Appendix A

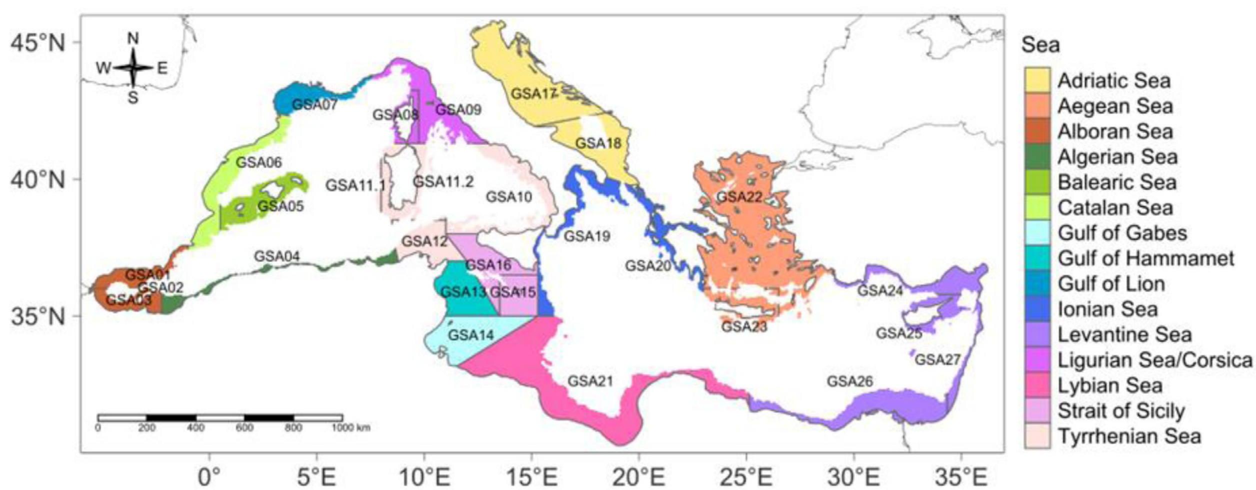

Fig. A1. Map of the GSAs (geographical sub-areas) defined by the General Fisheries Commission for the Mediterranean (GFCM), colored according to their respective sea/region within the Mediterranean basin.

