

Future change in ocean productivity: Is the Arctic the new Atlantic?

A. Yool,¹ E. E. Popova,¹ and A. C. Coward,¹

¹National Oceanography Centre,

University of Southampton Waterfront

Campus, European Way, Southampton,

SO14 3ZH, UK.

Supplementary material

Figures and Tables

Figures S1 and S2 augment Figure 7 within the main text by presenting Arctic sea-ice evolution as a “death spiral” (per A.L. Robinson; <http://www.haveland.com>). Figures S3 to S6, and S9 to S11 show medium resolution NEMO versions of figures included within the main text. Figures S7 and S8 are additional and show surface chlorophyll through the 21st century for both high and medium resolution NEMO. Finally, Figure S12 extends Figure 16.

Supporting information

The manuscript is accompanied by three model definition files for each of the two model instances: `depth_ORCAXXX.txt`, `namelist_ORCAXXX` and `namelist_medusa_ORCAXXX` (where XXX is 100 for medium resolution and 025 for high resolution). The first contains the depth specifications for the two model instances, specifically the depth from the surface of the tracer grid interfaces. The second is the input file that defines the physical parameterisation of NEMO. Finally, the third is the input file that defines the biogeochemical parameterisation of MEDUSA.

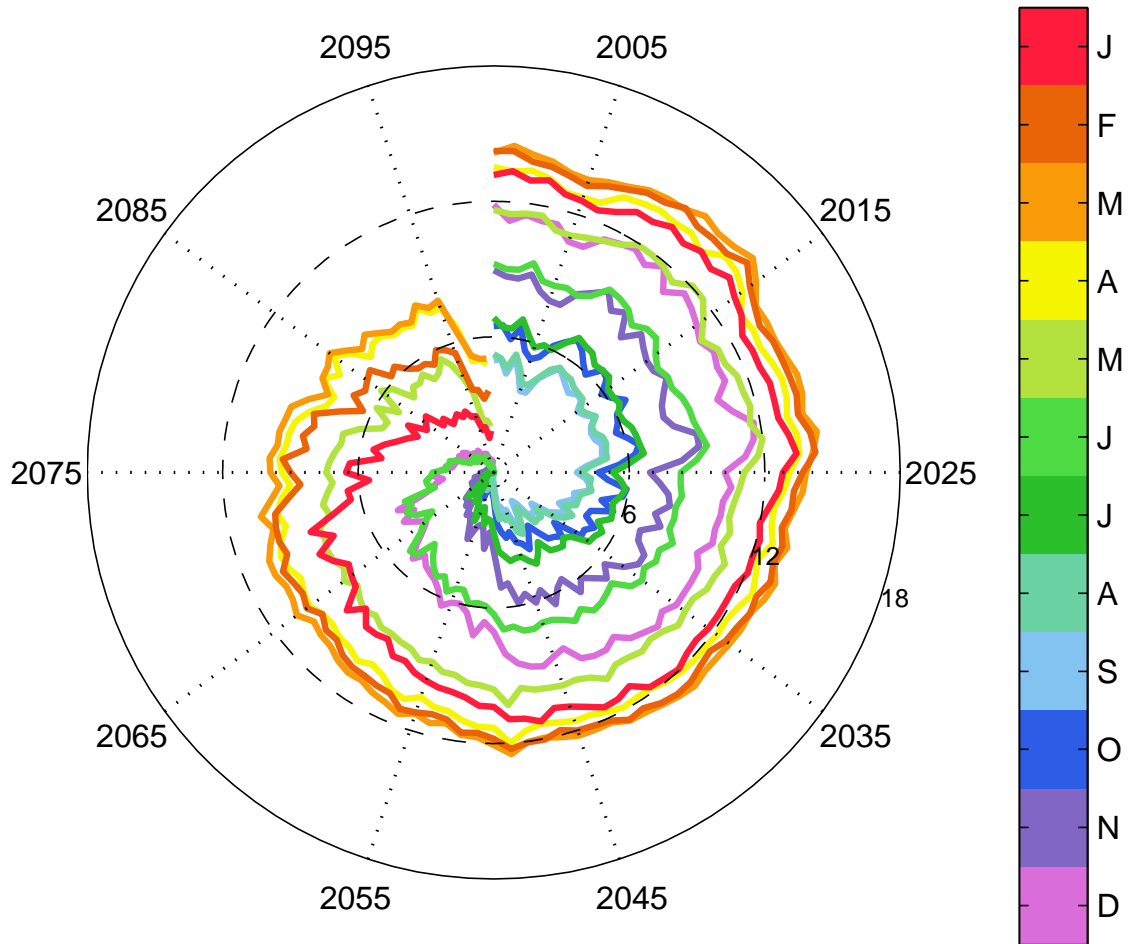


Figure S1. Monthly Arctic sea-ice extent from high resolution NEMO for the period 2000 to 2099 shown as a polar plot. Line colour denotes month, per the colour bar to right. Radial distance on the plot indicates sea-ice extent, where the centre of the plot denotes ice-free conditions. Sea-ice extent extends from 0 to $18 \times 10^6 \text{ km}^2$.

