Supplementary Material: Marine Heat Waves Are Transforming the Western Mediterranean Marine Ecosystems

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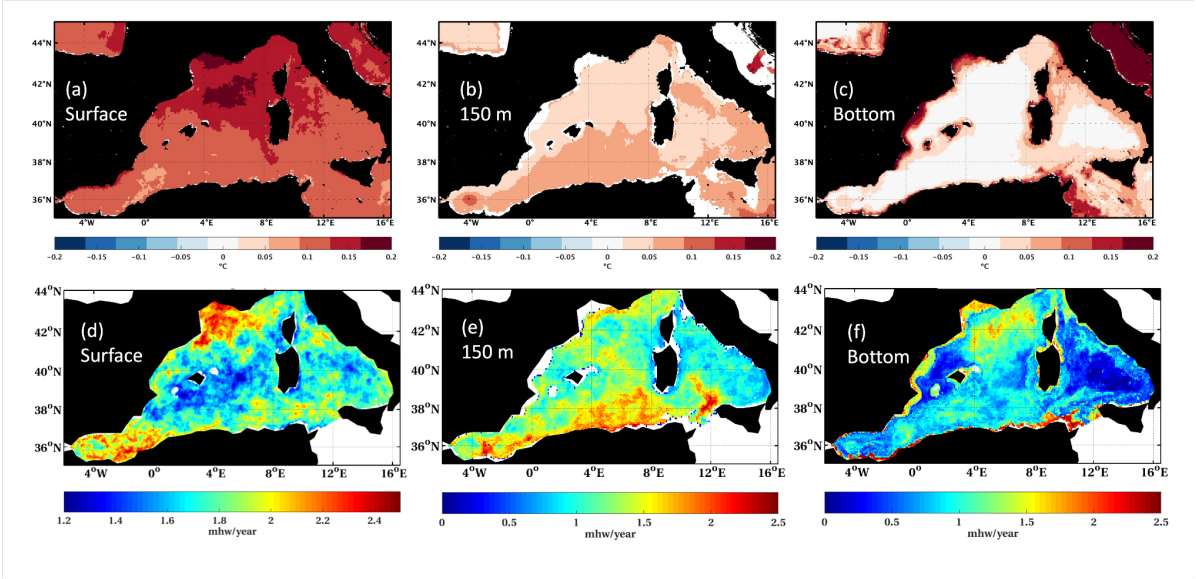


Figure S1: (a–b) Temperature difference between GLORYS12 outputs and temperature inputs for the control scenario in which MHWs were removed (d–e) Frequency of MHWs at each depth, expressed as the number of events per year (h–j).

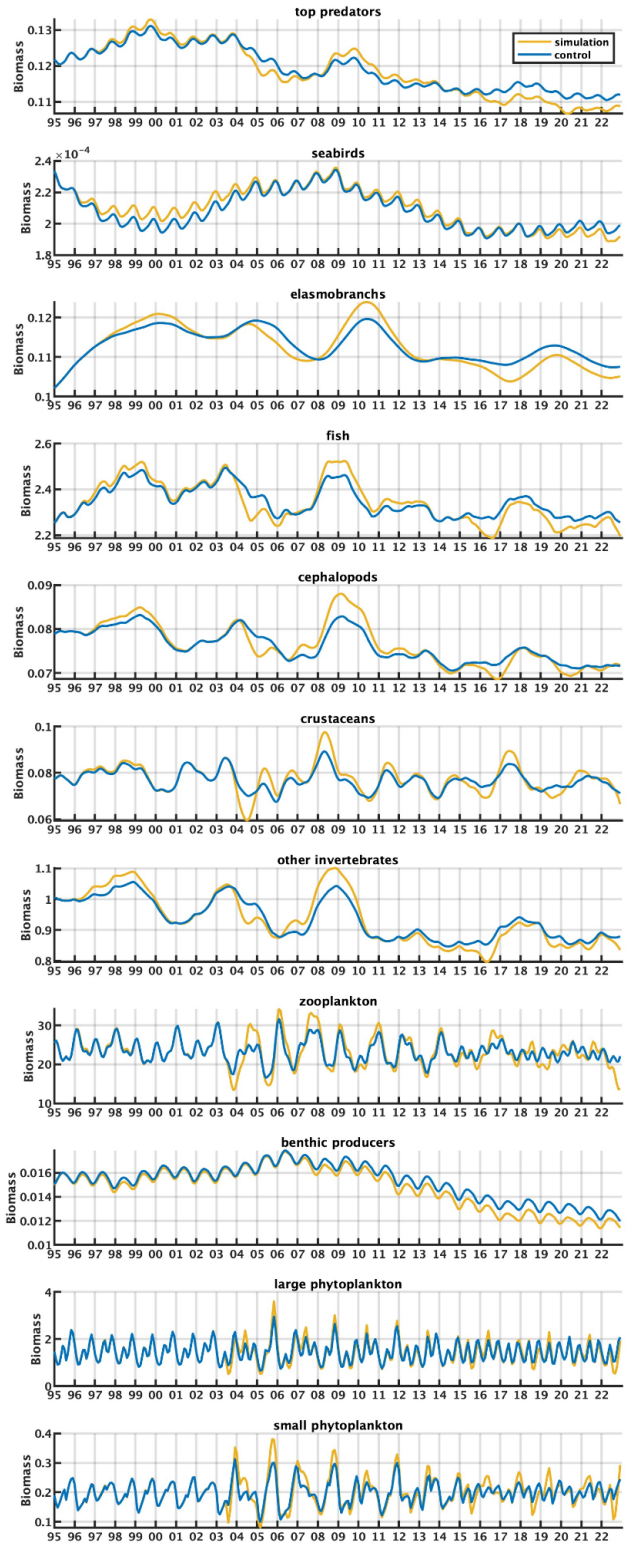
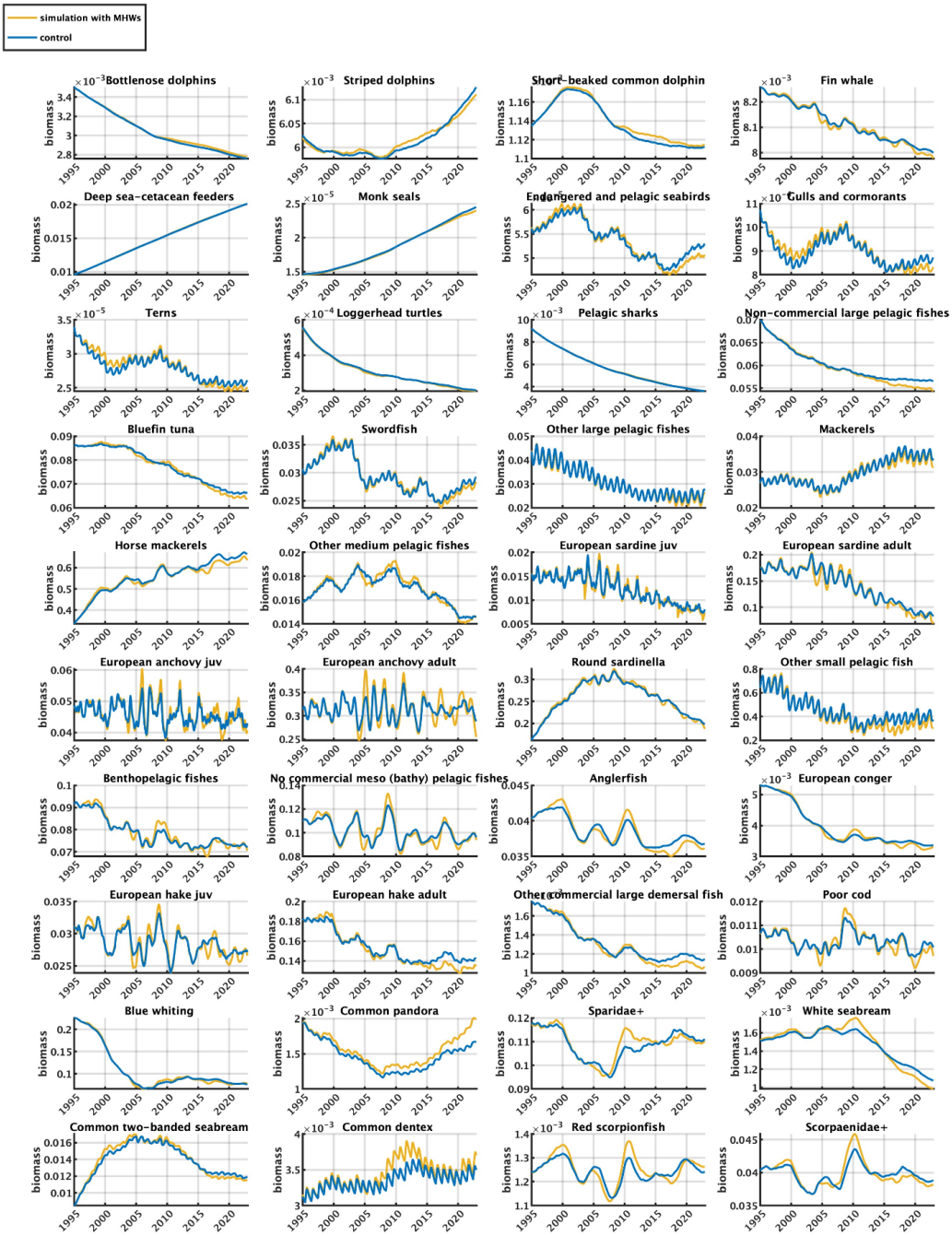


