Global Biogeochemical Cycles

Supporting Information for

Assessment and constraint of mesozooplankton in CMIP6 Earth system models

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Table S1. Details of the CMIP6 models used in this analysis.

Center	Earth system model (ESM)	ESM Reference	Ocean physics model	Ecosystem model	Ecosystem Reference	CMIP6 Variant	CMIP6 DOI
Canadian Centre for Climate Modelling and Analysis	CanESM5	Swart et al. 2019a	NEMO 3.4.1- LIM2	CanOE	Christian et al. 2021	r1i1p2f1	Swart et al. 2019b,c
Euro-Mediterranean Center on Climate Change	CMCC-ESM2	not published (Cherchi et al. 2019 - climate model)	NEMO3.6	BFMv5.2	Lovato et al. submitted	r1i1p1f1	Lovato et al. 2021a,b
National Meteorological Research Centre	CNRM-ESM2-1	Séférian et al. 2019a	NEMOv3.6-GELATOv6	PISCES 2.0gas	Aumont et al. 2015	r1i1p1f2	Séférian et al. 2019b,c
NOAA Geophysical Fluid Dynamics Laboratory	GFDL-ESM4	Held et al. 2019	MOM6	COBALTv2	Stock et al. 2014, 2020	r1i1p1f1	Krasting et al. 2018; John et al. 2018
Institute Pierre-Simon Laplace	IPSL-CM6A-LR	Boucher et al. 2020	NEMOv3.6-LIM3	PISCES 2.0	Aumont et al. 2015	r1i1p1f1	Boucher et al. 2018, 2019
Met Office and National Environment Research Council	UKESM1-0-LL	Sellar et al. 2019	NEMO v3.6	MEDUSA2.1	Yool et al. 2013	r1i1p1f2	Tang et al. 2019; Good et al. 2019

Text S1. References from Table S1 not listed in main text.

Boucher, O,. Servonnat, J., Albright, A. L., Aumont, O., Balkanski, Y., Bastrikov, V., et al. 2020. Presentation and evaluation of the IPSL-CM6A-LR climate model. Journal of Advances in Modeling Earth Systems. https://doi.org/10.1029/2019MS002010

Boucher, O., Denvil, S., Levavasseur, G., Cozic, A., Caubel, A., Foujols, M.-A., et al. 2018. IPSL IPSL-CM6A-LR model output prepared for CMIP6 CMIP historical. Version 20201026. Earth System Grid Federation. https://doi.org/10.22033/ESGF/CMIP6.5195

Boucher, O., Denvil, S., Levavasseur, G., Cozic, A., Caubel, A., Foujols, M.-A., et al. 2019. IPSL IPSL-CM6A-LR model output prepared for CMIP6 ScenarioMIP ssp585. Version 20210118. Earth System Grid Federation. https://doi.org/10.22033/ESGF/CMIP6.5271

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Held, I.M., Guo, H., Adcroft, A., Dunne, J.P., Horowitz, L.W., Krasting, J.P., et al. 2019. Structure and Performance of GFDL's CM4.0 Climate Model. Journal of Advances in Modeling Earth Systems, 11(11), HTTPS://DOI.ORG/10.1029/2019MS001829.

John, J.G., Blanton, C., McHugh, C., Radhakrishnan, A., Rand, K., Vahlenkamp, H., et al. 2018. NOAA-GFDL GFDL-ESM4 model output prepared for CMIP6 ScenarioMIP ssp585. Version 20200621. Earth System Grid Federation. https://doi.org/10.22033/ESGF/CMIP6.8706

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Swart, N.C., Cole, J.N.S., Kharin, V.V., Lazare, M., Scinocca, J.F., Gillett, N.P., et al. 2019c. CCCma CanESM5-CanOE model output prepared for CMIP6 ScenarioMIP ssp585. Version 20201120. Earth System Grid Federation. https://doi.org/10.22033/ESGF/CMIP6.10276

Tang, Y., Rumbold, S., Ellis, R., Kelley, D., Mulcahy, J., Sellar, A., Walton, J., Jones, C. 2019. MOHC UKESM1.0-LL model output prepared for CMIP6 CMIP historical. Version 20201016. Earth System Grid Federation. https://doi.org/10.22033/ESGF/CMIP6.6113

Voldoire, A. 2019. CNRM-CERFACS CNRM-ESM2-1 model output prepared for CMIP6 ScenarioMIP ssp585. Version 20201120. Earth System Grid Federation. https://doi.org/10.22033/ESGF/CMIP6.4226

Table S2. The final linear mixed effects model for zooplankton biomass (response, based on data from the COPEPOD database) and its suite of environmental predictors (as reported in Heneghan et al. 2020).