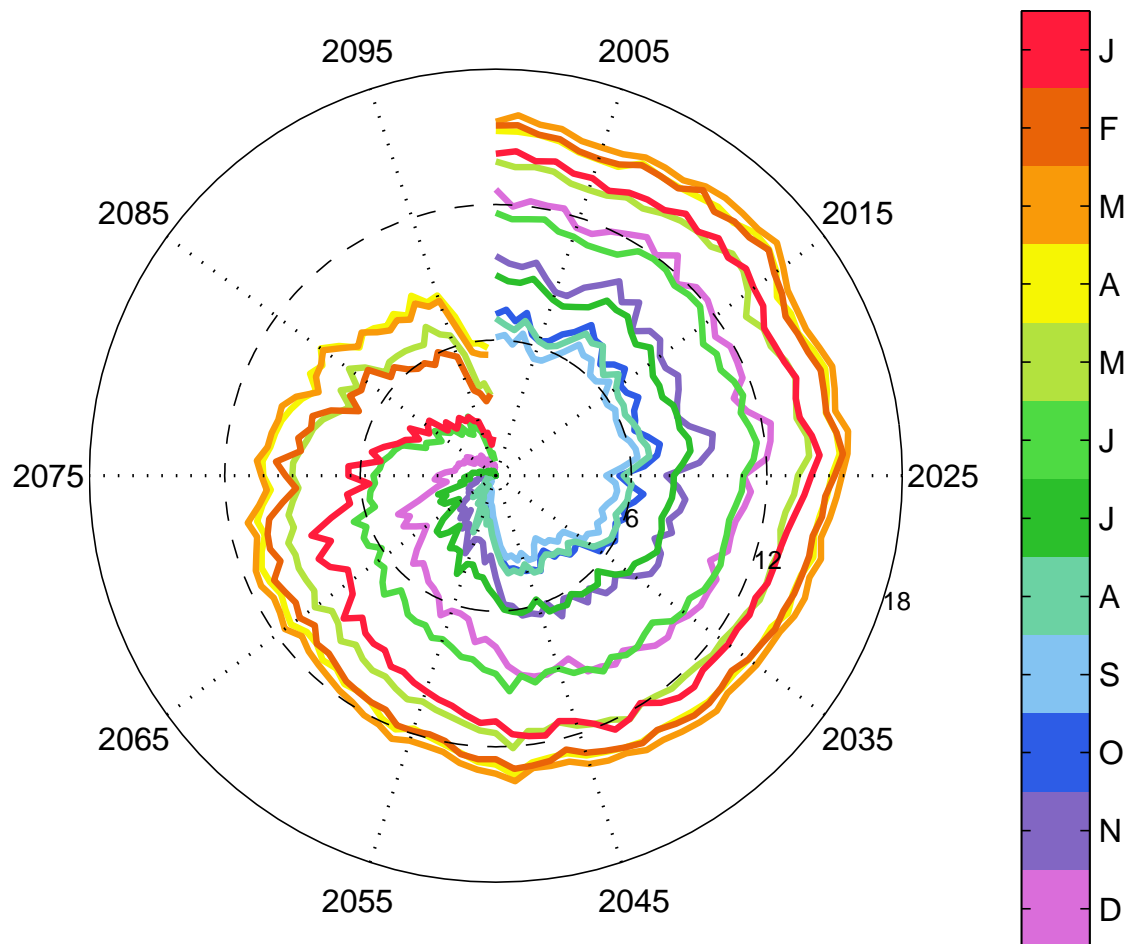


Figure S2. Monthly Arctic sea-ice extent from medium resolution NEMO for the period 2000 to 2099 shown as a polar plot. Line colour denotes month, per the colour bar to right. Radial distance on the plot indicates sea-ice extent, where the centre of the plot denotes ice-free conditions. Sea-ice extent extends from 0 to $18 \times 10^6 \text{ km}^2$. See Supplementary Figure S1.