Figure S2: Time series of biomass (t/km^2) for each functional group obtained with the simulation with (yellow) and without (blue) MHWs.


simulation with MHWs
control
Bottlenose dolphins
Striped dolphins
Short-beaked common dolphin
Fin whale
Deep sea-cetacean feeders
Monk seals
Endangered and pelagic seabirds
Gulls and cormorants
Terns
Loggerhead turtles
Pelagic sharks
Non-commercial large pelagic fishes
Bluefin tuna
Swordfish
Other large pelagic fishes
Mackerels
Horse mackerels
Other medium pelagic fishes
European sardine juv
European sardine adult
European anchovy juv
European anchovy adult
Round sardinella
Other small pelagic fish
Benthopelagic fishes
No commercial meso (bathy) pelagic fishes
Anglerfish
European conger
European hake juv
European hake adult
Other commercial large demersal fish
Poor cod
Blue whiting
Common pandora
Sparidae+
White seabream
Common two-banded seabream
Common dentex
Red scorpionfish
Scorpaenidae+
biomass

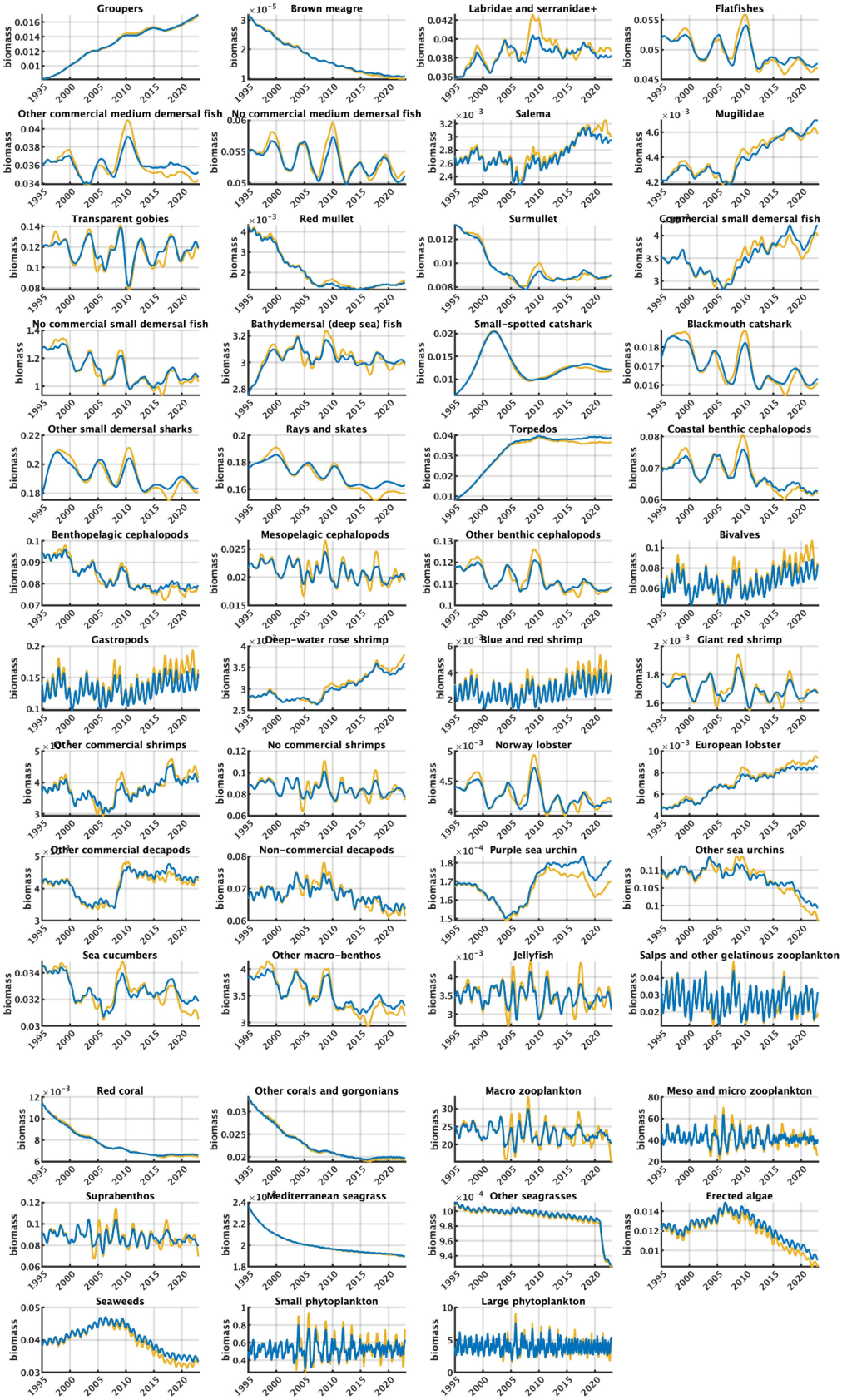
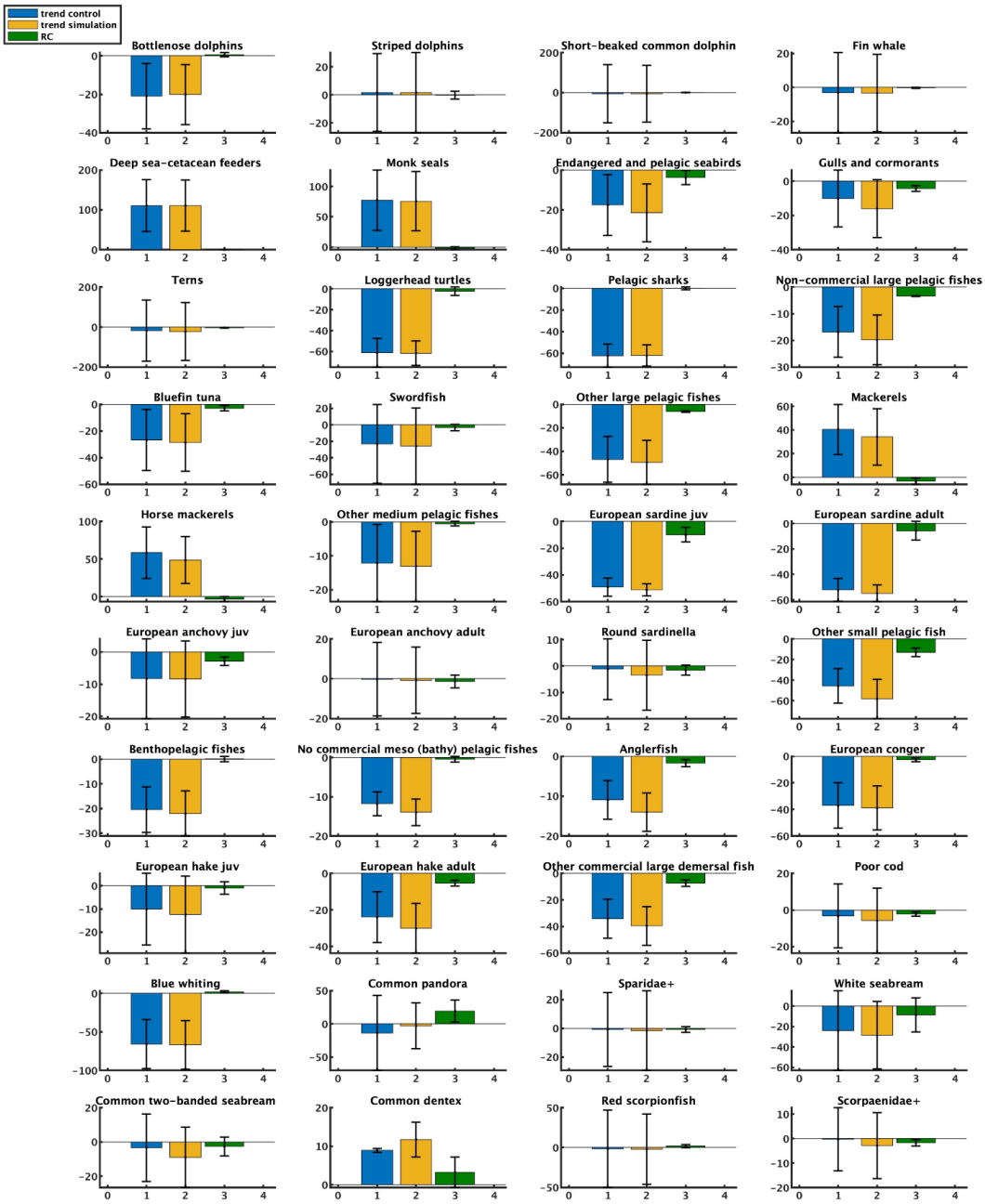


