Supplementary information

Table S1. Overview of marine ecosystem models included in the ensemble projections (modified from Tittensor et al. (2018a) and Lotze et al. (in review)).

Fish-MIP model	Model description	Key ecological processes	Spatial and temporal scale for Fish-MIP simulations	Vertical resolution	Taxonomic scope	Key reference
BiOeconomic mArine Trophic Size-spectrum (BOATS)	Size-structure model, that combines marine biogeochemistry with size-based trophic theory and metabolic constraints to calculate the production of commercially-harvested fish across multiple size spectra.	Applies empirical parameterizations to describe phytoplankton community structure, trophic transfer of primary production from phytoplankton to fish, fish growth rates, and natural mortality of fish. No direct or passive movement of fish, larvae or eggs between grid cells considered.	1 x 1˚ grid Monthly mean timestep	None (2-dimensional domain). NPP is vertically-integrated through the water column. Temperature changes with SST.	3 size groups (small, medium, large) defined by their asymptotic mass, representing all commercial fish.	Carozza et al. (2016)
Macroecological Model	Static size-structure model. Uses minimal input parameters together with ecological and metabolic scaling theory to calculate mean size composition and abundance of marine animals (including fish).	Simple characterization of marine ecosystems in terms of body mass distribution and marine animal abundance based on estimates of predator-prey mass ratios, transfer efficiency and changing metabolic demands with body mass and temperature. Animal movement is not included.	1 x 1˚ grid Annual mean timestep	Single vertical (surface-integrated) layer.	180 body mass classes. Species are not resolved.	Jennings and Collingridge (2015)
Dynamic Pelagic Benthic Model (DPBM)	Dynamic size-and trait based model. Incorporates a pelagic predator size-spectrum with a benthic	Individual processes of predation, food-dependent growth, natural mortality, and	1 x 1˚ grid Monthly mean timestep	2 vertical layers (sea surface and sea floor). No vertical transport or	1 pelagic predator and 1 benthic detritivore size spectrum, with	Blanchard et al. (2012)

	detritivore size-spectrum.	reproduction give rise to emergent size spectra for each functional group (pelagic predator and benthic detritivore).		movement.	100 size classes each.	
Dynamic Bioclimate Envelope Model (DBEM)	Species distribution model based on bioclimatic envelopes (niche) defined for each species. Simulates changes in species abundance and carrying capacity under environmental change. Carrying capacity is a function of the environment and species' habitat preferences.	Population dynamics is dependent of habitat suitability and movement of adult species driven by a gradient of habitat suitability and population density. Larval dispersal is driven by currents and temperature. Growth, reproduction, and natural mortality are dependent on oxygen, pH, and temperature.	0.5 x 0.5˚ grid Annual mean ocean conditions	Vertical layers (sea surface and bottom) defined by species niche preferences.	892 commercial fish and invertebrate species.	Cheung et al. (2011)
EcoOcean	Trophodynamic model, based on species interactions and energy transfer across trophic levels. Ecosim-with-Ecopath (EwE) framework designed to evaluate the impacts of fisheries and climate change on marine resources and ecosystems.	Combines a food web model comprising a mass-balance component (Ecopath; input: biomass, production/biomass ratio, consumption/biomass ratio, diet composition, catches), a temporal dynamic predator-prey component (Ecosim), and a spatio-temporal dynamic component which is a function of grid cell specific habitat attributes i.e. pH, water depth, temperature, and bottom type (Ecospace).	1 x 1˚ grid Monthly mean timestep	Vertical layers defined by food web interactions and habitat preference patterns; vertical movement and transportation through the establishment of trophic links and the generation and consumption of dead organic matter linking pelagic organisms to demersal and benthic organisms.	51 trophic biomass groups; including all trophic level and taxonomic groups (marine mammals, birds, fish, invertebrates, primary producers and bacteria)	Christensen et al. (2015)
Apex Predators ECOSystem Model	Composite (hybrid) model. 3D dynamic energy budget Eulerian model of size-	Size-based predation, food- and temperature-driven growth,	1 x 1˚ grid Monthly mean timestep	3D explicit vertical movement considered.	Explicit size-based communities	Maury (2010)

(APECOSM)	structured marine populations and communities, based on individual environmentally driven bio-energetics, trophic interactions and behaviors, that are upscaled to populations and communities.	reproduction and senescence. Includes environmental impacts on vertical and horizontal movements and schooling.			including 3 communities (epipelagic, migratory, mesopelagic); 95 species length classes and 100 size classes	

Table S2. Overview of layer configuration and selected forcing variables used in the marine ecosystem models included in the ensemble projections. Forcing variables were provided by the two Earth system models GFDL-ESM2M (1˚ by 1˚ degree grid cell, 50 depth levels) and IPSL-CM5A-LR (1˚ by 1˚ degree grid cell, 31 depth levels). Layers included surface, bottom, depth-integrated surface to bottom, or depth resolved, depending on each ecosystem model's requirements.