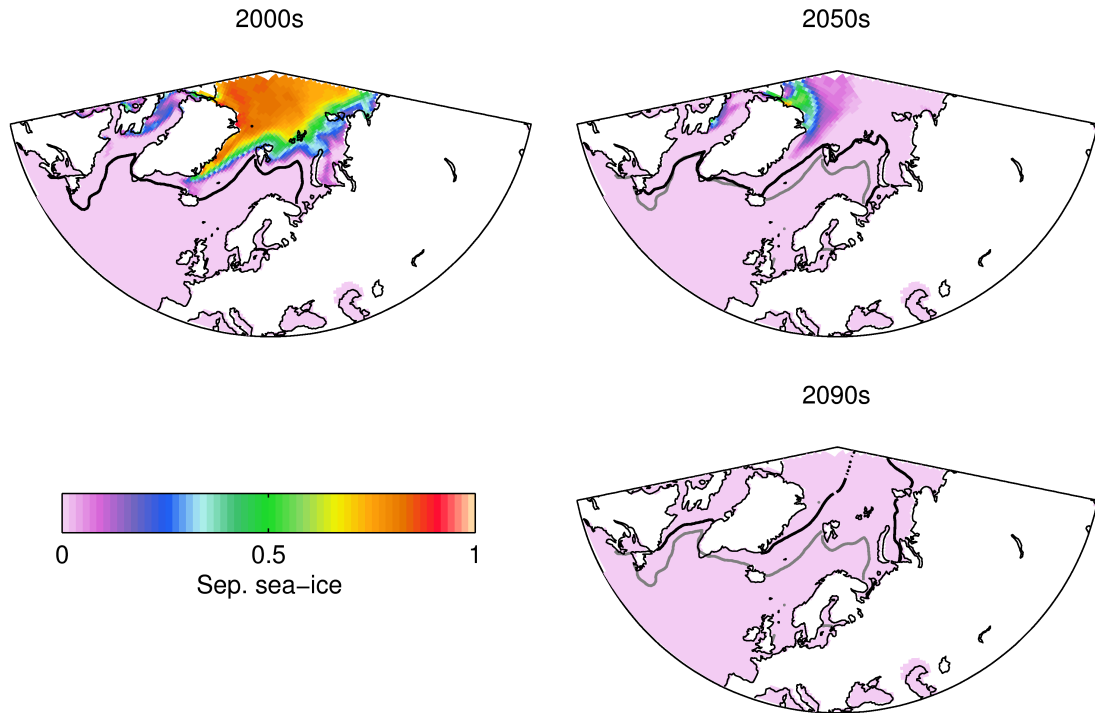


Figure S3. Decadally averaged sea-ice concentration at the annual minimum (September) in medium resolution NEMO for the 2000s, 2050s and 2090s. The black lines on each panel show the corresponding 15% contour of sea-ice concentration at the annual maximum (March), with the additional grey lines marking this for the 2000s for comparison. Sea-ice concentration is non-dimensional. See main text Figure 8.

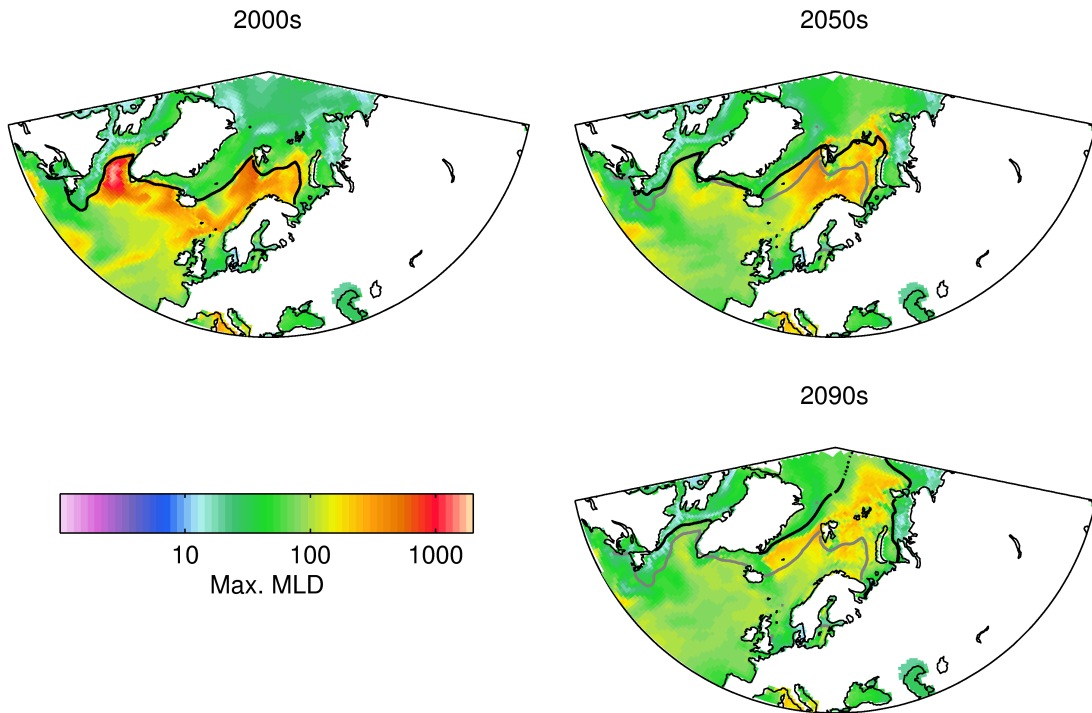


Figure S4. Decadally averaged annual maximum mixed layer depth in medium resolution NEMO for the 2000s, 2050s and 2090s. The black lines on each panel show the 15% contour of sea-ice concentration at the annual maximum (March), with the additional grey lines marking this for the 2000s for comparison. Mixed layer depth is in m and is shown here on a logarithmic scale. See main text Figure 9.