Figure S3: Time series of biomass (t/km^2) for each individual group obtained with the simulation with (yellow) and without (blue) MHWs.


trend control
trend simulation
RC
Bottlenose dolphins
Striped dolphins
Short-beaked common dolphin
Fin whale
Deep sea-cetacean feeders
Monk seals
Endangered and pelagic seabirds
Gulls and cormorants
Terns
Loggerhead turtles
Pelagic sharks
Non-commercial large pelagic fishes
Bluefin tuna
Swordfish
Other large pelagic fishes
Mackerels
Horse mackerels
Other medium pelagic fishes
European sardine juv
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Round sardinella
Other small pelagic fish
Benthopelagic fishes
No commercial meso (bathy) pelagic fishes
Anglerfish
European conger
European hake juv
European hake adult
Other commercial large demersal fish
Poor cod
Blue whiting
Common pandora
Sparidae+
White seabream
Common two-banded seabream
Common dentex
Red scorpionfish
Scorpaenidae+

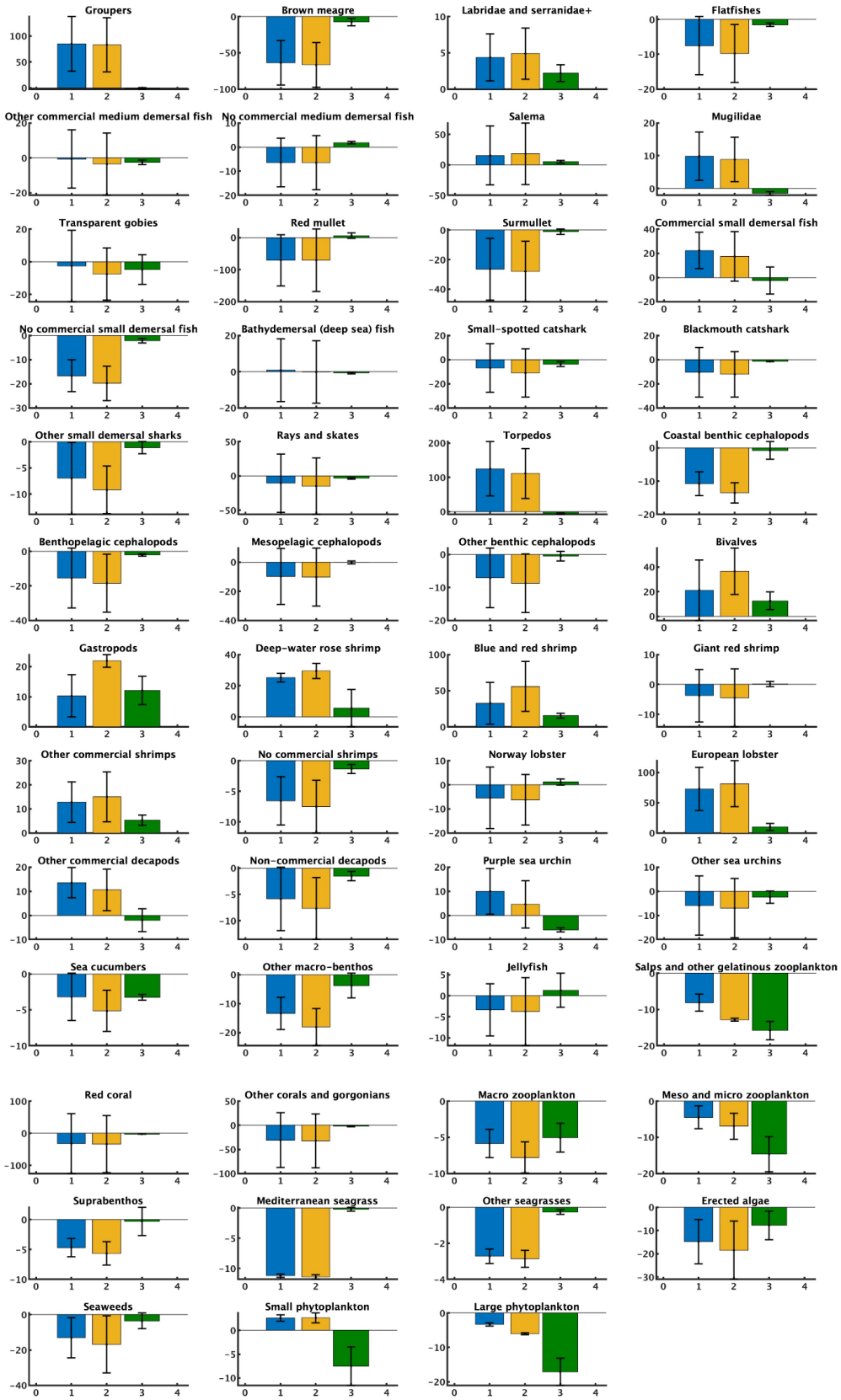

Figure S4: Historical trend in Biomass for each individual group expressed as a percentage for the simulations with (yellow bars) and without (blue bars) MHWs. The RC for individual groups averaged over the final year of the simulation is represented by a green bar.