Fish-MIP model	**Depth integration**	**Current speed**	**Sea temperature**	**Dissolved oxygen conc.**	**NPP - primary organic carbon production**	**Phytoplankton carbon conc.**	**Zooplankton carbon conc.**	**pH**	**Salinity**	**Total alka-linity**	**Ice coverage**	**Mixed layer depth**
BOATS	Integrated over full water column	N/A	Upper ocean temperature (average of upper 75m)	N/A	Depth integrated primary production (full water column)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Macroeco-logical model	Integrated over full water column	N/A	Sea surface temperature (0-200m)	N/A	Depth integrated primary production (assumed to be allocated to the mixed layer depth or euphotic depth if deeper)	Large and small phytoplankton	N/A	N/A	N/A	N/A	N/A	Areas shallower than mixed layer depth (or euphotic depth if deeper) treated as productive zone

DPBM	2 layers, surface (0-100m) and bottom.	N/A	Sea surface and sea bottom temperature	N/A	Depth integrated primary production.	Large/ small phytoplankton	N/A	N/A	N/A	N/A	N/A	Mixed layer depth incl.
DBEM	Vertical dimension is dependent on species specific min/max depth limits	Zonal and meridional velocity	Sea surface and sea bottom temperature	Dis. oxygen included	Depth integrated primary production.	Large/ small phytoplankton	N/A?	Sea surf ace pH	Sea surface and sea bottom salinity	N/A?	Ice coverage incl.	N/A
EcoOcean	Vertical dimension is dependent on depth distribution from species/ functional groups	N/A	Sea surface (150 m)	N/A	N/A	Large/small phytoplankton	Large/small zooplankton	N/A	N/A	N/A	Ice coverage incl. (not floating ice)	N/A
APECOSM	3D depth-resolved	Zonal, meridional and vertical velocity	Vertically (3D) resolved sea temperature	Dissolved oxygen included	N/A	Large/small phytoplankton	Large/small zooplankton.	pH incl ude d	N/A	Turbu-lent mixing incl.	Ice coverage incl.	N/A

Table S3. Overview of projected changes in total marine animal biomass under climate change (Emissions scenario RCP2.6 and RCP8.5) for individual ecosystem models and ocean basins. All changes are represented as the average of 2090-2099 relative to the average of 1990-1999. Light grey shading: changes <5%; grey shading: changes between 5-10%; dark grey shading: changes >10%.

Ecosystem model	Ocean basin	RCP 2.6	RCP 8.5
APECOSM	North Atlantic Ocean	-11.19%	-15.67%
	South Atlantic Ocean	-3.65%	-9.19%
	North Pacific Ocean	-2.81%	-10.50%
	South Pacific Ocean	-2.81%	-9.22%
	Indian Ocean	-1.36%	-9.44%
	Southern Ocean	-1.06%	4.53%
	Arctic Ocean	2.22%	-12.66%
BOATS	North Atlantic Ocean	-16.42%	-39.51%
	South Atlantic Ocean	-9.69%	-29.95%
	North Pacific Ocean	-12.22%	-37.97%
	South Pacific Ocean	-10.12%	-27.29%
	Indian Ocean	-10.96%	-31.53%
	Southern Ocean	-0.81%	4.31%
	Arctic Ocean	23.78%	17.68%
EcoOcean	North Atlantic Ocean	-8.78%	-23.84%
	South Atlantic Ocean	1.66%	-0.76%
	North Pacific Ocean	-15.25%	-21.96%
	South Pacific Ocean	-1.30%	-5.99%
	Indian Ocean	0.43%	-3.35%
	Southern Ocean	-3.50%	8.95%
	Arctic Ocean	12.24%	13.70%
DBEM	North Atlantic Ocean	-12.00%	-42.96%
	South Atlantic Ocean	-9.87%	-8.73%
	North Pacific Ocean	-2.17%	-16.34%
	South Pacific Ocean	-9.97%	-34.34%
	Indian Ocean	-3.53%	-36.08%
	Southern Ocean	-7.53%	91.68%
	Arctic Ocean	239.07%	491.57%
DPBM	North Atlantic Ocean	-6.74%	-18.69%
	South Atlantic Ocean	-2.32%	-7.72%
	North Pacific Ocean	-5.34%	-12.87%
	South Pacific Ocean	-4.91%	-11.19%

	Indian Ocean	-4.48%	-11.14%
	Southern Ocean	0.62%	1.95%
	Arctic Ocean	4.61%	-7.13%
Macroecological	North Atlantic Ocean	-19.03%	-49.62%
	South Atlantic Ocean	-6.20%	-29.42%
	North Pacific Ocean	-13.43%	-53.60%
	South Pacific Ocean	-8.69%	-27.16%
	Indian Ocean	-8.23%	-30.76%
	Southern Ocean	-5.30%	3.47%
	Arctic Ocean	8.09%	-11.25%
Ensemble mean	**North Atlantic Ocean**	**-12.36%**	**-31.71%**
	South Atlantic Ocean	**-5.01%**	**-14.29%**
	North Pacific Ocean	**-8.53%**	**-25.54%**
	South Pacific Ocean	**-6.30%**	**-19.20%**
	Indian Ocean	**-4.69%**	**-20.38%**
	Southern Ocean	**-2.93%**	**19.15%**
	Arctic Ocean	**48.33%**	**81.99%**