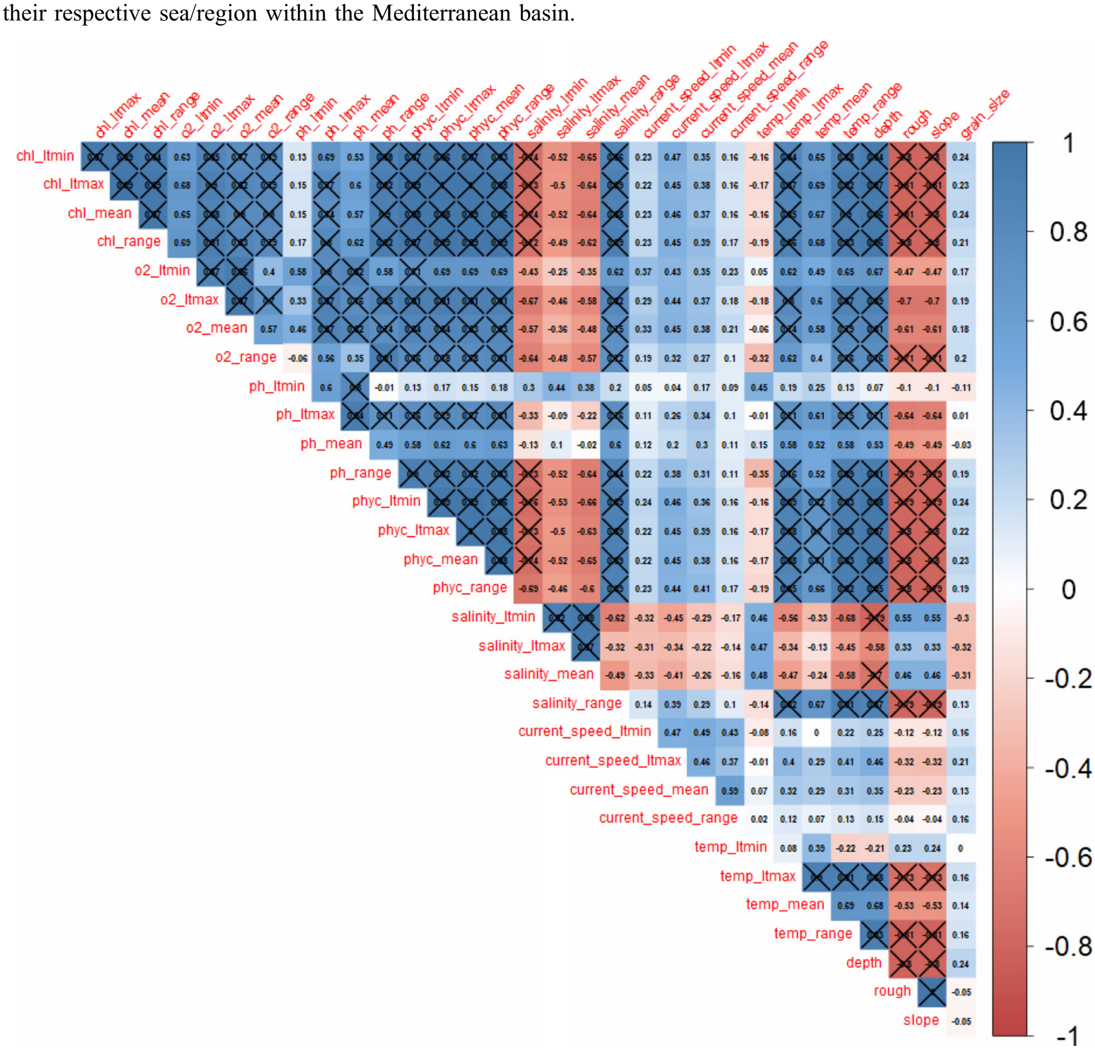

Fig. A2. Correlation matrix among all available environmental predictors based on Spearman's rank coefficient. Positive correlations are colored in blue and negative correlations in red. Coefficients higher than 0.7 are crossed. See Appendix B, Table B2 for the meaning of the abbreviations.

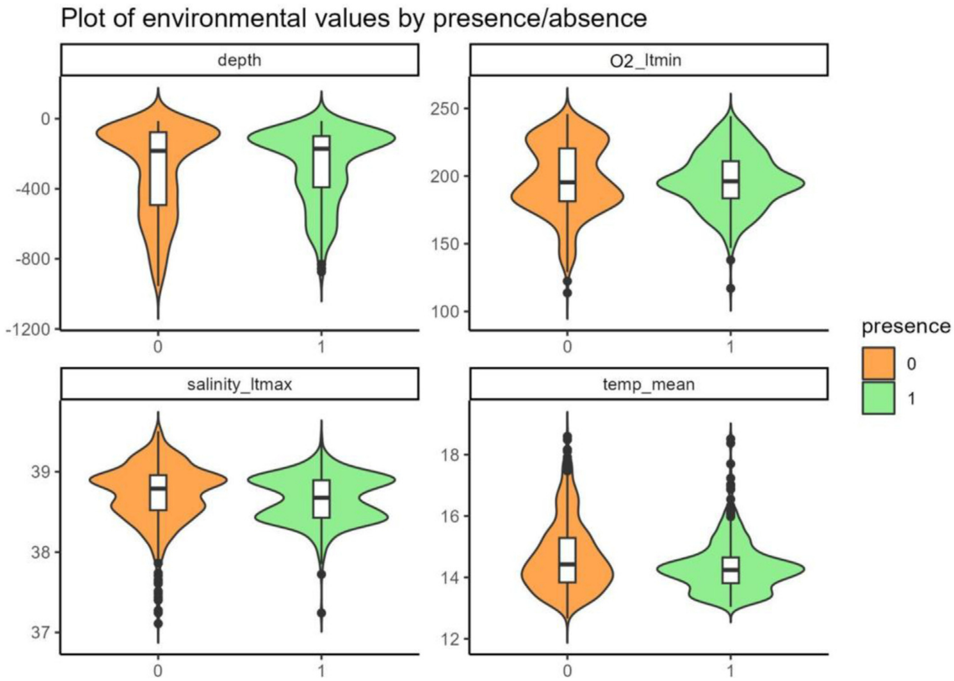

Fig. A3. Environmental range of a resampled presence–absence dataset of *Funiculina quadrangularis* records in the Mediterranean basin.