*lmer(log10(Biomass) ~ BiomassMethod + Mesh + log10(Chl) + exp(-Depth/1000) * fHarmonic(TOD, k = 1) + ns(Bathy, df = 3) + fHarmonic(DOY, k = 1) * ns(SST, 3) + (1|Gear) + (1|Institution), data = dat).*

Intercept	-0.475					
Method	-0.528 (C)	-0.614 (CHN)	-2.176 (Disp)	-0.113 (DW)	-1.302 (Set)	0.878 (WW)
Mesh	-0.001					
log10(Chl)	0.381					
exp(-Depth)	1.979					
TOD	-0.062 (c1)	-0.006 (s1)				
ns(Bathy)	0.047 (k=1)	0.172 (k=2)	0.054 (k=3)			
DOY	-0.525 (c1)	-0.256 (s1)				
ns(SST, k=3)	-0.129 (k=1)	0.149 (k=2)	0.055 (k=3)			
exp(-Depth):TOD	0.102	0.019				
DOY:ns(SST, k=3)	0.373 (c1, k=1)	0.148 (s1, k=1)	0.708 (c1, k=2)	0.462 (s1, k=2)	0.451 (c1, k=3)	0.164 (s1, k=3)

* C = carbon biomass, CHN = Carbon biomass via CHN analyzer, Disp = Displacement Volume, DW = Dry Weight, Set = Settled Volume, WW = Wet Weight.

Table S3. Slope coefficients in the linear regression of mesozooplankton biomass on surface chlorophyll concentration globally and by biome for the Historical simulation shown in Figure 6 and Figure S4.

Model/Obs	Global	LC	HCSS	HCPS
CAN	1.70	1.08	3.01	2.32
CMCC	0.80	1.06	0.12	-0.15
CNRM	0.59	0.95	0.61	0.54
GFDL	0.51	0.56	0.78	0.19
IPSL	0.55	1.32	0.54	0.48
UKESM	0.98	2.02	1.75	-0.35
obsGLMM	0.38	0.41	0.36	0.10
obsSM	0.71	0.84	0.80	0.69
obsCS	0.55	0.64	0.56	0.29
obsCM	0.54	0.79	0.58	0.23

Note. obsGLMM: GLMM of Heneghan et al. (2020); obsSM: Strömberg et al. (2009) model; obsCS: COPEPOD data with SeaWiFS chlorophyll and related biomes; obsCM: COPEPOD data with MODIS chlorophyll and related biomes.