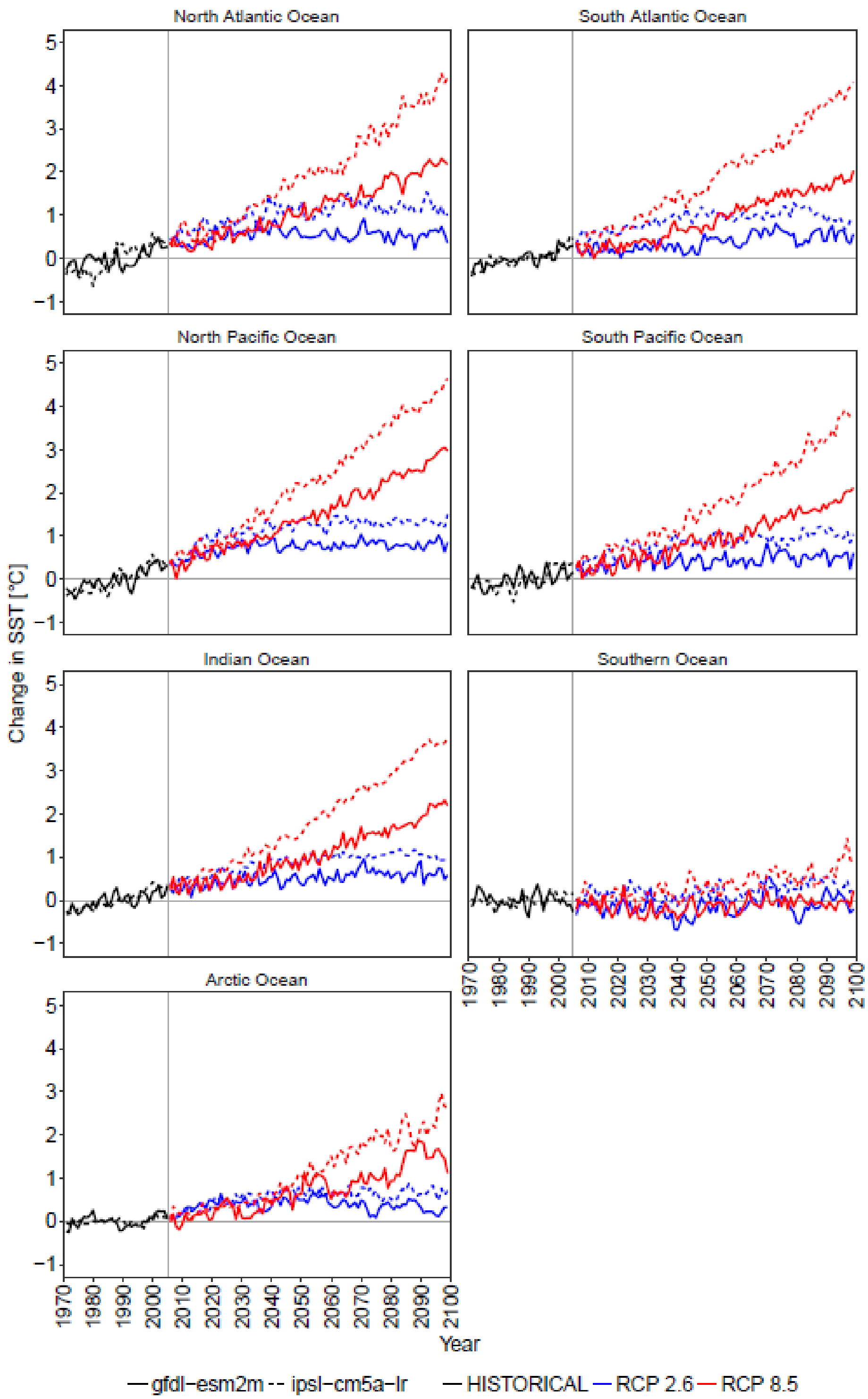


Figure S1 Earth system model projections for sea surface temperature (SST) across ocean basins under climate change (RCP2.6 and RCP8.5) for 1970-2100. SST trends in degree °C relative to 1990-1999.

