.00014(p<0.05)	0.074(p<0.05)	0.00045(p<0.05)	0.038(p<0.05)	0.00023(p<0.05)
	EC-Earth-Veg	-0.017(p<0.05)	-0.00020(p<0.05)	-0.0090(p<0.05)	-0.00011(p<0.05)	0.063(p<0.05)	0.00038(p<0.05)	0.032(p<0.05)	0.00019(p<0.05)
	IPSL-CM6A	-0.038(p<0.05)	-0.00045(p<0.05)	-0.0199(p<0.05)	-0.00024(p<0.05)	0.140 (p<0.05)	0.00082(p<0.05)	0.071(p<0.05)	0.00042(p<0.05)
	NorESM-MM	-0.003(p=0.009)	-0.00007(p=0.001)	-0.0016(p<0.05)	-0.00004(p<0.05)	0.032(p<0.05)	0.00013(p<0.05)	0.016(p<0.05)	0.00007(p<0.05)
	GFDL-ESM4	-0.003(p=0.0001)	-0.00007(p=0.0005)	-0.0010(p=0.007)	-0.00002(p<0.05)	0.021(p<0.05)	0.00008(p<0.05)	0.011(p<0.05)	0.00004(p<0.05)

Table S4: Predicted surface and subsurface slopes of deseasonalised timeseries from 2015 to 2100 under scenarios SSP5-8.5 at BATS and HOT.

Station	Input data	z_m [m yr ⁻¹]	I_s [W m ⁻² yr ⁻¹]	$N_{c,s}$ [mmol N m ⁻³ yr ⁻¹]	$Z_{c,s}$ [mmol N m ⁻³ yr ⁻¹]	z_{eu} [mmol N m ⁻³ yr ⁻¹]	I_d [mmol N m ⁻³ yr ⁻¹]	$N_{c,d}$ [mmol N m ⁻³ yr ⁻¹]	$Z_{c,d}$ [mmol N m ⁻³ yr ⁻¹]
BATS	Mean	-0.11 (P<<0.05)	0.18(P<<0.05)	-0.000005(P<<0.05)	-0.00002(P<<0.05)	0.02(P<<0.05)	0.009 (P<<0.05)	-0.0002(P<<0.05)	0.00003(P<<0.05)
	BCC-CSM2-MR	-0.14(P<<0.05)	0.14 (P<<0.05)	-0.000005(P<<0.05)	-0.00002(P<<0.05)	0.02(P<<0.05)	0.003(P<<0.05)	-0.0002(P<<0.05)	0.00002(P<<0.05)
	CESM2-WACCM	-0.10(P<<0.05)	0.14(P<<0.05)	-0.000005(P<<0.05)	-0.00002(P<<0.05)	0.02(P<<0.05)	0.003(P<<0.05)	-0.0001(P<<0.05)	0.00003(P<<0.05)
	CMCC-CM2-SR5	-0.07(P<<0.05)	0.14(P<<0.05)	-0.000003(P<<0.05)	-0.00001(P<<0.05)	0.01(P<<0.05)	0.012(P<<0.05)	-0.0001(P<<0.05)	0.00003(P<<0.05)
	CMCC-ESM2	-0.10(P<<0.05)	0.21(P<<0.05)	-0.000004(P<<0.05)	-0.00002(P<<0.05)	0.02 (P<<0.05)	0.010(P<<0.05)	-0.0002(P<<0.05)	0.00004(P<<0.05)