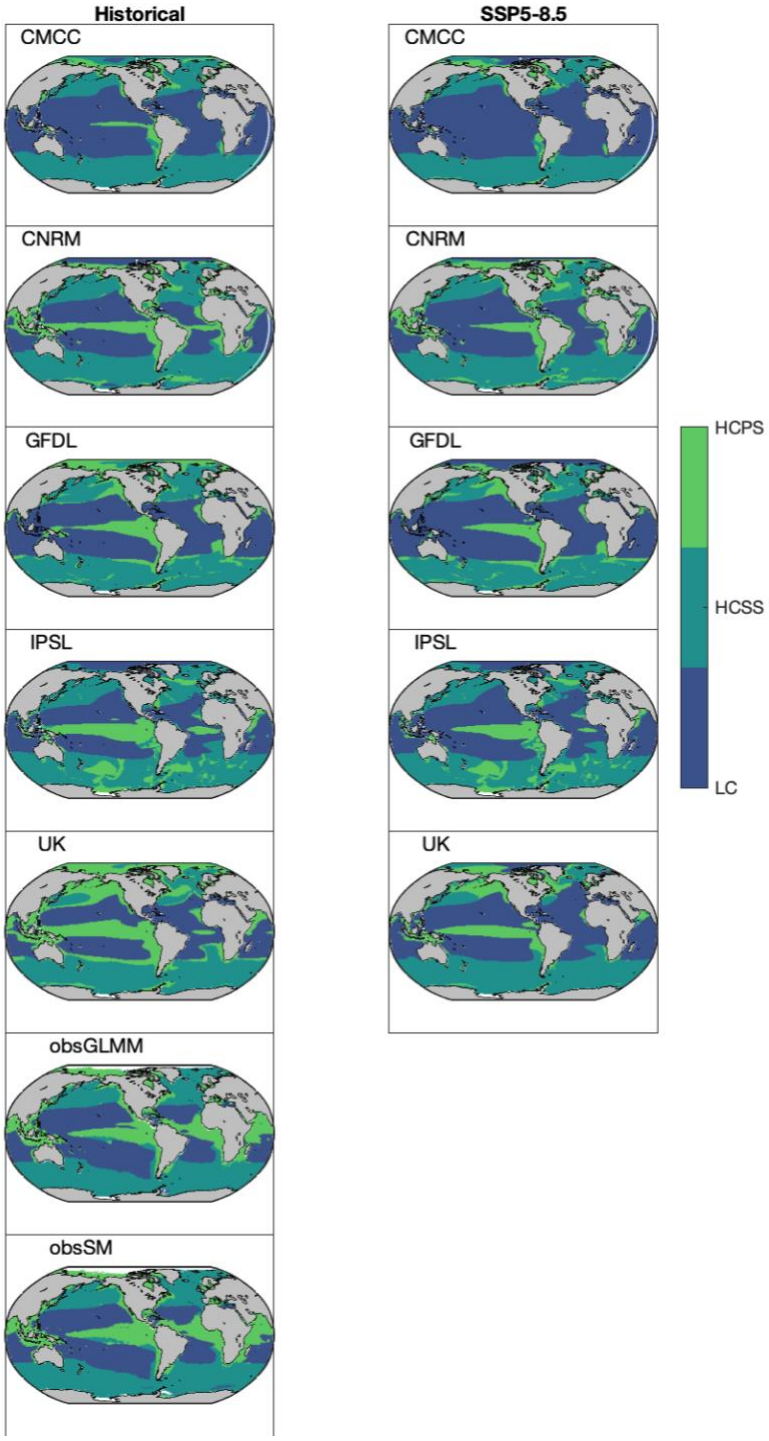

Figure S1. Distribution of biomes in the (left) Historical and (right) SSP5-8.5 simulations. LC – low chlorophyll, HCPS – high chlorophyll, permanently stratified, HCSS – high chlorophyll, seasonally stratified. Note that LC regions above 45ºN/below 45ºS were excluded from the analyses. The low chlorophyll (mg m^{-3}) thresholds used to define each LC biome in each ESM were: CAN 0.255; CMCC 0.100; CNRM 0.165; GFDL 0.272; IPSL 0.122; UK 0.140; obsGLMM 0.125; obsSM 0.125.

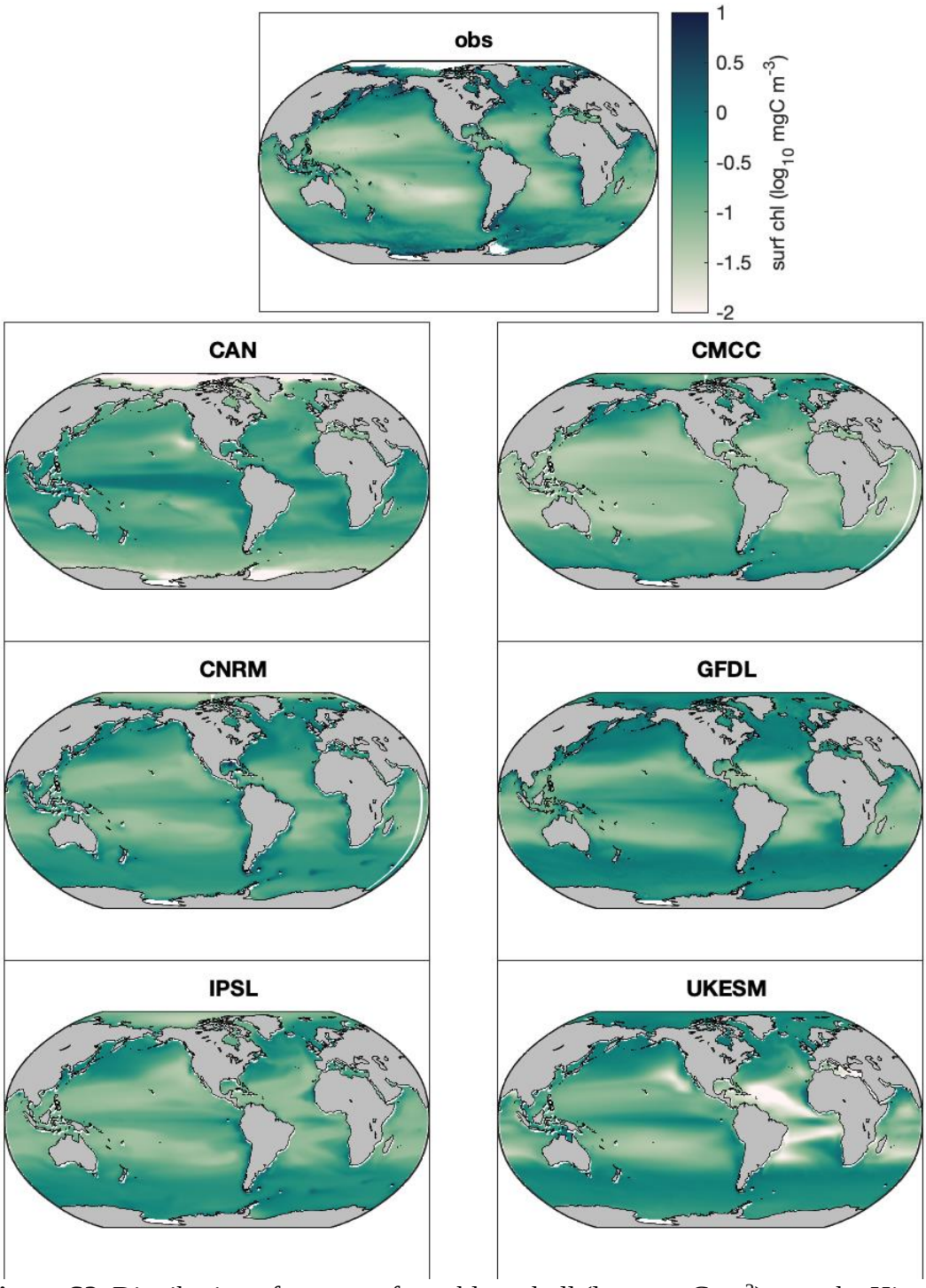

Figure S2. Distribution of mean surface chlorophyll (log_{10} mgC m^{-3}) over the Historical period (1965-2014) in the ESMs and satellite observations used to force the obsGLMM.