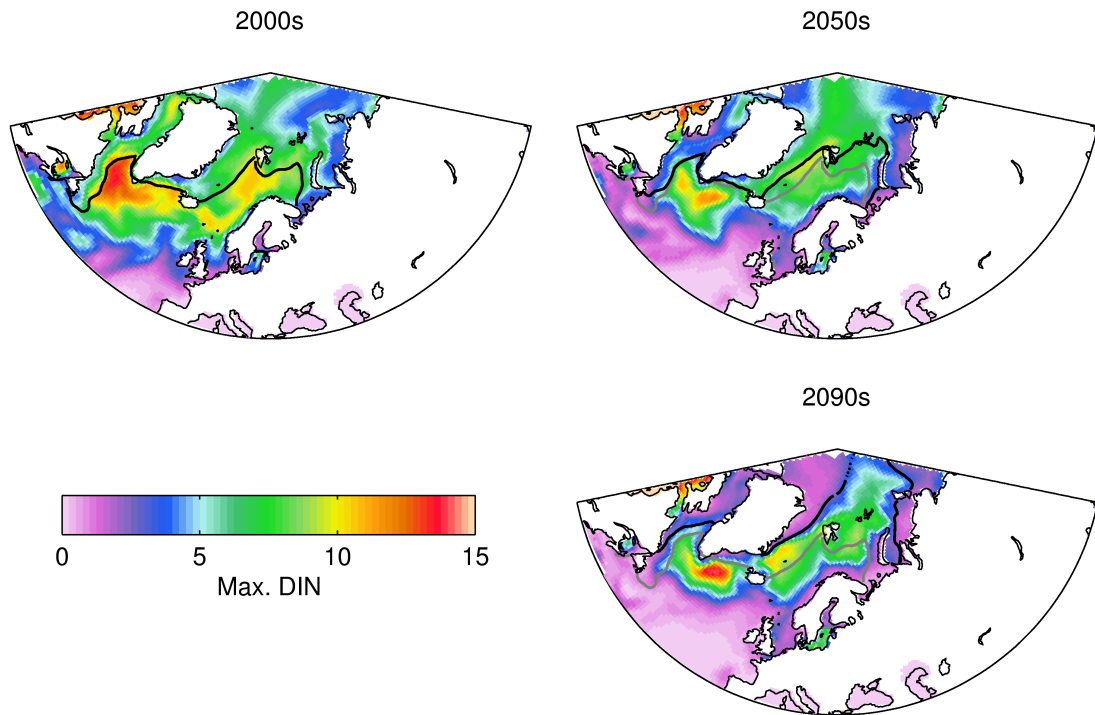


Figure S5. Decadally averaged annual maximum surface DIN in medium resolution NEMO for the 2000s, 2050s and 2090s. The black lines on each panel show the 15% contour of sea-ice concentration at the annual maximum (March), with the additional grey lines marking this for the 2000s for comparison. Surface DIN is in mmol N m^{-3} . See main text Figure 10.

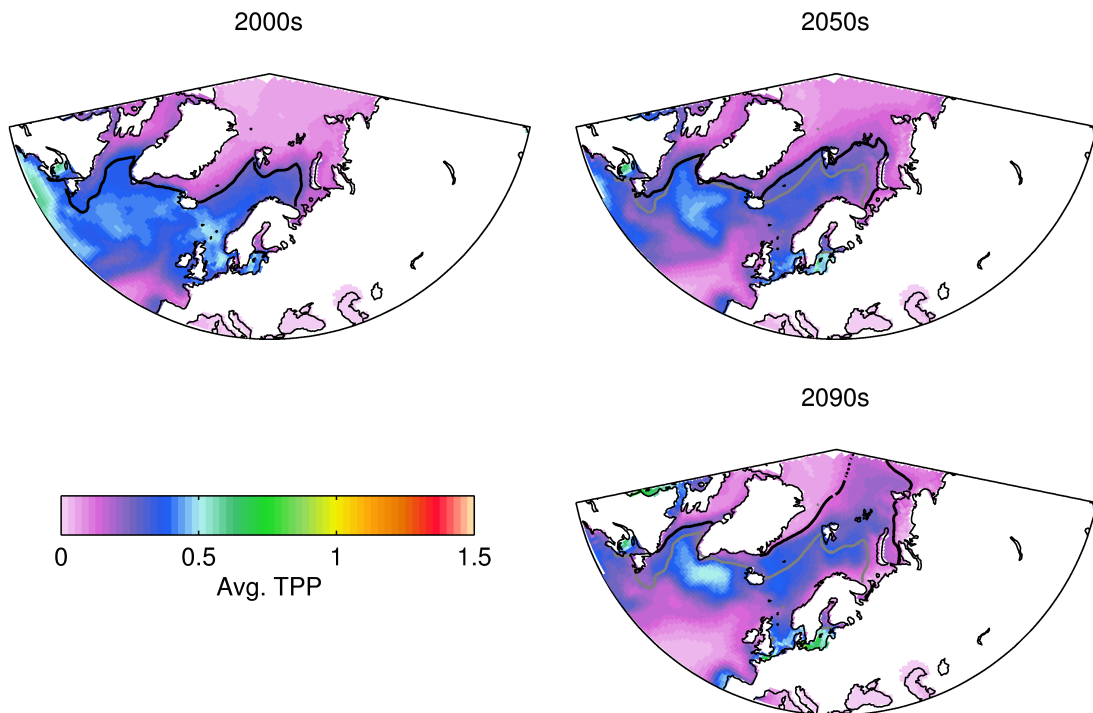


Figure S6. Decadally averaged vertically-integrated primary production in high resolution NEMO for the 2000s, 2050s and 2090s. The black lines on each panel show the 15% contour of sea-ice concentration at the annual maximum (March), with the additional grey lines marking this for the 2000s for comparison. Vertically-integrated primary production is in $\text{g C m}^{-2} \text{d}^{-1}$. See main text Figure 11.