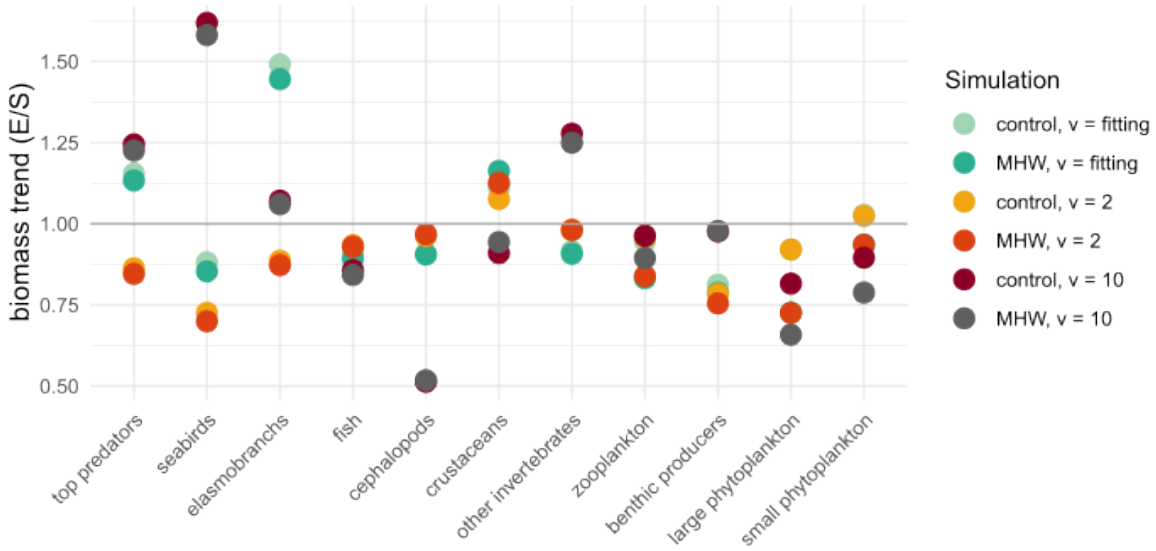

Figure S5. Initial/final biomass ratio for each species group under each model simulation (control simulations and MHW simulations with three different vulnerability values, represented by the different colours shown in the legend).

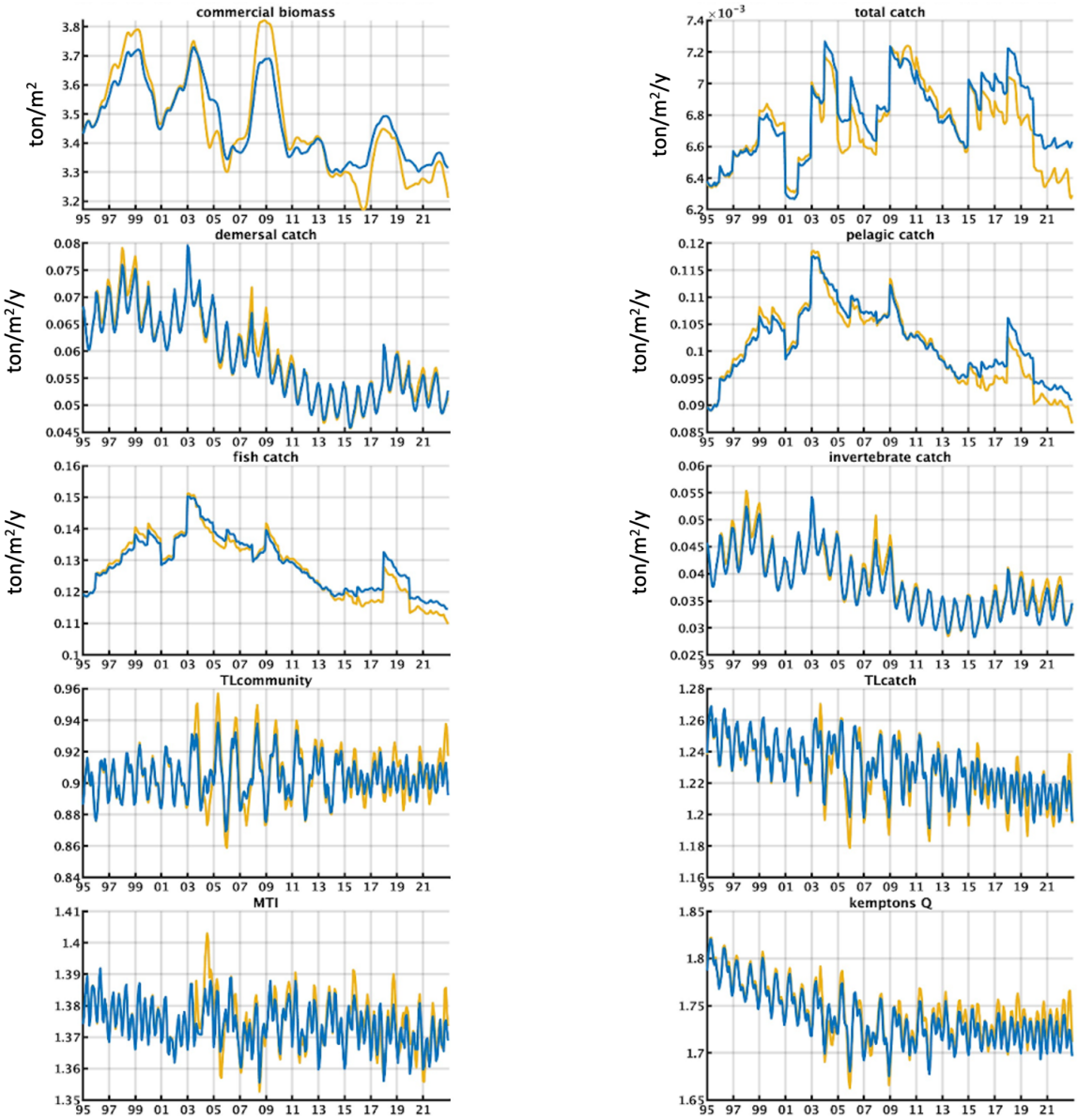

Figure S6: Time series of the ecological indicators obtained with the simulation with (yellow) and without (blue) MHWs.

In order to distinguish the different vertical and temporal behaviour of MHWs we selected 3 five-year periods with markedly different MHW patterns: 1995-2000, 2003-2008 and 2017-2022. Maps of temperature MHW frequency, and absolute temperature during MHWs averaged over the period 2017–2022 reveal marked contrasts compared to earlier periods (1995–2000 and 2003–2008) (Figures S7, and S8). During the most recent period the highest absolute temperatures during MHWs were observed in the north at the surface (~25°C) and in the south at 150 m depth (~15°C) (Figure S7). Maps of MHWs frequency show that MHWs were much more frequent during the last period (Figure S8). At the surface, the northern part of the basin showed a frequency of 6 MHWs per year, being even more frequent at 150 m. This stands in stark contrast to the frequency of MHWs observed during the periods 2003–2008 and 1995–2003, which did not exceed 2 MHWs per year.

When comparing the maximum intensities of MHW events through the three periods, we observe that the latitudinal temperature gradient between the cooler north and warmer south tends to diminish during extreme events (Figure S9). In fact, maximum surface temperatures during MHWs reach values around 30°C in the northern part of the basin, comparable to those from the south. These patterns suggest that, starting from 2003 and particularly during the 2017–2022 period, during MHW events the thermal structure of the western Mediterranean was strongly altered. During such events, surface conditions in the northern basin increasingly resembled those of the southern region.