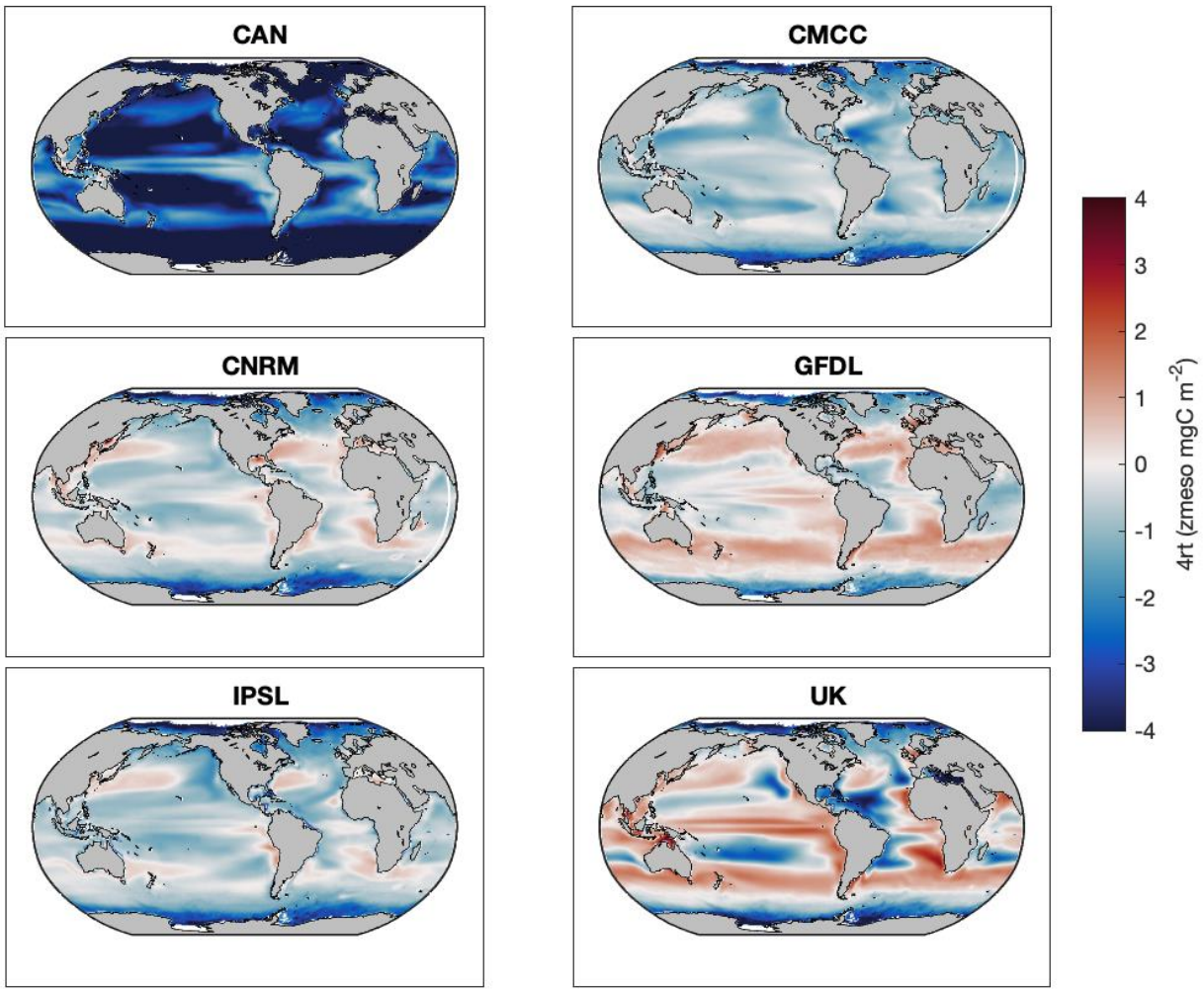

Figure S3. Maps of mean bias of annual climatologies of mesozooplankton biomass (mgC m^{-2}) after 4th-root transformation in the Historical simulations compared to the obsGLMM.