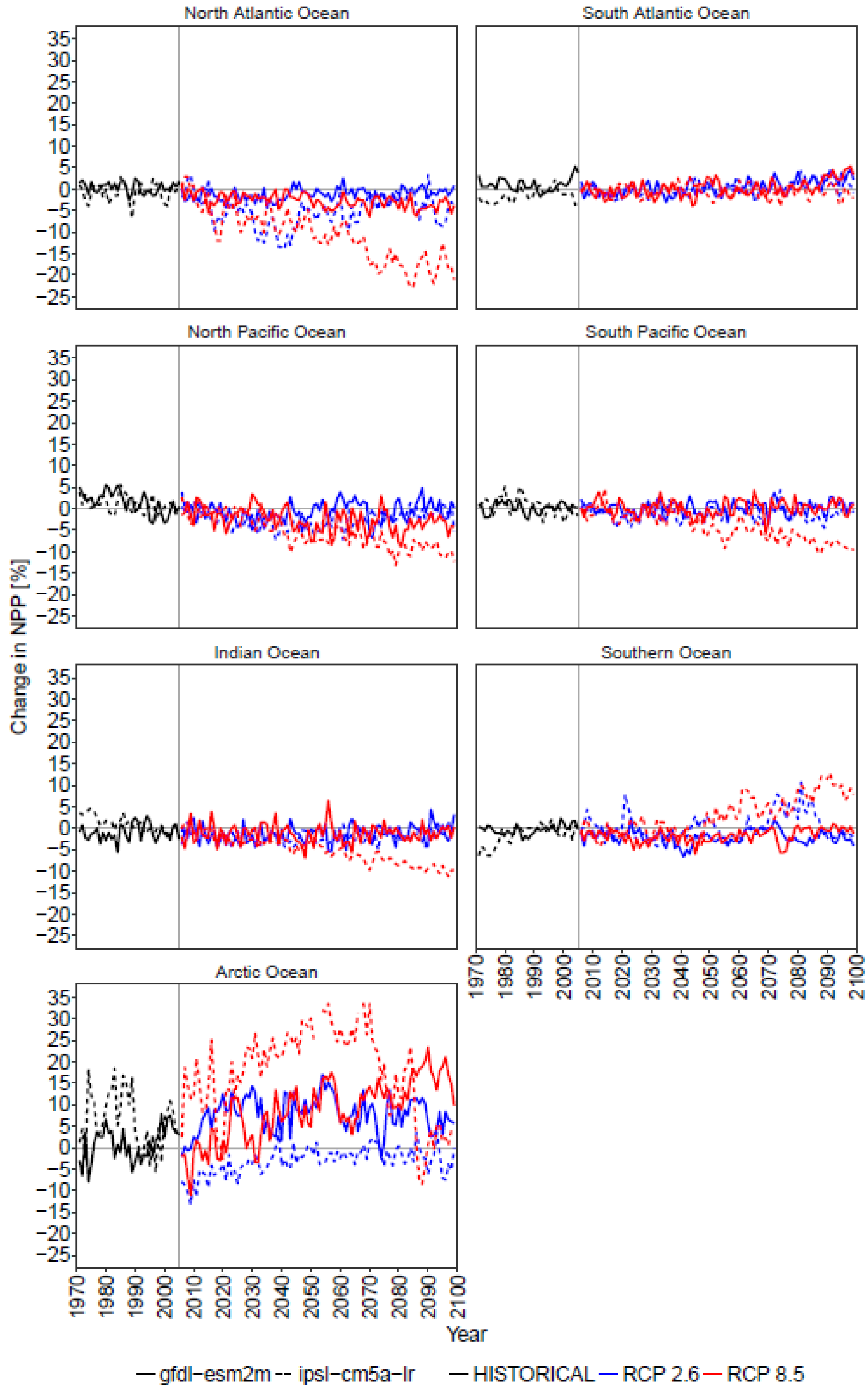
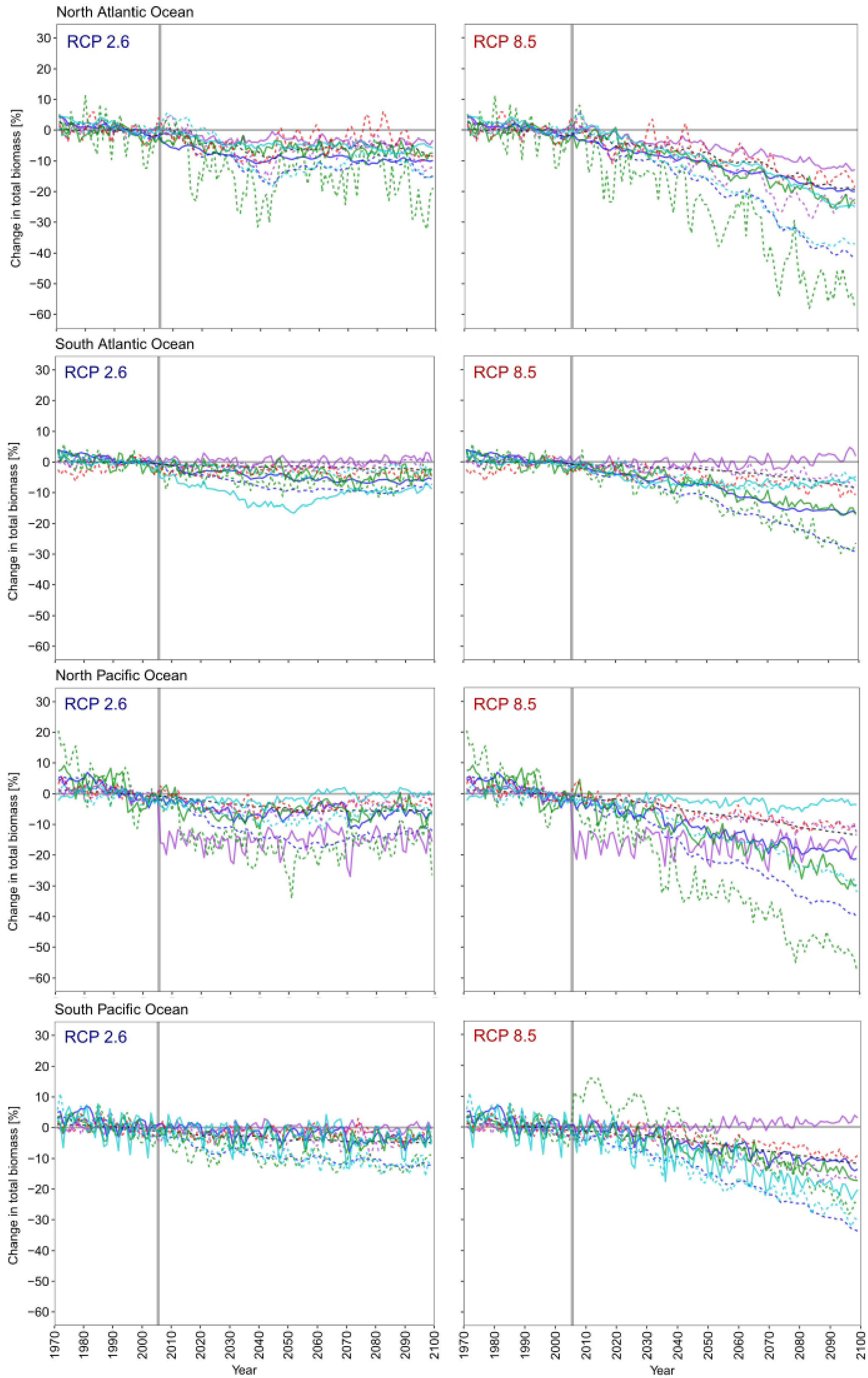