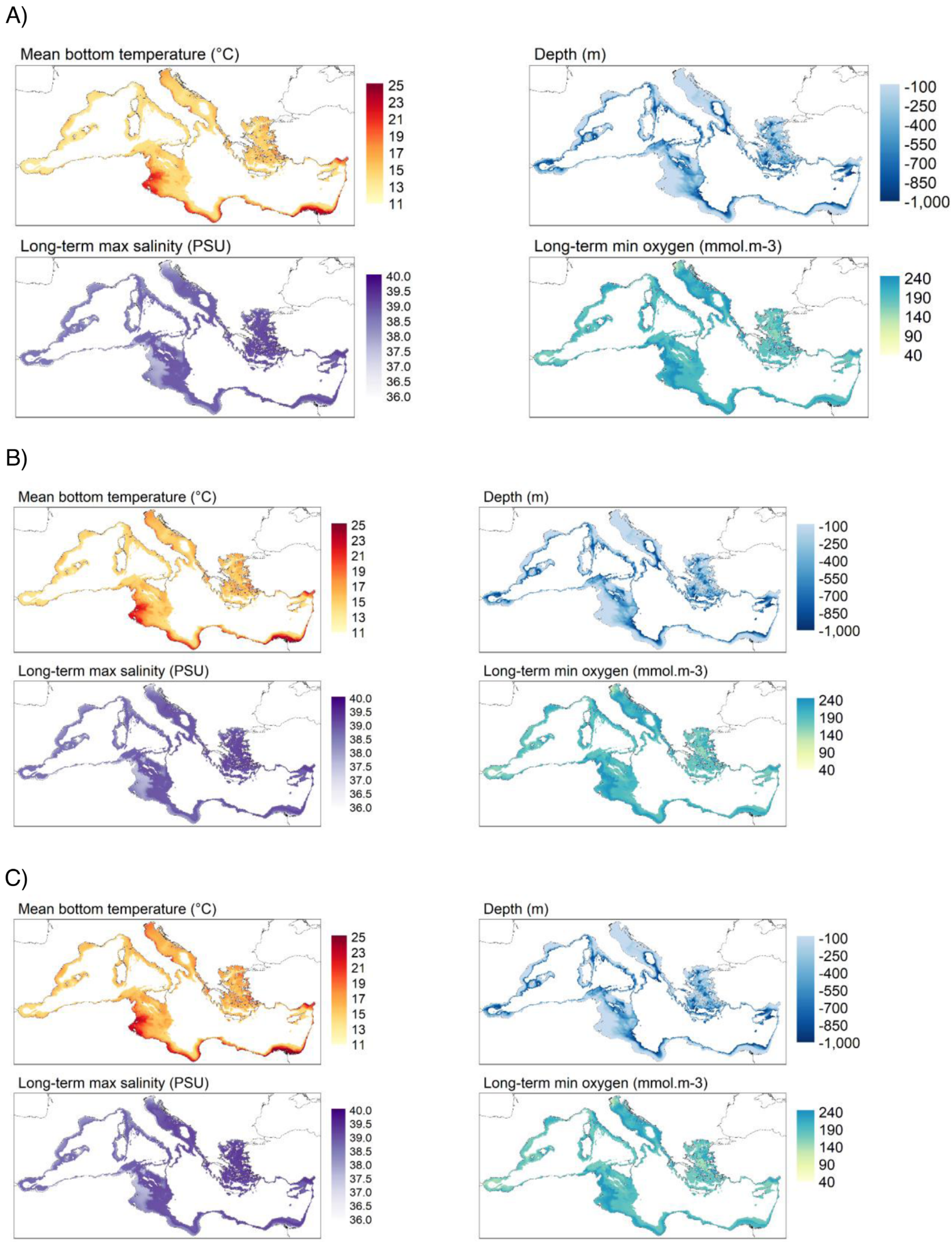

Fig. A4. Maps of the four environmental predictors used in the models to predict the potential distribution of *Funiculina quadrangularis* across the Mediterranean basin (A) under present conditions and under the SSP2–4.5 scenario of the IPCC (B) by 2050 and (C) by 2100.