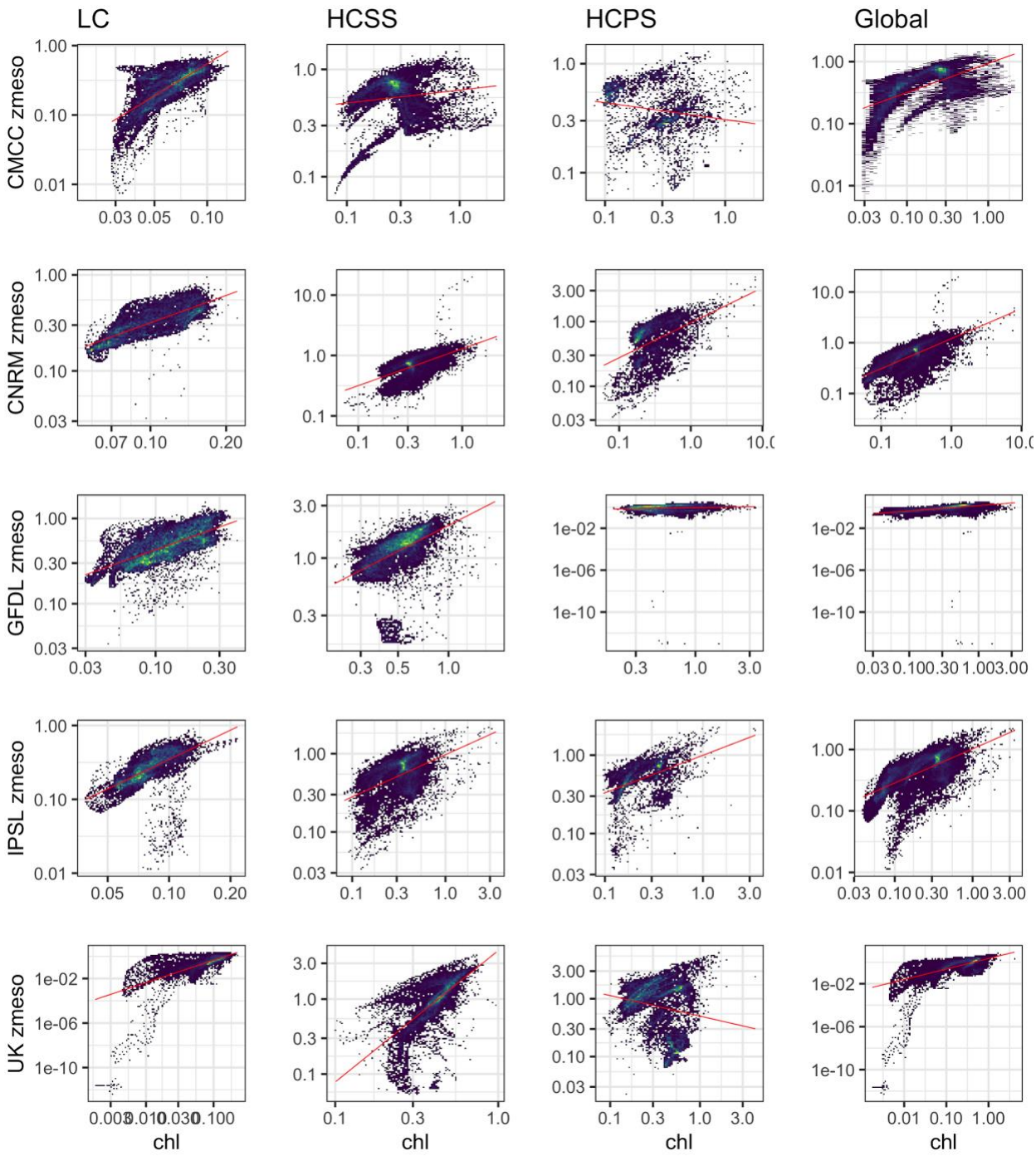

Figure S4a-e. Correlations between mesozooplankton biomass (mgC m^{-2}) and chlorophyll concentration (mg m^{-3}) by biome in each ESM during the Historic period. LC regions above 45ºN/below 45ºS were excluded from the analysis. For the values of the scaling scopes of these models, see Table S3.