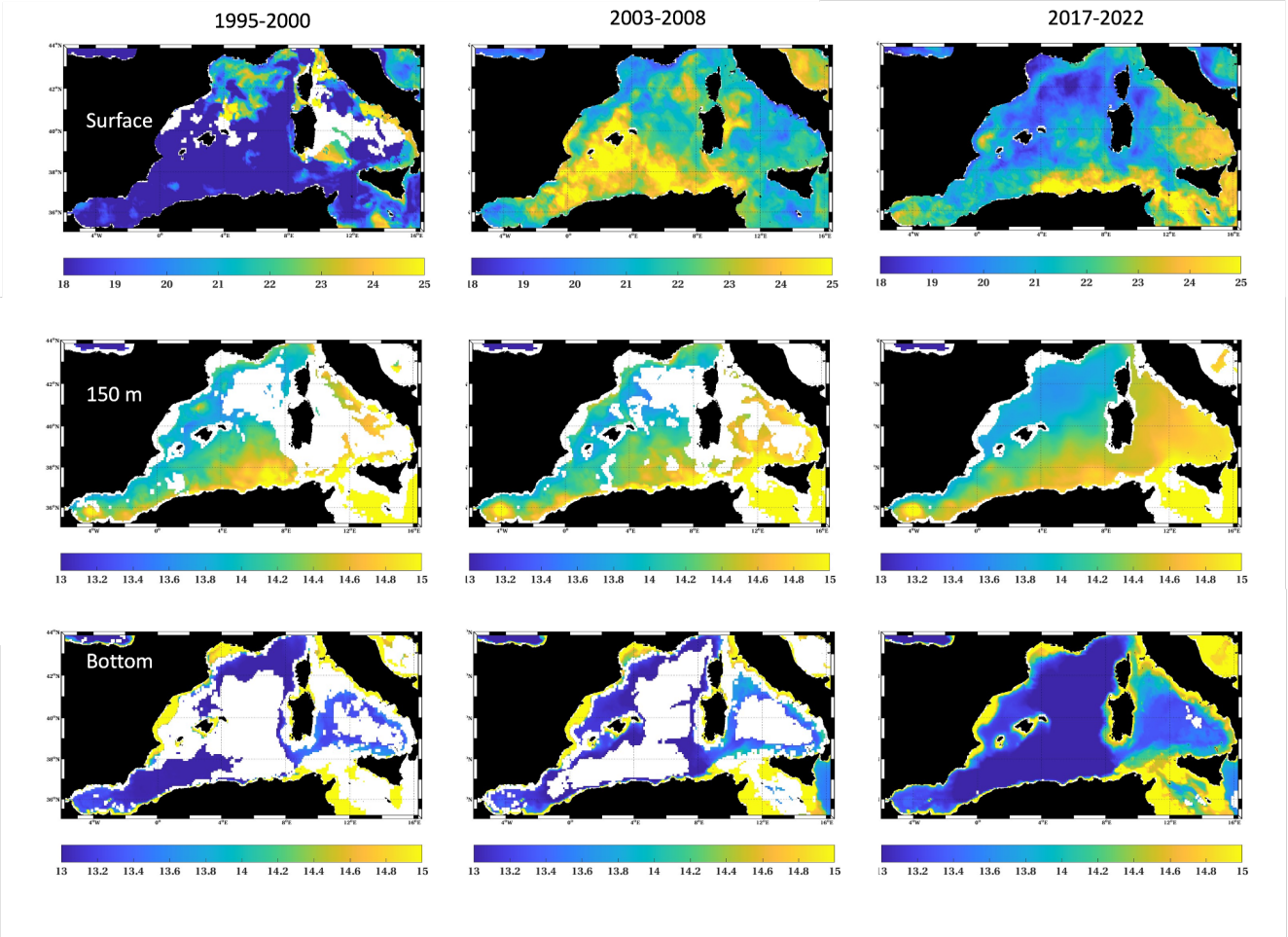

Figure S7: Mean absolute temperature during MHW events at the surface, 150 m, and bottom depths over the period 1995–2000, 2003-2008 and 2017-2022.

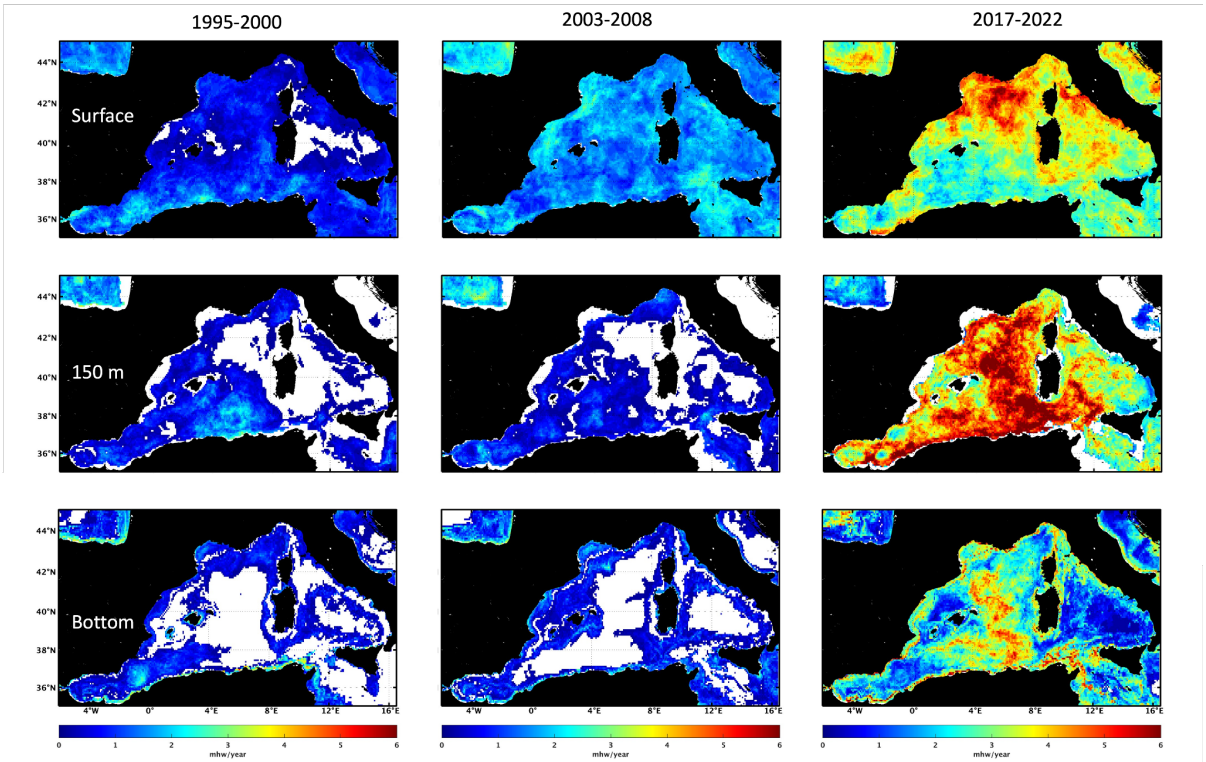

Figure S8: Frequency of MHW events at the surface, 150 m, and bottom depths over the period 1995–2000, 2003-2008 and 2017-2022.