Figure S2. Earth system model projections for net primary production (NPP) across ocean basins under climate change (RCP2.6 and RCP8.5) for 1970-2100. Trends are relative (%) to the average of 1990-1999.

54 

North Atlantic Ocean
RCP 2.6
RCP 8.5
South Atlantic Ocean
RCP 2.6
RCP 8.5
North Pacific Ocean
RCP 2.6
RCP 8.5
South Pacific Ocean
RCP 2.6
RCP 8.5
Change in total biomass [%]
30
20
10
0
−10
−20
−30
−40
−50
−60
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year

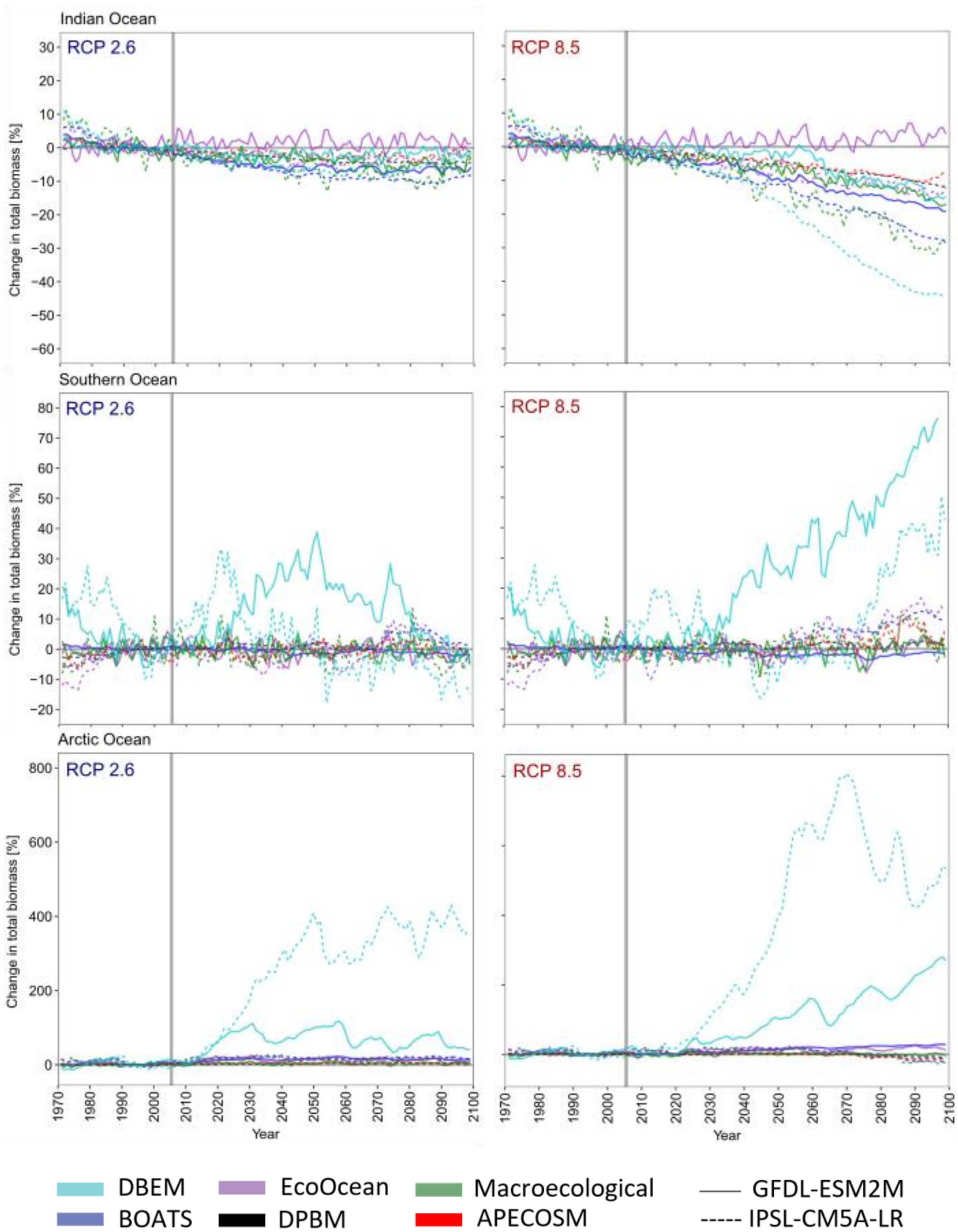


Figure S3. Individual model projections for total marine animal biomass across ocean basins under climate change (Emissions scenarios RCP2.6 and RCP8.5) for 1970-2100. Vertical grey line separates historical trends (1970-2005) and future projections (2006-2100). All trends are relative (%) to the average of 1990-1999.