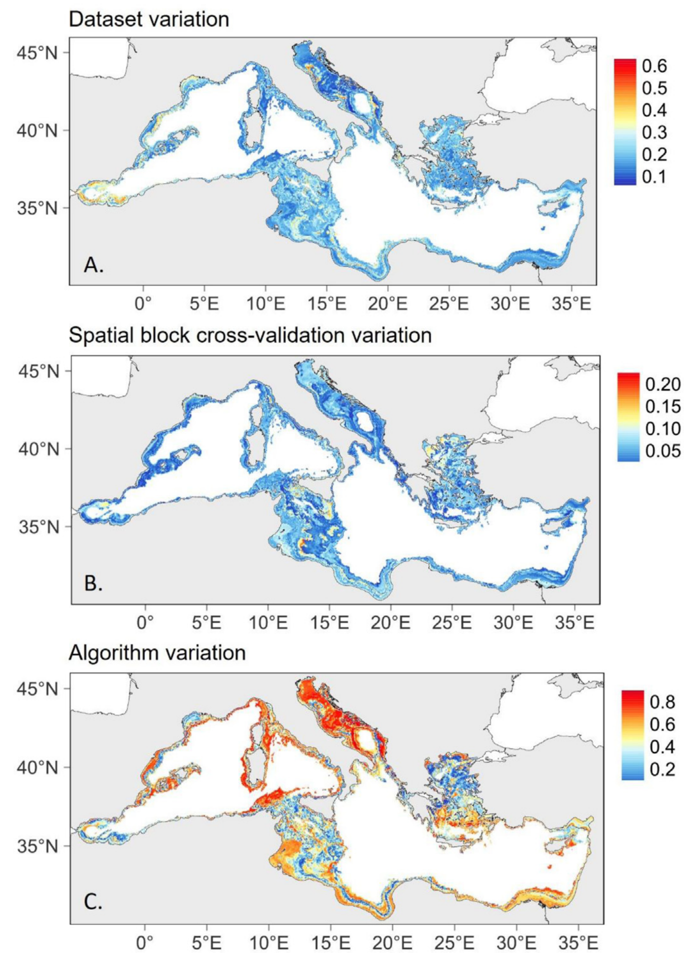

Fig. A5. Proportion of total variance explained by (A) dataset, (B) spatial block cross-validation, and (C) algorithm.