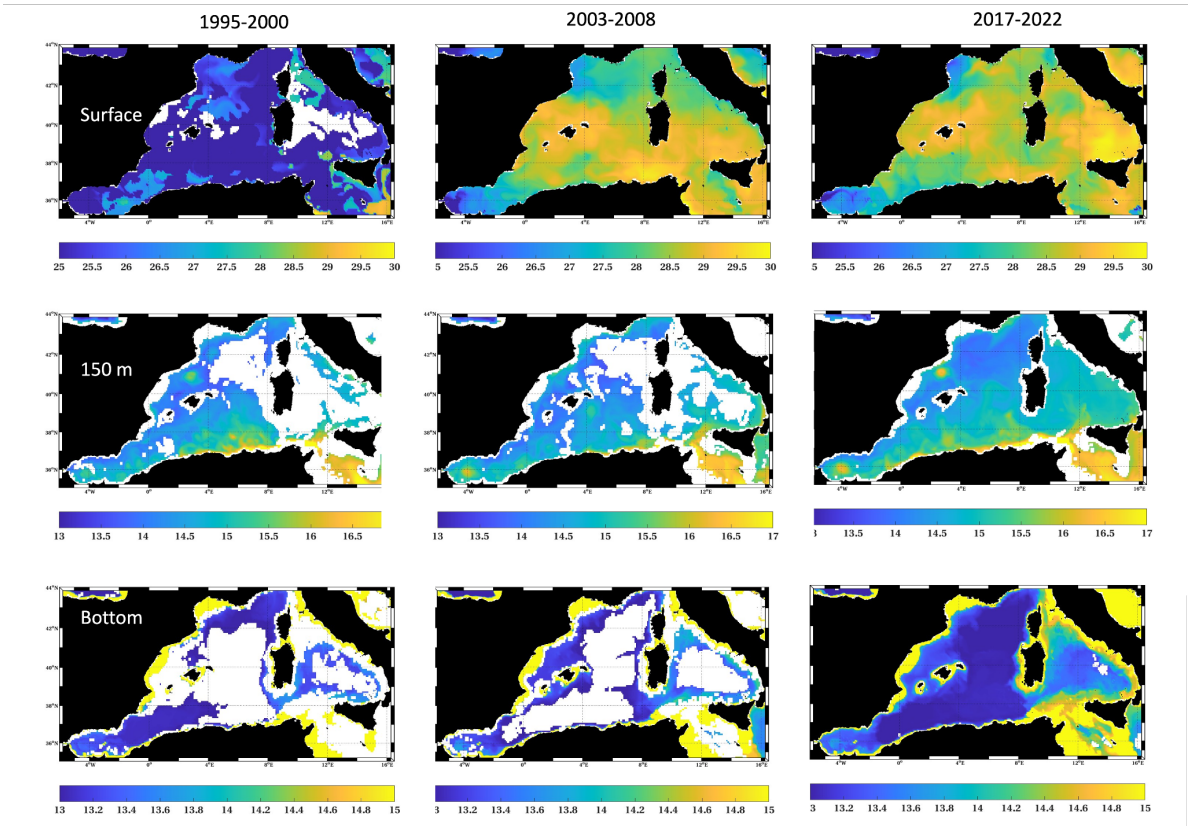

Figure S9: Maximum MHW intensity at the surface, 150 m, and bottom depths over the period 1995–2000, 2003-2008 and 2017-2022.

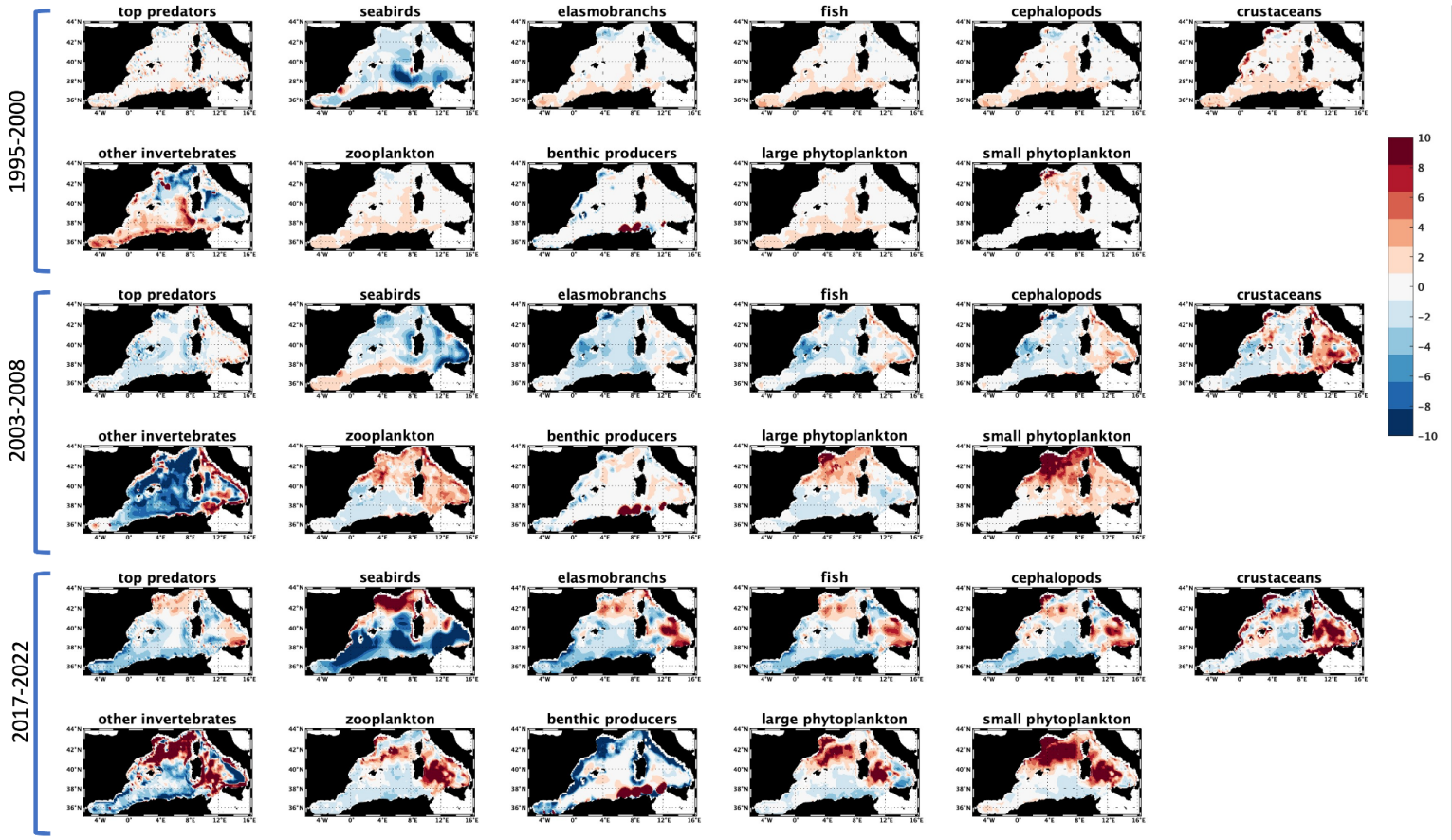

Figure S10: Mean rate of change of biomass computed for each period (1995-2000, 2003-2008 and 2017-2022) and for each functional group.