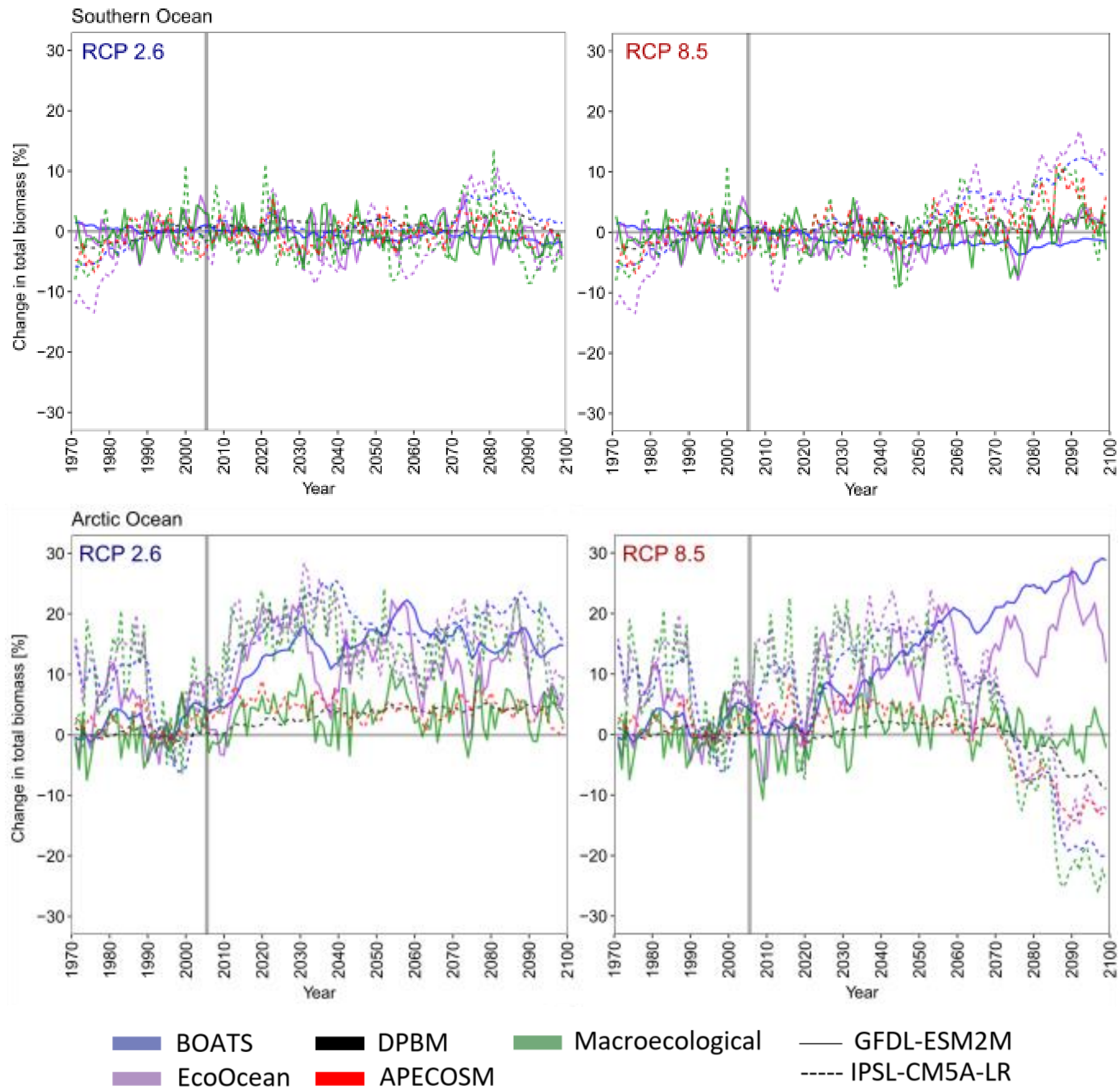


Figure S4. Individual model projections for total marine animal biomass in the Arctic Ocean and Southern Ocean without DBEM under RCP2.6 and RCP8.5 for 1970-2100. DBEM is excluded to visualize temporal trends of the other ecosystem models in the polar ocean basins. Vertical grey line separates historical trends (1970-2005) and future projections (2006-2100). All trends are relative (%) to the average of 1990-1999.