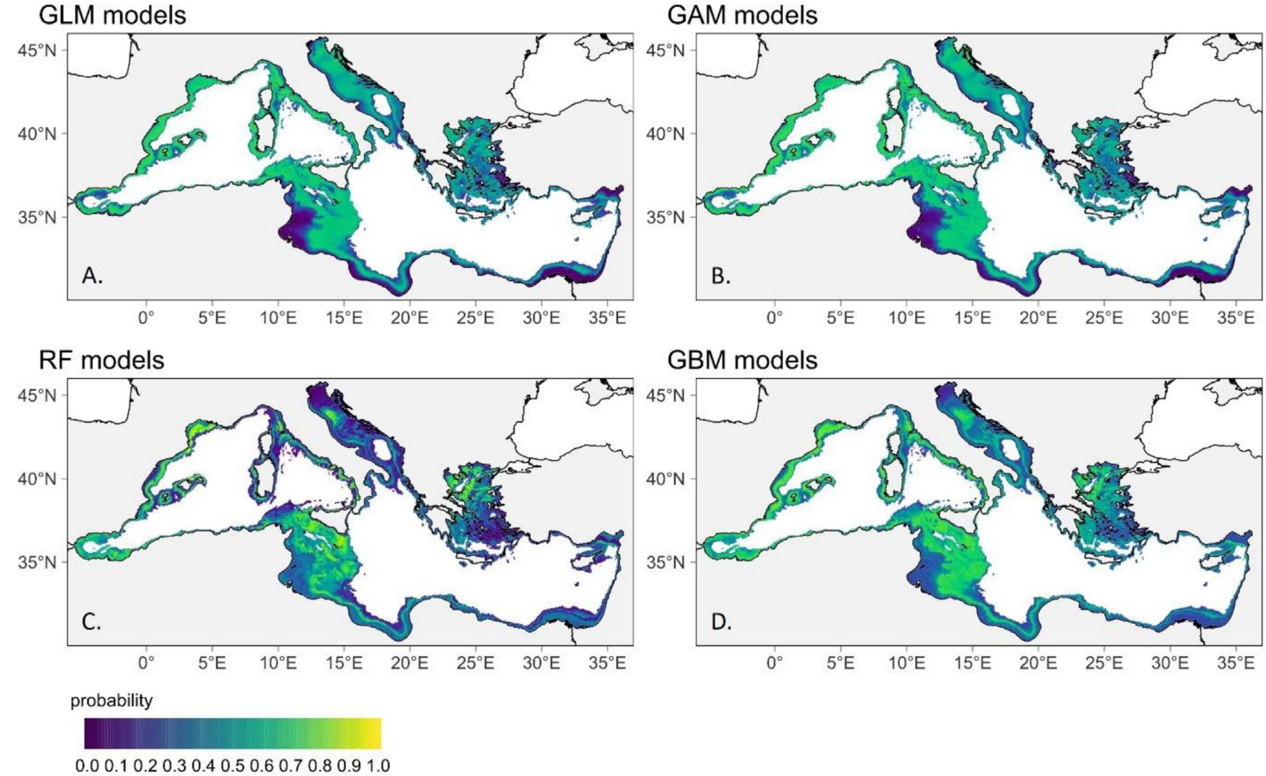

Fig. A6. Mean present-day predictions of the selected models for each algorithm: (A) GLM, (B) GAM, (C) RF, and (D) GBM.