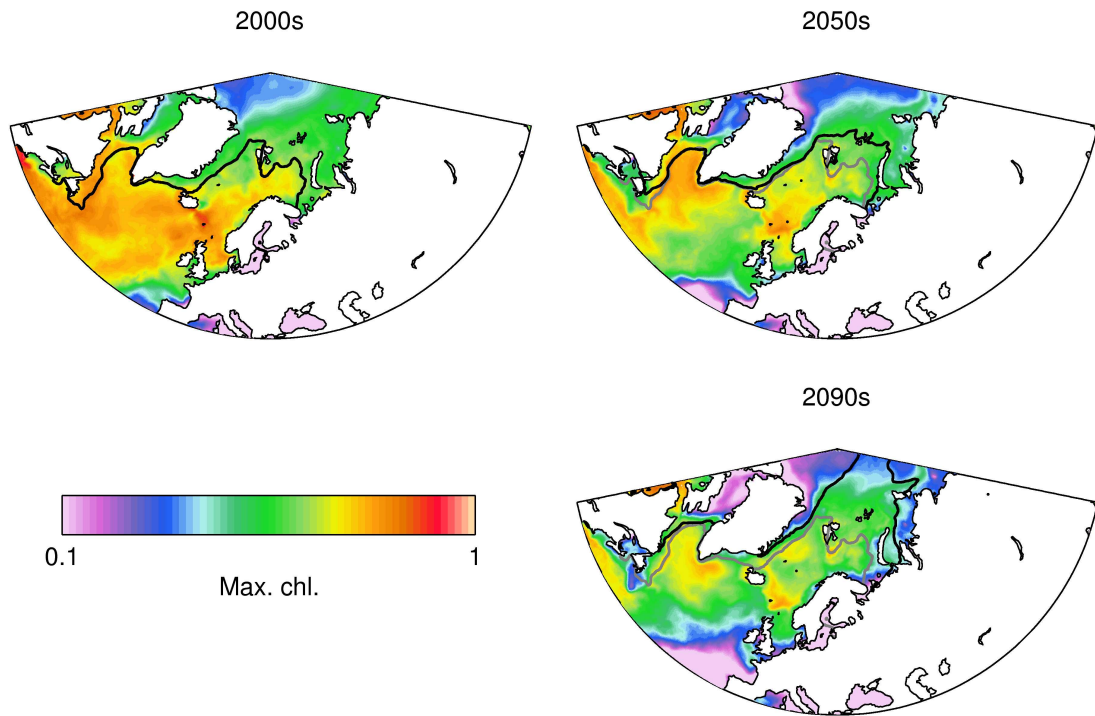


Figure S7. Decadally averaged annual maximum surface chlorophyll in high resolution NEMO for the 2000s, 2050s and 2090s. The black lines on each panel show the 15% contour of sea-ice concentration at the annual maximum (March), with the additional grey lines marking this for the 2000s for comparison. Surface chlorophyll is in mg m^{-3} and is shown here on a logarithmic scale.