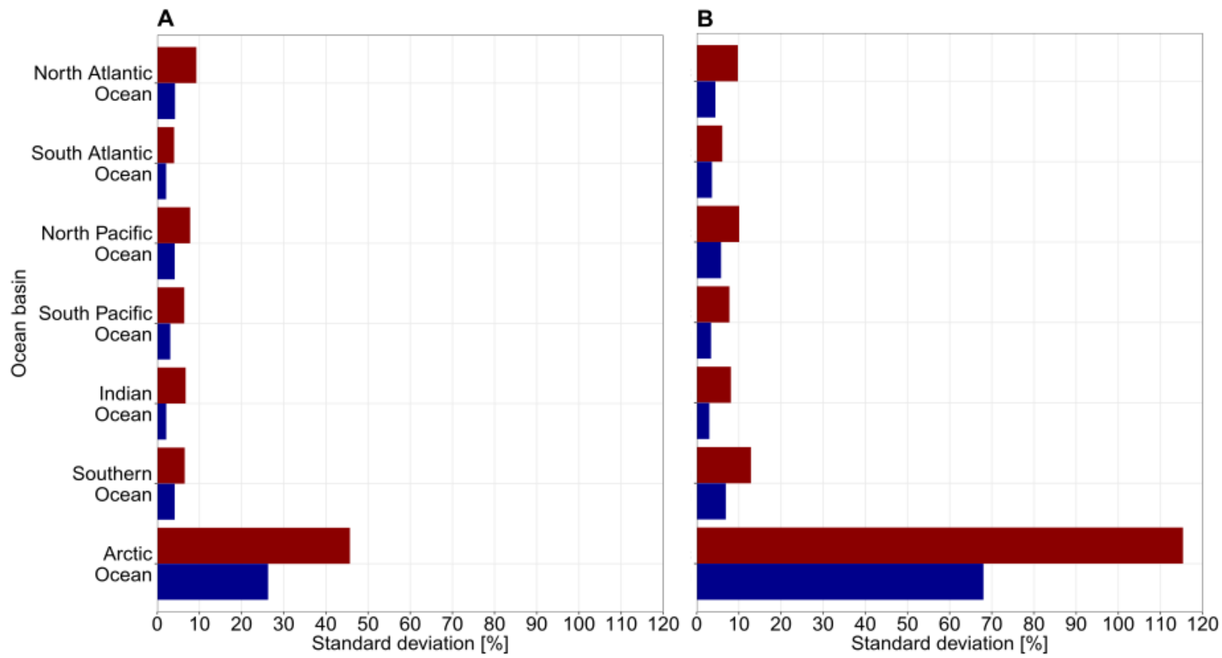


Figure S5. Variability in projections of total marine animal biomass as mean standard deviation due to different Earth system models and different ecosystem models under RCP2.6 (blue) and RCP8.5 (red). **A**: Earth system model variability. **B**: Marine ecosystem model variability.