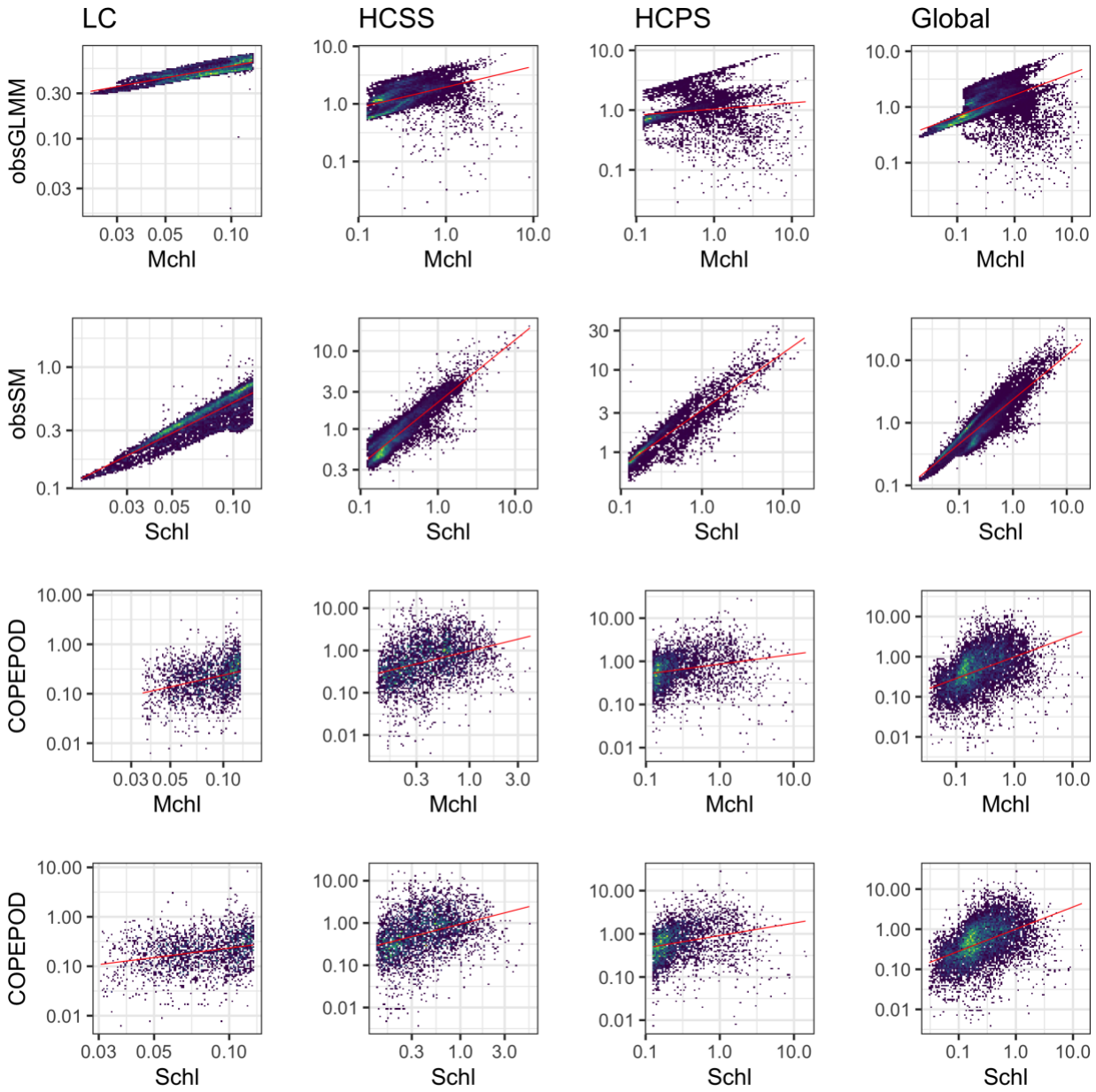

Figure S4f-i. Correlations between mesozooplankton biomass (mgC m^{-2}) and chlorophyll concentration (mg m^{-3}) by biome in the obsGLMM, obsSM, and COPEPOD dataset. LC regions above 45ºN/below 45ºS were excluded from the analysis. For the values of the scaling scopes of these models, see Table S3. Mchl: MODIS chlorophyll; Schl: SeaWiFS chlorophyll.