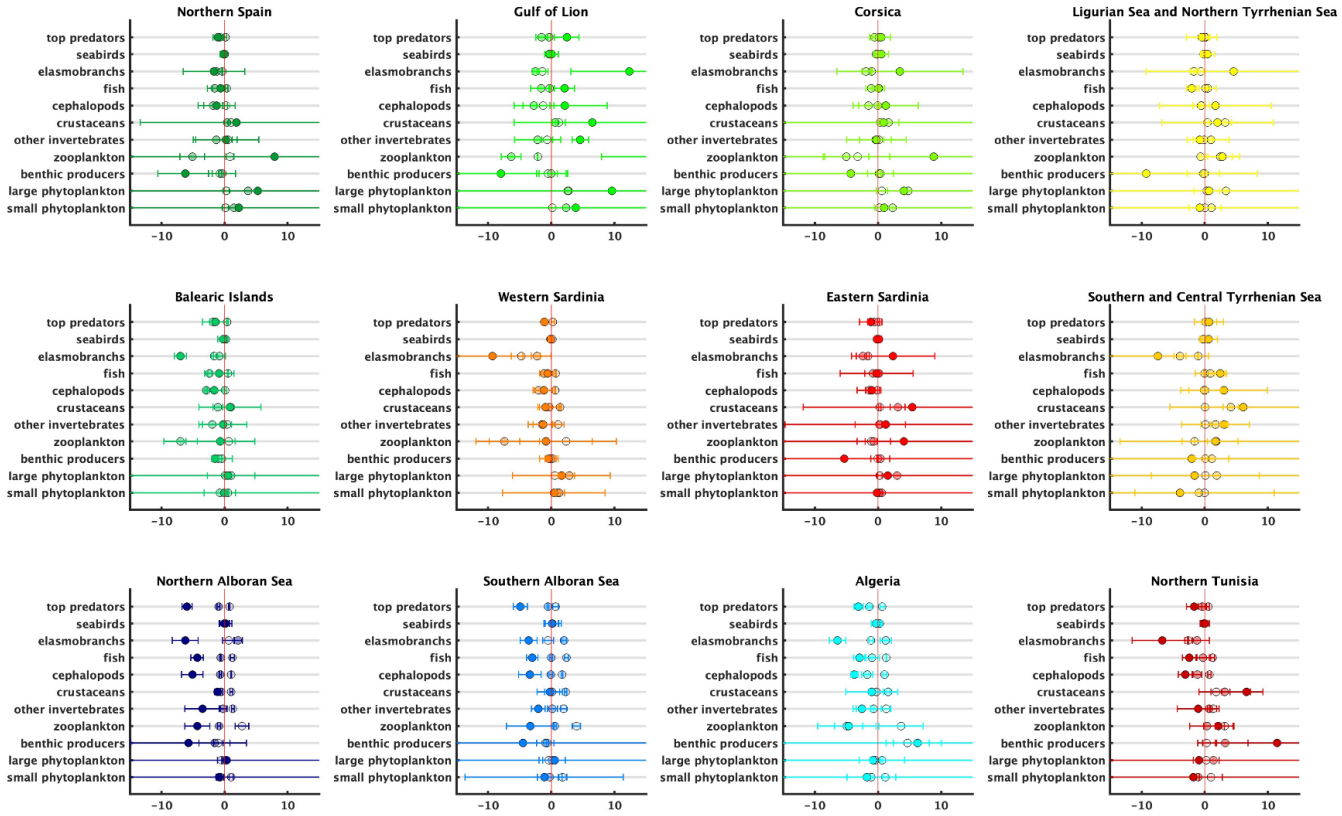

Figure S11: Lollipop plots illustrating the rate of change in biomass for each functional group within each GSA. Coloured dots (same colour code as in Figure 4) represent mean values of the rate of change for three distinct periods: 1995–2000, 2003–2008, and 2017–2022 and bars the corresponding errors.

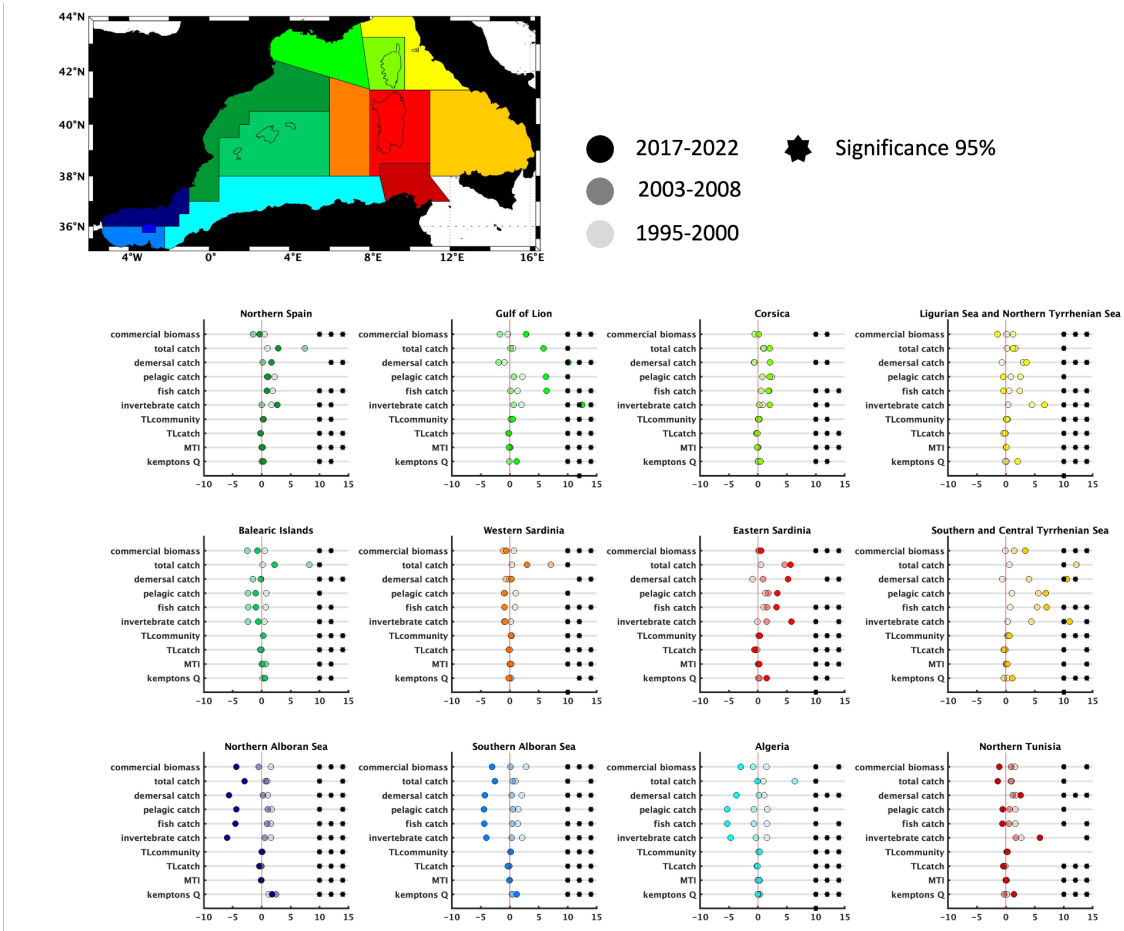

Figure S12: Lollipop plots illustrating the rate of change in indicators within each GSA. Coloured dots represent mean values of the rate of change for three distinct periods: 1995–2000, 2003–2008, and 2017–2022. Asterisks (*) indicate values that are significantly different from the mean over the entire period (1995–2022) at the 95% confidence level. The position of each asterisk corresponds to a specific period: first position for 1995–2000, second for 2003–2008, and third for 2017–2022.