	GFDL-ESM4	-0.13(P<<0.05)	0.25(P<<0.05)	-0.000007(P<<0.05)	-0.00003(P<<0.05)	0.03(P<<0.05)	0.016(P<<0.05)	-0.0002(P<<0.05)	0.00005(P<<0.05)
HOTS	Mean	-0.0(P<<0.05)	0.24(P<<0.05)	-0.000001(P<<0.05)	-0.00002(P<<0.05)	0.02(P<<0.05)	0.03(P<<0.05)	-0.0002(P<<0.05)	0.00007(P<<0.05)
	CanESM5	-0.10(P<<0.05)	0.33(P<<0.05)	-0.000001(P<<0.05)	-0.00002(P<<0.05)	0.02 (P<<0.05)	0.04(P<<0.05)	-0.0002(P<<0.05)	0.00008(P<<0.05)
	CESM2-WACCM	-0.05(P<<0.05)	0.15(P<<0.05)	-0.000001(P<<0.05)	-0.00001(P<<0.05)	0.01(P<<0.05)	0.01(P<<0.05)	-0.0001(P<<0.05)	0.00004(P<<0.05)
	CMCC-CM2-SR5	-0.09(P<<0.05)	0.28(P<<0.05)	-0.000001(P<<0.05)	-0.00002(P<<0.05)	0.02(P<<0.05)	0.04(P<<0.05)	-0.0002(P<<0.05)	0.00007(P<<0.05)
	CMCC-ESM2	-0.10(P<<0.05)	0.25(P<<0.05)	-0.000002(P<<0.05)	-0.00003(P<<0.05)	0.02(P<<0.05)	0.03(P<<0.05)	-0.0002(P<<0.05)	0.00009(P<<0.05)
	EC-Earth3	-0.07(P<<0.05)	0.20(P<<0.05)	-0.000001(P<<0.05)	-0.00002(P<<0.05)	0.01(P<<0.05)	0.02(P<<0.05)	-0.0002(P<<0.05)	0.00006(P<<0.05)
HOTS	EC-Earth-Veg	-0.07(P<<0.05)	0.17(P<<0.05)	-0.000001(P<<0.05)	-0.00002(P<<0.05)	0.01(P<<0.05)	0.02(P<<0.05)	-0.0001(P<<0.05)	0.00006(P<<0.05)
	IPSL-CM6A	-0.12(P<<0.05)	0.16(P<<0.05)	-0.000002(P<<0.05)	-0.00002(P<<0.05)	0.02(P<<0.05)	0.03(P<<0.05)	-0.0002(P<<0.05)	0.00009(P<<0.05)
	NorESM-MM	-0.06(P<<0.05)	0.38(P<<0.05)	-0.0000001(p=0.33)	-0.00003(P<<0.05)	0.01(P<<0.05)	0.04(P<<0.05)	-0.0001(P<<0.05)	0.00005(P<<0.05)
	GFDL-ESM4	-0.06(P<<0.05)	0.22(P<<0.05)	-0.000001(P<<0.05)	-0.00001(P<<0.05)	0.02(P<<0.05)	0.03(P<<0.05)	-0.0001(P<<0.05)	0.00004(P<<0.05)

Table S5: Predicted surface and subsurface slopes of deseasonalised timeseries from 2015 to 2100 under scenarios SSP1-2.6 at BATS and HOT.