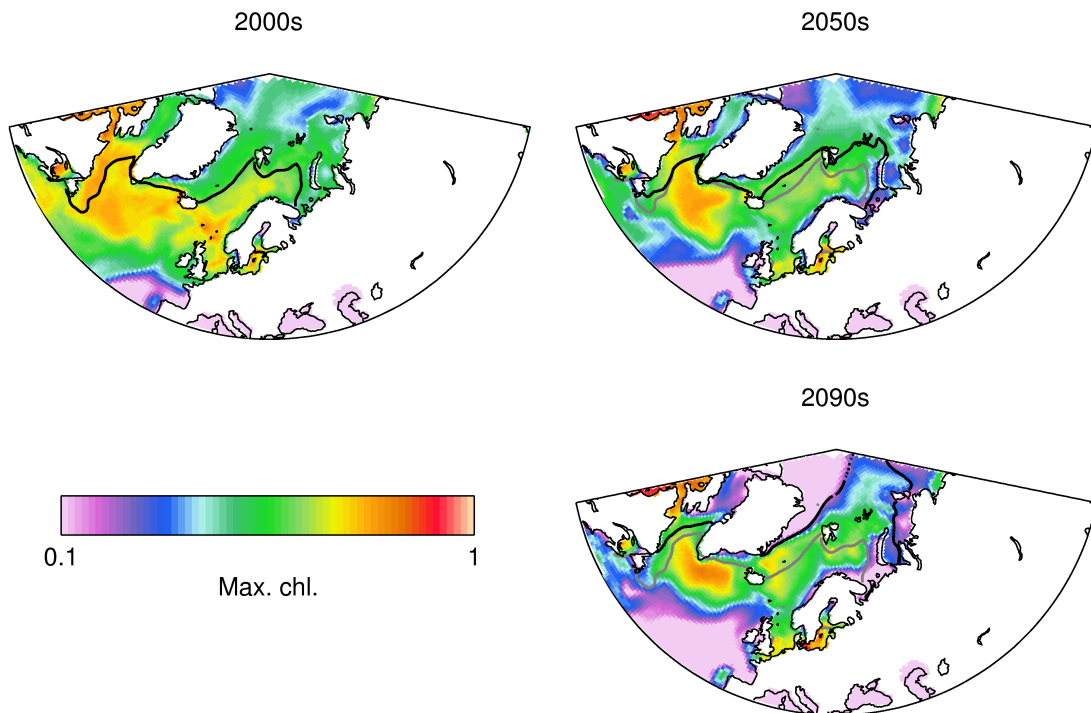


Figure S8. Decadally averaged annual maximum surface chlorophyll in medium resolution NEMO for the 2000s, 2050s and 2090s. The black lines on each panel show the 15% contour of sea-ice concentration at the annual maximum (March), with the additional grey lines marking this for the 2000s for comparison. Surface chlorophyll is in mg m^{-3} and is shown here on a logarithmic scale. See Supplementary Figure S7.

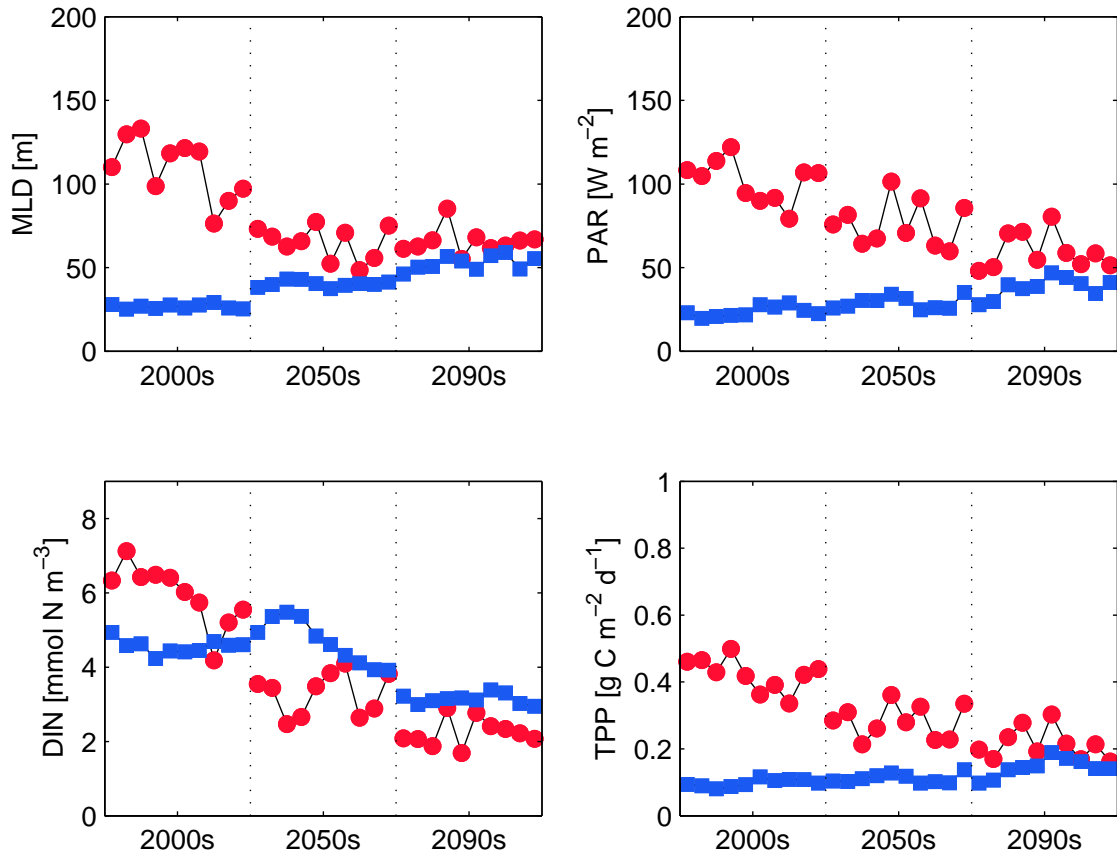


Figure S9. The time evolution for the 2000s, 2050s and 2090s of pre-bloom MLD (top left; m), surface PAR (top right; W m^{-2}), surface DIN (bottom left; mmol N m^{-3}) and vertically integrated TPP (bottom right; $\text{g C m}^{-2} \text{d}^{-1}$) averaged across the North Atlantic (red) and Arctic Ocean (blue) for medium resolution NEMO. See main text Figure 13.