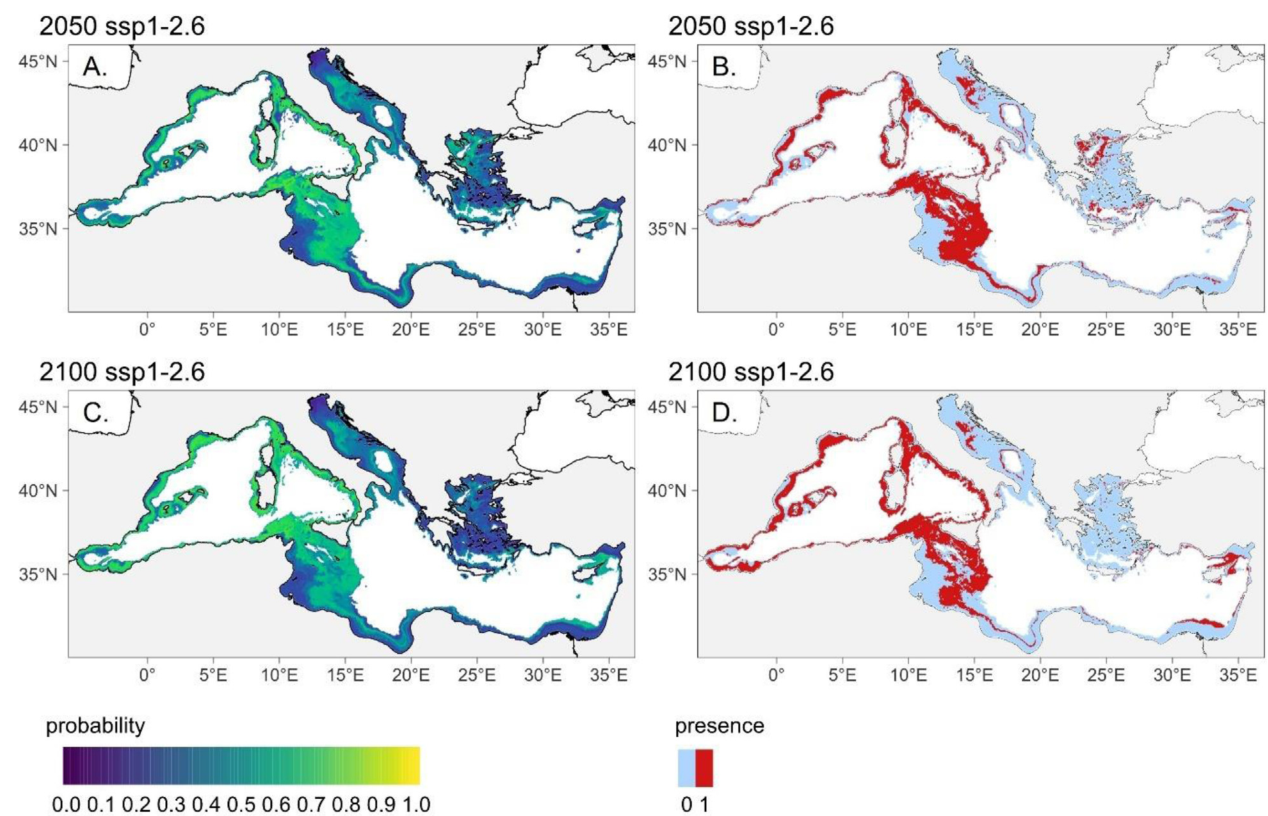

Fig. A7. Probabilities of presence (left) converted into binary presence–absence data (right) using a threshold of 0.52, illustrating the distribution of the potential habitat of *F. quadrangularis* in the Mediterranean basin under the IPCC scenario SSP1–2.6 (A–B) by 2050 and (C–D) by 2100.