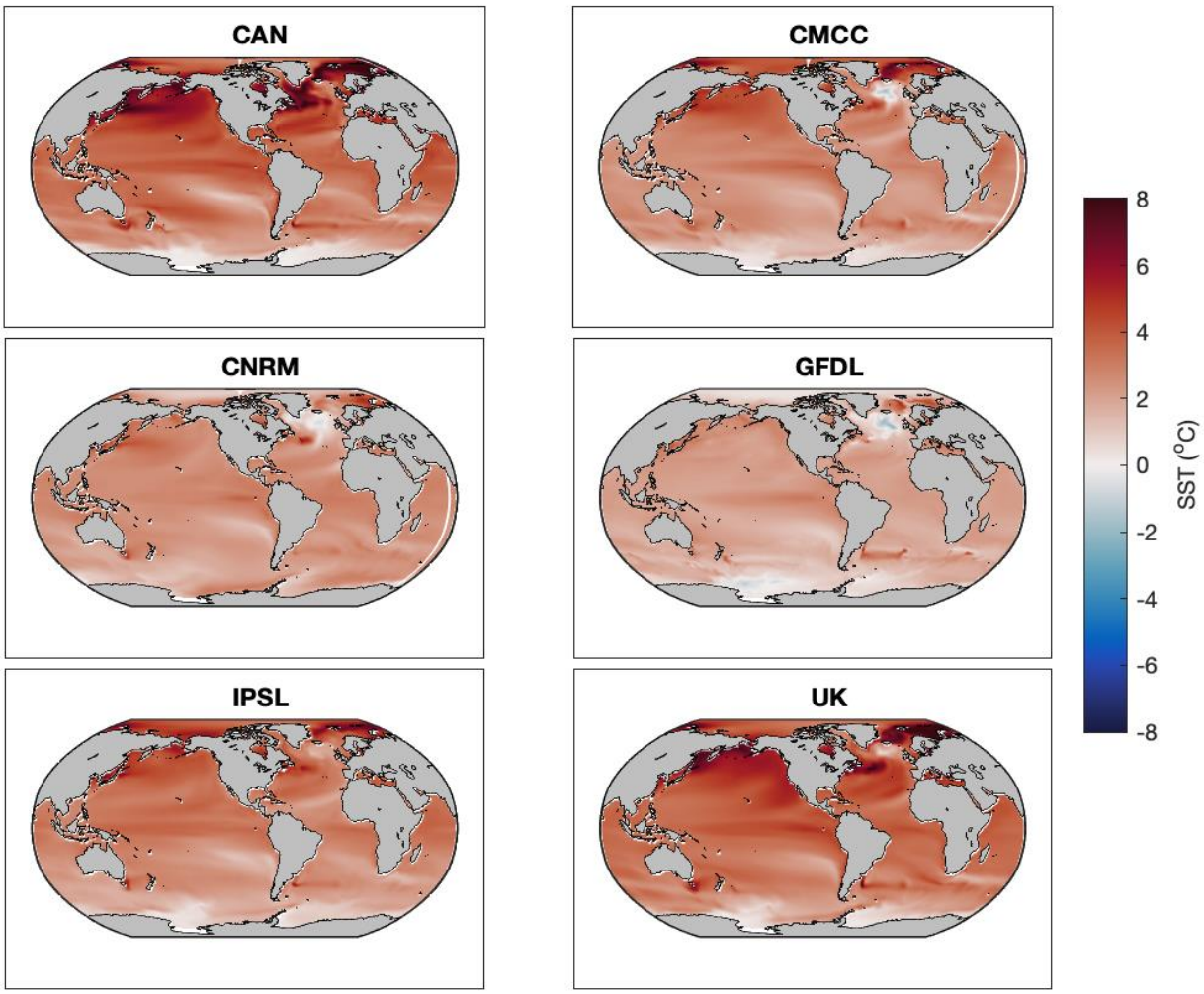

Figure S6. Change in sea surface temperature in the ESMs from the Historical (1965-2014) to the SSP5-8.5 (2051-2100) simulations.

APPENDIX: CAN-specific Results

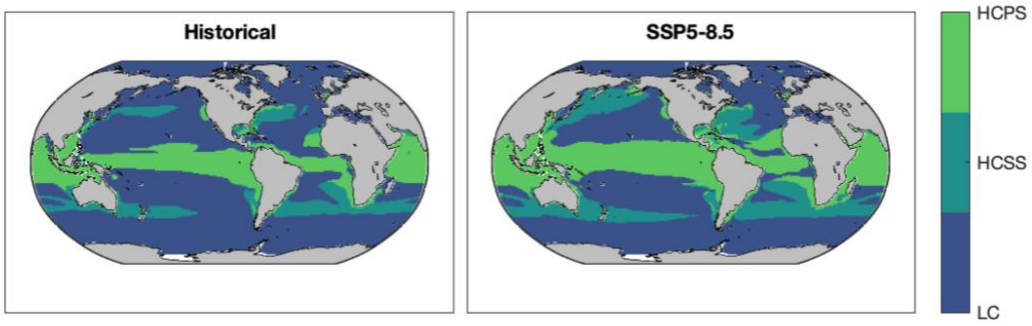

Figure A1. CAN biomes. Distribution of biomes in the (left) Historical and (right) SSP5-8.5 simulations. LC – low chlorophyll, HCPS – high chlorophyll, permanently stratified, HCSS – high chlorophyll, seasonally stratified. Note that LC regions above 45ºN/below 45ºS were excluded from the analyses.

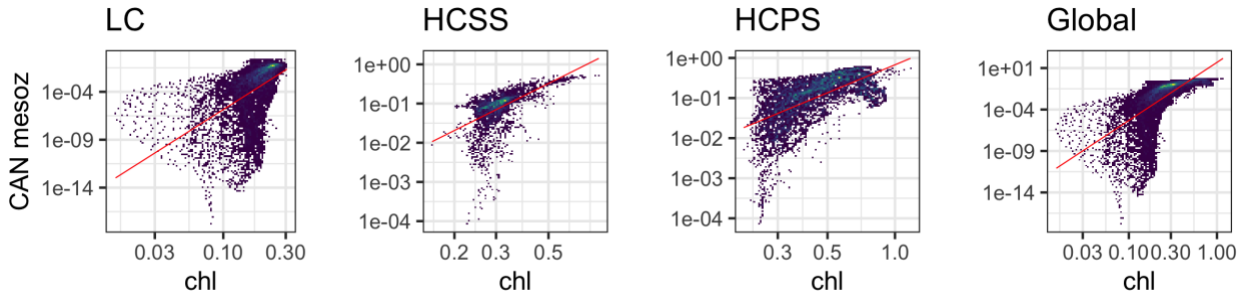

Figure A2. Correlations between mean mesozooplankton biomass (mgC m^{-2}) and mean chlorophyll concentration (mg m^{-3}) in each grid cell by biome and globally in the CAN ESM during the Historic period (1965-2014). LC regions above 45ºN/below 45ºS were excluded from the analysis.