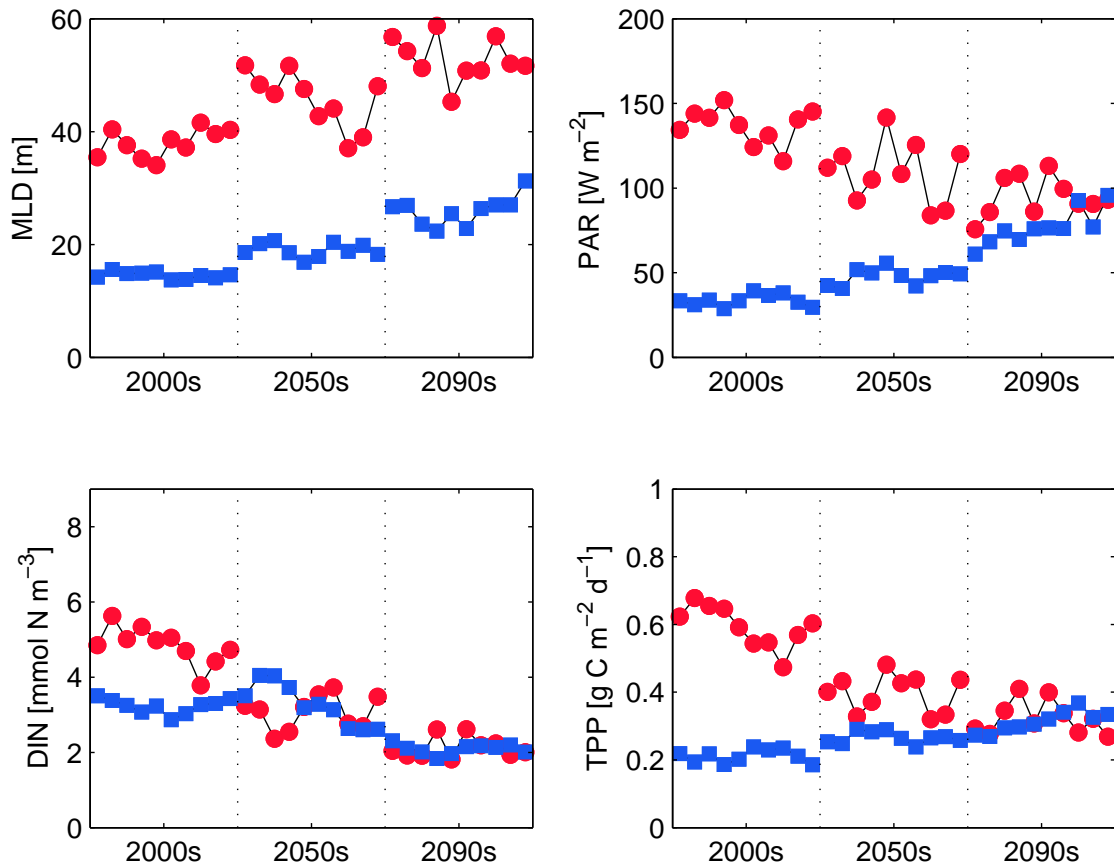


Figure S10. The time evolution for the 2000s, 2050s and 2090s of bloom period MLD (top left; m), surface PAR (top right; W m^{-2}), surface DIN (bottom left; mmol N m^{-3}) and vertically integrated TPP (bottom right; $\text{g C m}^{-2} \text{d}^{-1}$) averaged across the North Atlantic (red) and Arctic Ocean (blue) for medium resolution NEMO. See main text Figure 14.