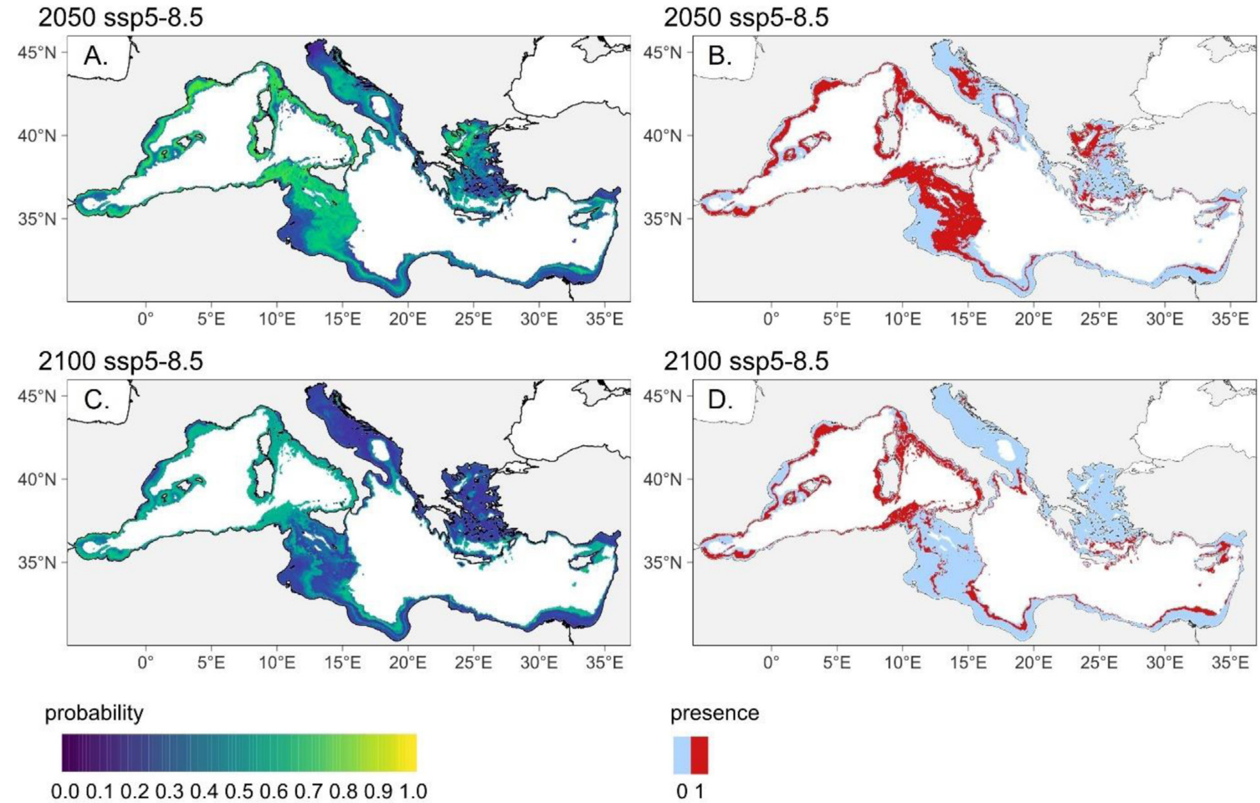

Fig. A8. Probabilities of presence (left) converted into binary presence–absence data (right) using a threshold of 0.52, illustrating the distribution of the potential habitat of *F. quadrangularis* in the Mediterranean basin under the IPCC scenario SSP5–8.5, are (A–B) by 2050 and (C–D) by 2100.

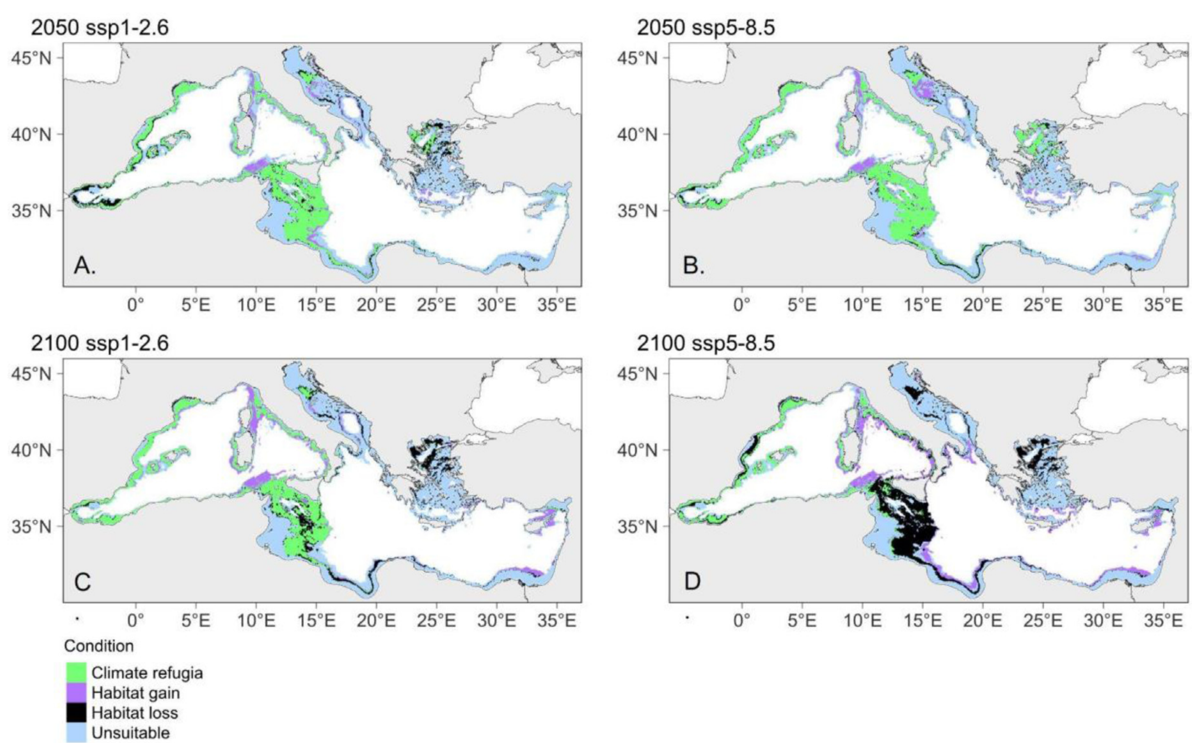

Fig. A9. Areas predicted as climate refugia, habitat gain, habitat loss, or unsuitable for *F. quadrangularis* under the IPCC SSP1–2.6 scenario (left) and the IPCC SSP5–8.5 scenario (right) are (A–B) by 2050 and (C–D) by 2100. Climate refugia are defined as areas that remain suitable under both present and future conditions; habitat gain refers to currently unsuitable areas that become suitable in the future, and habitat loss are suitable areas becoming unsuitable.