Station	Input data	z_m [m yr ⁻¹]	I_s [W m ⁻² yr ⁻¹]	$N_{c,s}$ [mmol N m ⁻³ yr ⁻¹]	$Z_{c,s}$ [mmol N m ⁻³ yr ⁻¹]	z_{eu} [mmol N m ⁻³ yr ⁻¹]	I_d [mmol N m ⁻³ yr ⁻¹]	$N_{c,d}$ [mmol N m ⁻³ yr ⁻¹]	$Z_{c,d}$ [mmol N m ⁻³ yr ⁻¹]
BATS	Mean	-0.02(p<<0.05)	0.06(p<<0.05)	-0.00001(p<<0.05)	-0.0001(p<<0.05)	0.006(p<<0.05)	0.002(p<<0.05)	-0.0003(p<<0.05)	0.0003(p<<0.05)
	BCC-CSM2-MR	0.06(p<<0.05)	-0.01 (p= 0.20)	0.00004(p<<0.05)	0.0002(p<<0.05)	-0.013(p<<0.05)	0.001(p=0.002)	0.0011(p<<0.05)	0.0002(p<<0.05)
	CESM2-WACCM	-0.08(p<<0.05)	0.12(p<<0.05)	-0.00004(p<<0.05)	-0.0002(p<<0.05)	0.023(p<<0.05)	0.001(p<<0.05)	-0.0012(p<<0.05)	0.0003(p<<0.05)
	CMCC-CM2-SR5	-0.03(p<<0.05)	0.10(p<<0.05)	-0.00002(p<<0.05)	-0.0001(p<<0.05)	0.011(p<<0.05)	0.006(p<<0.05)	-0.0005(p<<0.05)	0.0003(p<<0.05)
	CMCC-ESM2	0.03(p<<0.05)	-0.03 (p=0.002)	0.00001(p=0.01)	0.0000(p=0.53)	-0.005(p=0.01)	-0.004(p<<0.05)	0.0004(p<<0.05)	0.0004(p<<0.05)
	GFDL-ESM4	-0.07(p<<0.05)	0.11(p<<0.05)	-0.00004(p<<0.05)	-0.0002(p<<0.05)	0.015(p<<0.05)	0.007(p<<0.05)	-0.0010(p<<0.05)	0.0005(p<<0.05)
HOTS	Mean	-0.02(p<<0.05)	0.09(p<<0.05)	-0.000003(p<<0.05)	-0.00006(p<<0.05)	0.004(p<<0.05)	0.006(p<<0.05)	-0.0004(p<<0.05)	0.0002(p=0.0001)
	CanESM5	-0.01 (p=0.004)	0.09(p<<0.05)	-0.000003(p=0.01)	-0.00002 (p=0.29)	0.002(p=0.06)	0.006(p<<0.05)	-0.0002(p=0.001)	0.0001(p=0.001)
	CESM2-WACCM	0.02(p<<0.05)	0.02(p=0.06)	0.000005(p<<0.05)	0.00007(p<<0.05)	-0.004(p<<0.05)	-0.002(p<<0.05)	0.0003(p=0.0003)	-0.0001(p<<0.05)
	CMCC-CM2-SR5	-0.04(p<<0.05)	0.18(p<<0.05)	-0.000006(p<<0.05)	-0.00015(p<<0.05)	0.010(p<<0.05)	0.016(p<<0.05)	-0.0009(p<<0.05)	0.0004(p<<0.05)
	CMCC-ESM2	-0.06(p<<0.05)	0.17(p<<0.05)	-0.00001(p<<0.05)	-0.00017(p<<0.05)	0.012(p<<0.05)	0.012(p<<0.05)	-0.0012(p<<0.05)	0.0005(p<<0.05)
	EC-Earth3	-0.01(p=0.002)	0.04(p=0.0004)	0.000001(p=0.23)	-0.00001(p=0.37)	0.0001(p=0.91)	0.005(p<<0.05)	-0.0003(p=0.002)	0.0001(p=0.02)
IPSL-CM6A	EC-Earth-Veg	-0.01(p=0.07)	0.02(p=0.09)	-0.000003(p=0.006)	-0.00004(p=0.02)	0.002(p= 0.10)	0.003(p=0.05)	-0.0002(p=0.10)	0.0001(p=0.07)
	IPSL-CM6A	-0.03(p<<0.05)	0.11(p<<0.05)	-0.000001(p=0.68)	-0.00011(p<<0.05)	0.008(p<<0.05)	0.007(p<<0.05)	-0.0007(p<<0.05)	0.0003(p<<0.05)
	NorESM-MM	-0.01(p=0.15)	0.16(p<<0.05)	-0.000006(p<<0.05)	-0.00002(p= 0.32)	0.003(p=0.01)	0.0041(p=0.004)	-0.0003(p=0.001)	0.0001(p<<0.05)
	GFDL-ESM4	-0.01(p= 0.0002)	0.05(p<<0.05)	-0.000003(p=0.001)	-0.00005(p<<0.05)	0.003(p=0.0004)	0.005(p=0.0002)	-0.0002(p=0.0001)	0.0001(p<<0.05)