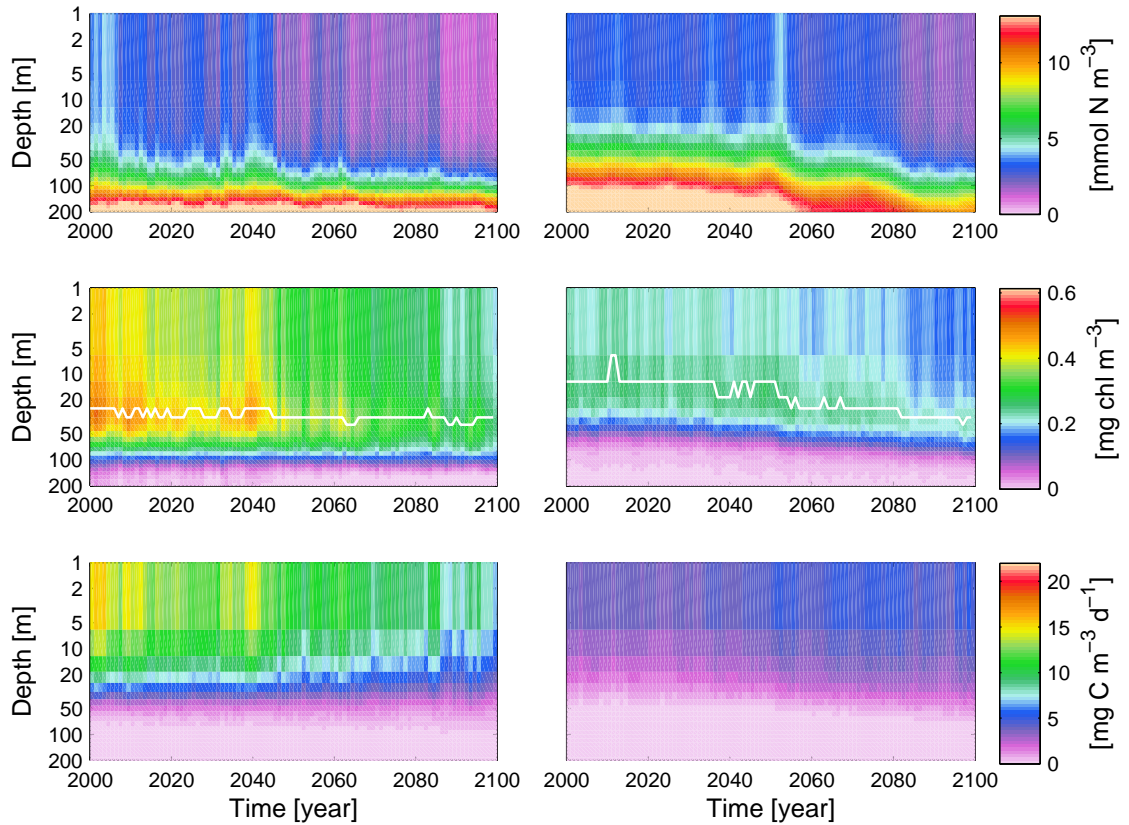


Figure S11. The time evolution of annually averaged vertical profiles of DIN (top; mmol N m^{-3}), chlorophyll (middle; mg chl m^{-3}) and primary production (bottom; $\text{mg C m}^{-3} \text{d}^{-1}$) in the North Atlantic (left) and Arctic (right) for medium resolution NEMO. The white line shown in both panels of the middle row marks the depth of the deep chlorophyll maximum. Note that the vertical scale is logarithmic. See main text Figure 15.

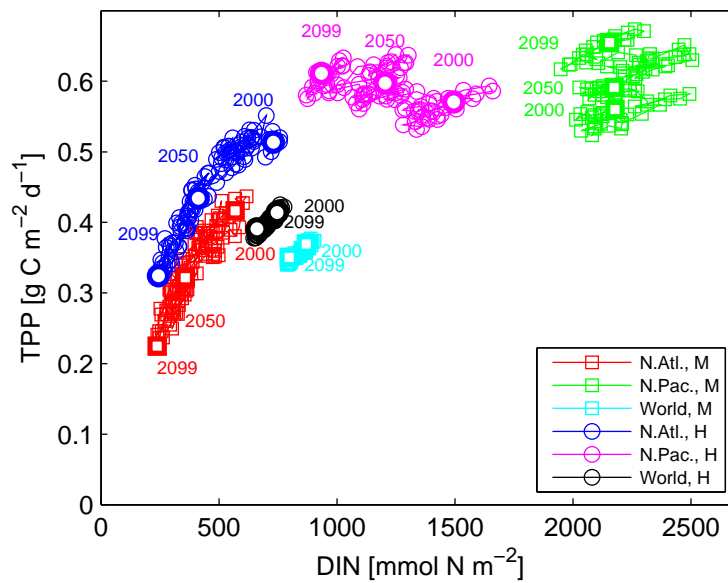


Figure S12. The time evolution of vertically-integrated DIN (0–100m; mmol N m^{-2}) against vertically-integrated primary production (0–100m; $\text{g C m}^{-2} \text{d}^{-1}$) for the North Atlantic (medium, red; high, blue), North Pacific (medium, green; high, magenta) and World Ocean (medium, cyan; high, black) in both high and medium resolution NEMO. See main text Figure 16.

Table S1. Regional (global, North Atlantic, North Pacific and Arctic; per Figure 12) summaries of decadal (2000s, 2050s and 2090s) values of sea surface temperature ($^{\circ}\text{C}$), mixed layer depth (m) and sea-ice extent (10^6 km^2) for medium resolution NEMO. Seasonal maximum sea-ice is that in March, while seasonal minimum is that in September. Note that “global” sea-ice areas refer to northern hemisphere sea-ice only. See main text Table 1.

	Global	N. Atl.	N. Pac.	Arctic
	Annual mean sea surface temperature			
2000s	18.41	8.29	6.37	-0.99
2050s	19.95	9.45	9.12	-0.06
2090s	21.70	12.33	12.11	2.81
	Annual maximum mixed layer depth			
2000s	114.7	207.8	110.9	50.2
2050s	101.7	88.7	103.3	80.6
2090s	95.0	81.6	97.0	85.8
	Seasonal maximum mean sea-ice area			
2000s	15.54	0.33	0.83	5.71
2050s	12.49	0.18	0.16	5.21
2090s	7.15	0.02	0.00	2.93
	Seasonal minimum mean sea-ice area			
2000s	6.03	–	–	4.24
2050s	1.20	–	–	0.90
2090s	0.00	–	–	0.00

Table S2. Regional (global, North Atlantic, North Pacific and Arctic; per Figure 12) summaries of decadal (2000s, 2050s and 2090s) values of mean annual surface DIN (mmol N m^{-3}), surface chlorophyll (mg chl m^{-3}) and vertically-integrated primary production ($\text{g C m}^{-2} \text{d}^{-1}$) for medium resolution NEMO. See main text Table 2.

	Global	N. Atl.	N. Pac.	Arctic
	Annual mean surface DIN			
2000s	6.59	3.65	17.50	3.09
2050s	6.41	2.04	18.70	3.26
2090s	5.90	1.32	16.85	1.85
	Annual mean surface chlorophyll			
2000s	0.225	0.417	0.527	0.222
2050s	0.213	0.309	0.553	0.206
2090s	0.203	0.234	0.563	0.165
	Annual mean primary production			
2000s	0.312	0.357	0.473	0.079
2050s	0.303	0.272	0.526	0.114
2090s	0.295	0.225	0.567	0.139