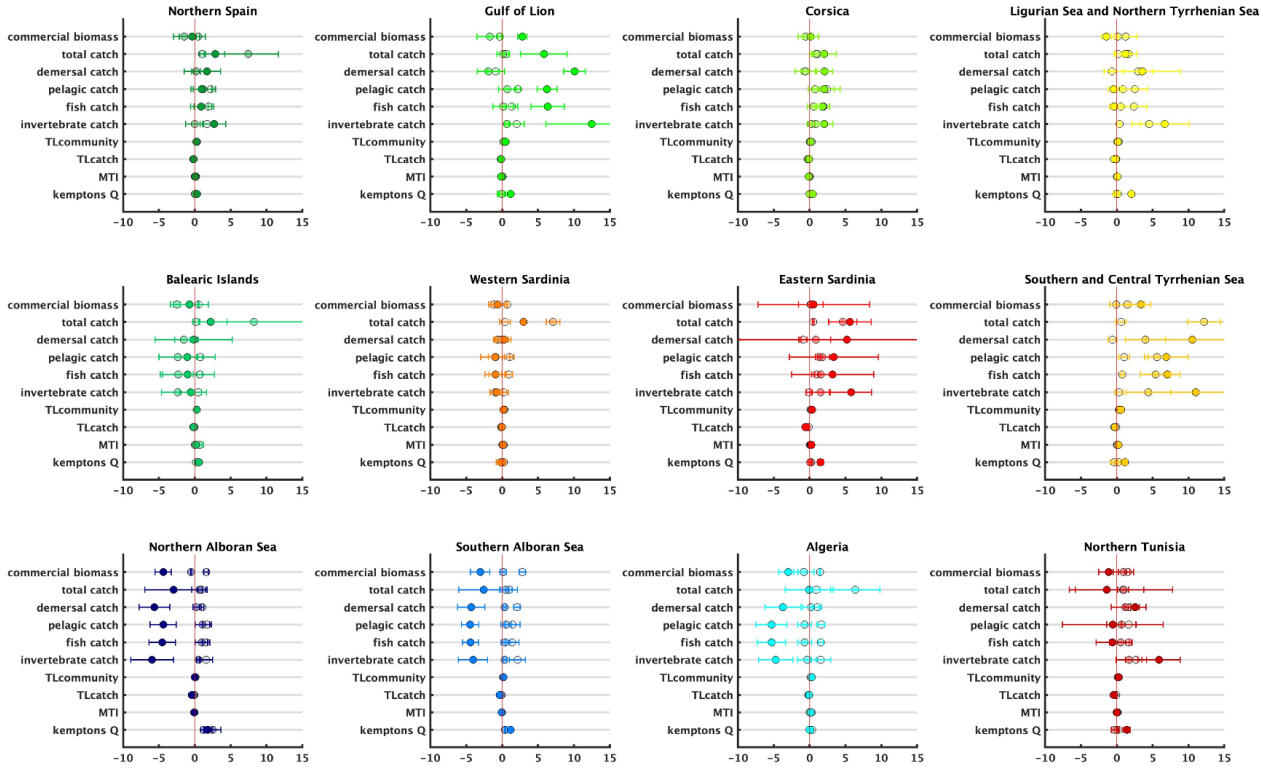

Figure S13 Lollipop plots illustrating the rate of change in ecosystem indicators within each GSA. Coloured dots represent mean values of the rate of change for three distinct periods: 1995–2000, 2003–2008, and 2017–2022 and bars the corresponding errors.

Modelled species	Assigned temperature layer	Functional Group
Bottlenose dolphins	150 m	Top predators
Striped dolphins	150 m	Top predators
Short-beaked common dolphin	150 m	Top predators
Fin whale	150 m	Top predators
Deep sea-cetacean feeders	150 m	Top predators
Monk seals	150 m	Top predators
Endangered and pelagic seabirds	Surface	Top predators/Seabirds
Gulls and cormorants	Surface	Top predators/Sea birds
Terns	Surface	Seabirds
Loggerhead turtles	150 m	Top predators
Pelagic sharks	Surface	Top predators/Elasmobranchs
Non-commercial large pelagic fishes	Surface	Fish
Bluefin tuna	Surface	Top predators/Fish
Swordfish	Surface	Top predators/Fish
Other large pelagic fishes	Surface	Top predators/Fish
Mackerels	Surface	Fish
Horse mackerels	Surface	Fish
Other medium pelagic fishes	Surface	Top predators/Fish
European sardine juv	Surface	Fish
European sardine adult	Surface	Fish
European anchovy juv	Surface	Fish
European anchovy adult	Surface	Fish
Round sardinella	Surface	Fish
Other small pelagic fish	Surface	Fish
Benthopelagic fishes	150	Fish
Non commercial meso (bathy) pelagic fishes	150	Fish
Anglerfish	Bottom	Top predators/ Fish
European conger	Bottom	Top predators/Fish
European hake juvenile	Bottom	Fish
European hake adult	150 m	Top predators/Fish
Other commercial large demersal fish	Bottom	Top predators/Fish
Poor cod	Bottom	Fish

Blue whiting	**Bottom**	**Fish**
Common pandora	**Bottom**	**Fish**
Sparidae+	**Bottom**	**Fish**
White seabream	**Bottom**	**Fish**
Common two-banded seabream	**Bottom**	**Fish**
Common dentex	**Bottom**	**Top predators/Fish**
Red scorpionfish	**Bottom**	**Top predators/ Fish**
Scorpaenidae+	**Bottom**	**Fish**
Groupers	**Bottom**	**Fish**
Brown meagre	**Bottom**	**Fish**
Labridae and serranidae+	**Bottom**	**Fish**
Flatfishes	**Bottom**	**Fish**
Other commercial medium demersal fish	**Bottom**	**Fish**
No commercial medium demersal fish	**Bottom**	**Fish**
Salema	**Bottom**	**Fish**
Mugilidae	**Bottom**	**Fish**
Transparent gobies	**Bottom**	**Fish**
Red mullet	**Bottom**	**Fish**
Surmullet	**Bottom**	**Fish**
Commercial small demersal fish	**Bottom**	**Fish**
No commercial small demersal fish	**Bottom**	**Fish**
Bathydemersal (deep sea) fish	**Bottom**	**Fish**
Small-spotted catshark	**Bottom**	**Top predators/Elasmobranchs**
Blackmouth catshark	**Bottom**	**Top predators/Elasmobranchs**
Other small demersal sharks	**Bottom**	**Elasmobranchs**
Rays and skates	**Bottom**	**Elasmobranchs**
Torpedos	**Bottom**	**Top predators/Elasmobranchs**
Coastal benthic cephalopods	**Bottom**	**Cephalopods**
Benthopelagic cephalopods	**150m**	**Cephalopods**
Mesopelagic cephalopods	**150 m**	**Cephalopods**
Other benthic cephalopods	**Bottom**	**Cephalopods**
Bivalves	**Bottom**	**Other invertebrates**
Gastropods	**Bottom**	**Other invertebrates**

Deep-water rose shrimp	Bottom	crustaceans
Blue and red shrimp	Bottom	crustaceans
Giant red shrimp	Bottom	crustaceans
Other commercial shrimps	Bottom	crustaceans
No commercial shrimps	Bottom	crustaceans
Norway lobster	Bottom	crustaceans
European lobster	Bottom	crustaceans
Other commercial decapods	Bottom	crustaceans
Non-commercial decapods	Bottom	crustaceans
Purple sea urchin	Bottom	Other invertebrates
Other sea urchins	Bottom	Other invertebrates
Sea cucumbers	Bottom	Other invertebrates
Other macro-benthos	Bottom	Other invertebrates
Jellyfish	Surface	Other invertebrates
Salps and other gelatinous zooplankton	Surface	Other invertebrates
Red coral	Surface	Other invertebrates
Other corals and gorgonians	Surface	Other invertebrates
Macro zooplankton	Bottom	Zooplankton
Meso and micro zooplankton	Bottom	Zooplankton
Suprabenthos	Bottom	crustaceans
Mediterranean seagrass	Bottom	Benthic producers
Other seagrasses	Bottom	Benthic producers
Erected algae	Bottom	Benthic producers
Seaweeds	Bottom	Benthic producers
Small phytoplankton	Surface	Small phytoplankton
Large phytoplankton	Surface	Large phytoplankton
Detritus	-	-
Discards	-	-

Table S1: Species included in each functional group and the temperature level assigned to each species.