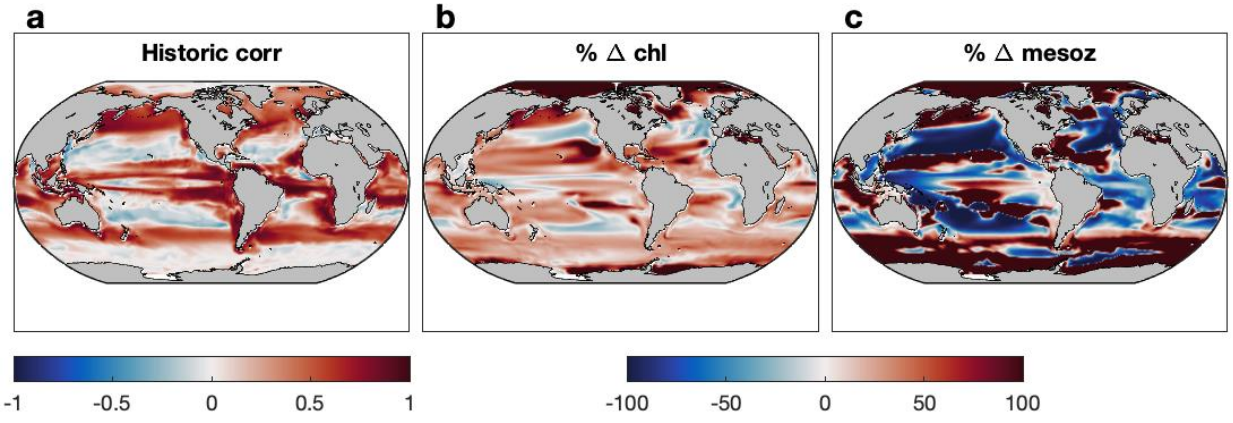

Figure A3. (a) Correlations between the CAN annual climatologies of mesozooplankton biomass and chlorophyll concentration during the Historic 50-yr period. Percent change in (b) surface chlorophyll concentration and (c) mesozooplankton biomass in the CAN ESM in the SSP5-8.5 (2051-2100) simulation compared to the Historical (1965-2014) simulation.

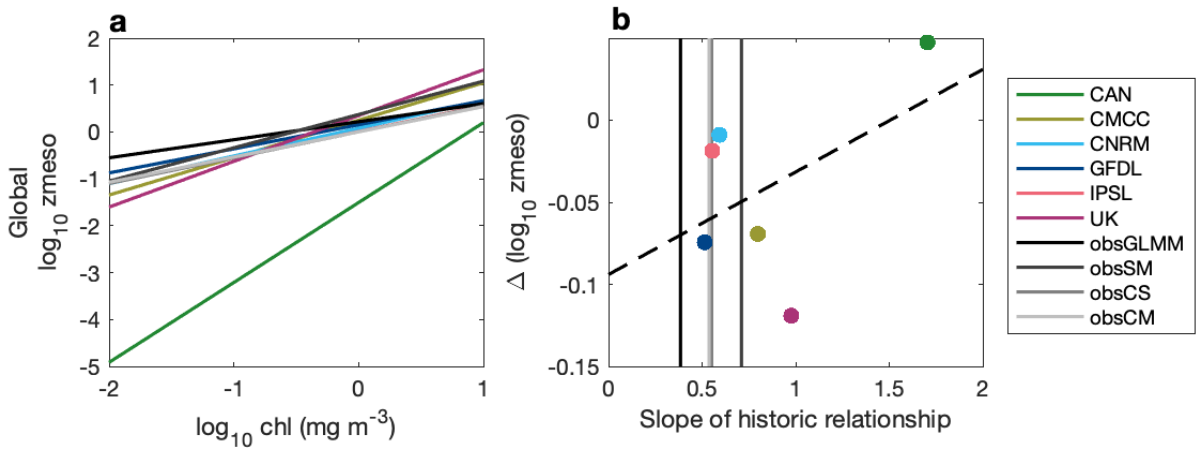

Figure A4. (A) Historic relationship (linear regression) between mesozooplankton biomass and surface chlorophyll concentration globally. (B) Comparison of the change in mesozooplankton biomass under the RCP5-8.5 Projection and the Historic relationship between mesozooplankton and chlorophyll (linear regression slopes). In (B), dotted black line: linear regression fit. obsGLMM: observation-based GLMM; obsSM: Stromberg et al. model; obsCS: COPEPOD data with SeaWiFS chlorophyll and related biomes; obsCM: COPEPOD data with MODIS chlorophyll and related biomes.