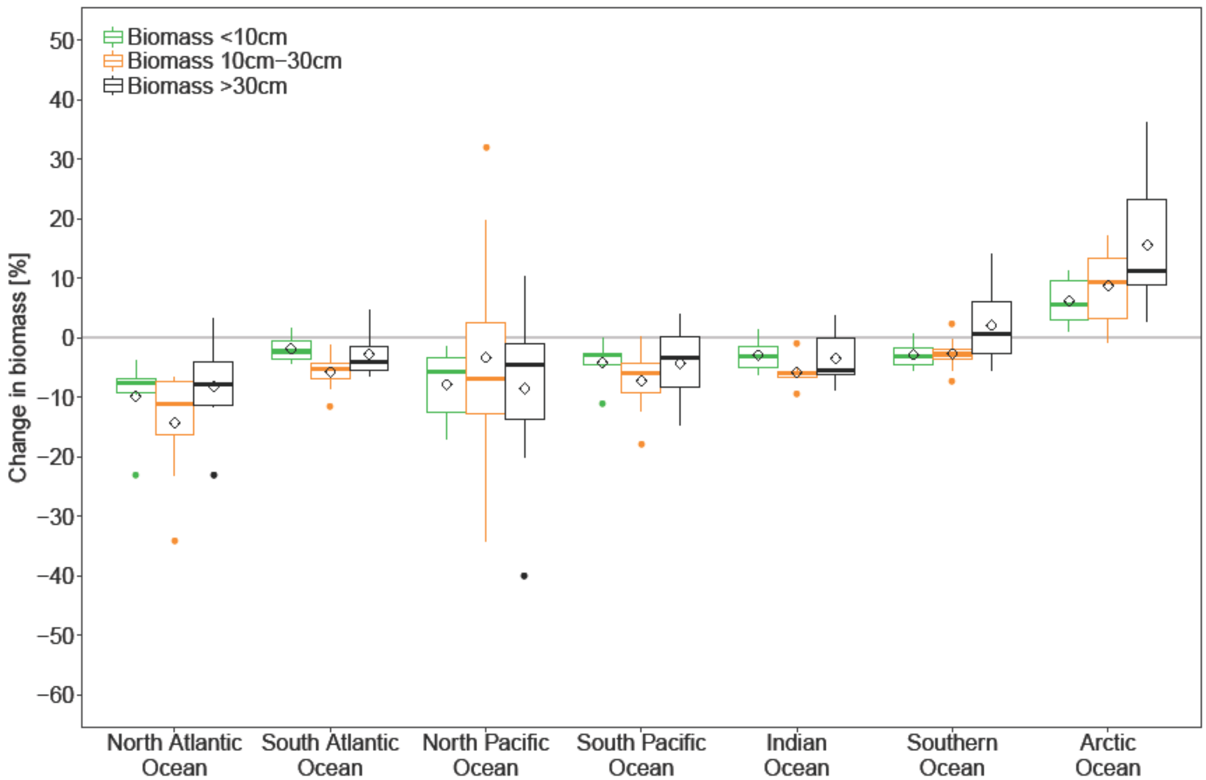


Figure S6. Model projections for marine animal biomass of three size ranges across ocean basins under climate change for the emissions scenario RCP2.6. Green: small marine animals <10cm (n-6); orange: medium-sized marine animals 10–30cm (n=8); black: large marine animals >30cm (n=8). All changes are the average of the 2090s relative to the 1990s. Boxplots: the upper and lower hinges correspond to the 1st and 3rd quartiles; the upper/lower whisker extends to the highest/lowest value that is within 1.5 times the interquartile range; horizontal line within the box corresponds to the median; diamonts represents the mean. Outlier dots are representing data beyond the end of the whiskers.

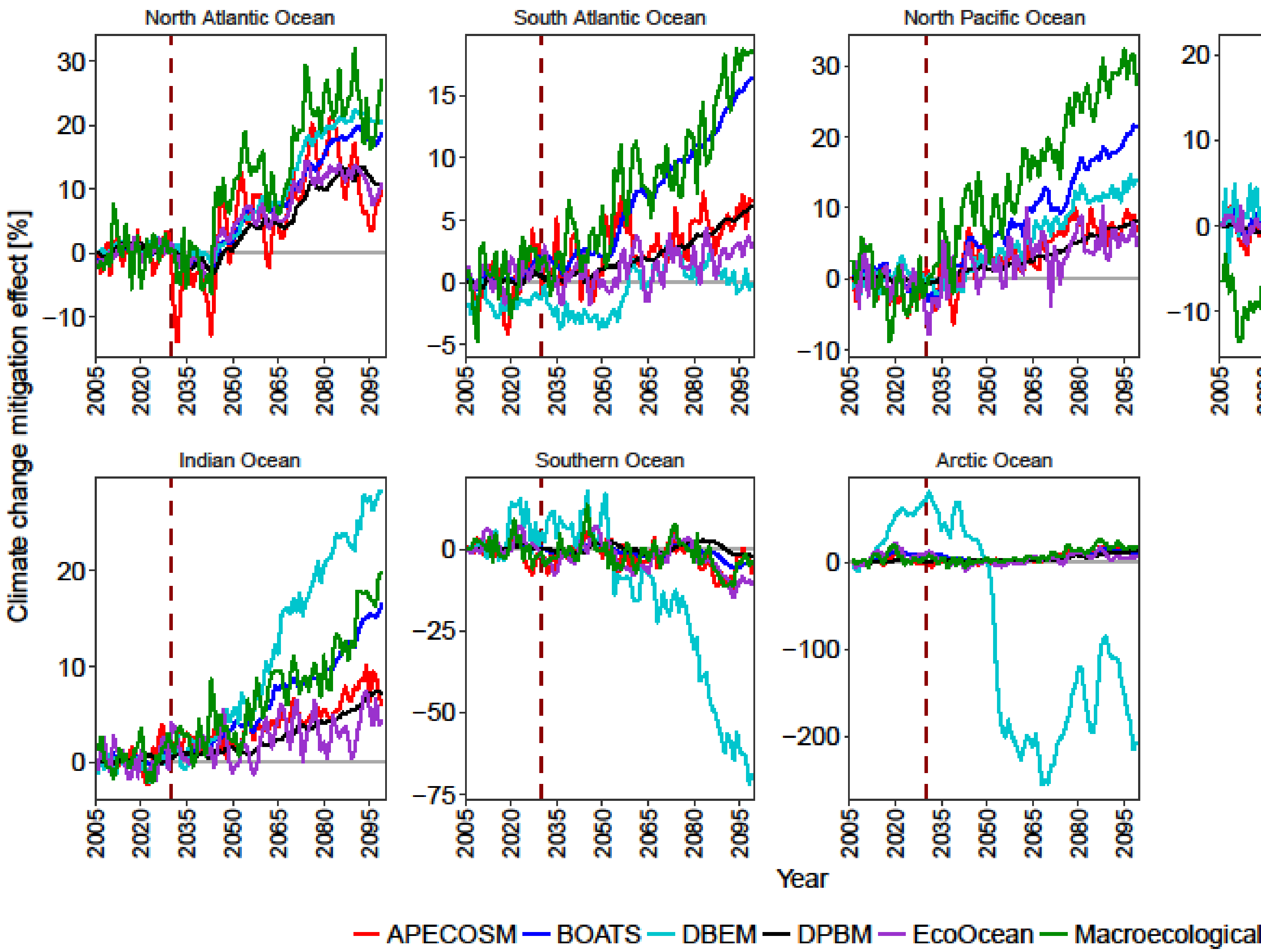


Figure S7. Climate change mitigation effect (RCP2.6 – RCP8.5) on model projections of total marine animal biomass. Vertical dashed line: target year (2030) for most UN Sustainable Development Goals.