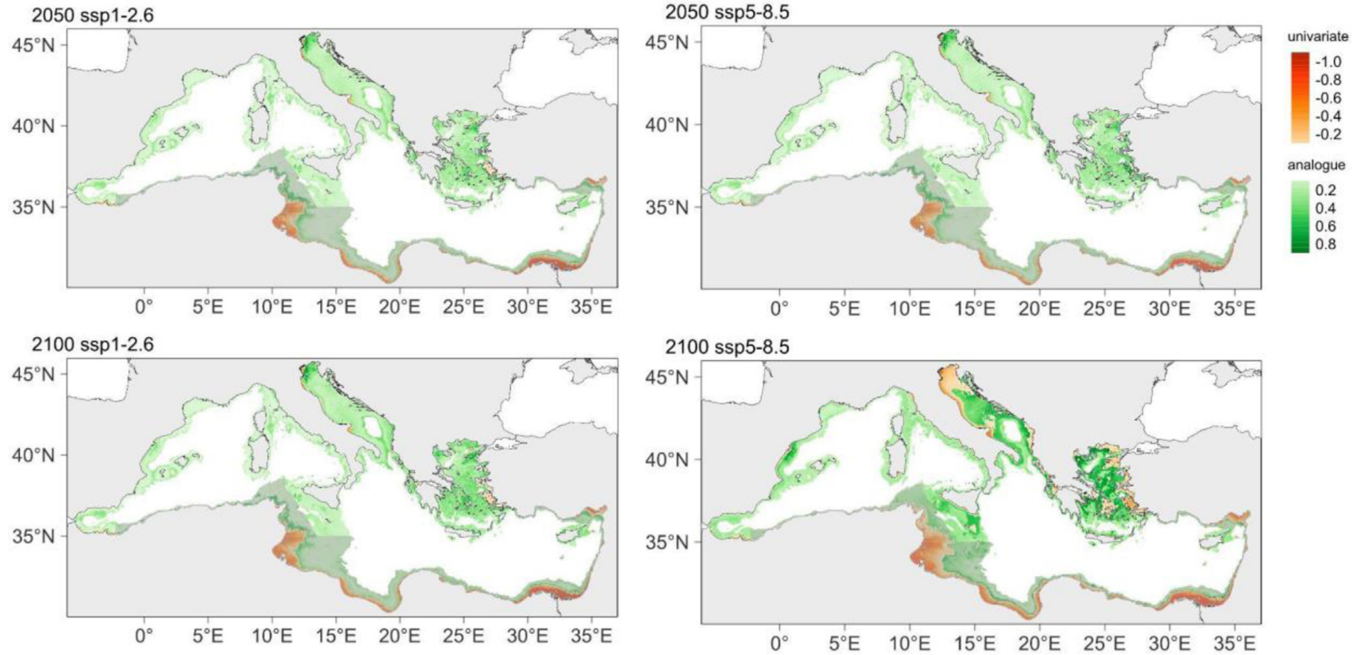

Fig. A10. Environmental extrapolations associated with the predictions under the IPCC scenario SSP1–2.6 (left) and the IPCC SSP5–8.5 scenario (right) are (A–B) by 2050 and (C–D) by 2100. For each period, univariate extrapolations (i.e., projections outside the range of the environmental space of calibrating data for at least one predictor) are shown in orange, combinatorial extrapolations (i.e., projections in unknown combinations of predictors) in purple, and analogue conditions (i.e., projections in environmental conditions already known by calibrating data) in green. Areas with no sampled data are shown with faded shading, and projections in such areas must be interpreted with caution because of higher uncertainties.

Appendix B

Table B1. Metadata of raw presence and absence records of *Funiculina quadrangularis* before any filtering process.

GSA area	Survey	Method (period)	Sources	Database	Number of records
1-2-3-5-6 -7-8-9-10 -11-15-16 -17-18-19 -20-22-23-25	MEDITS	Trawl (2012–2023)	•IEO - Instituto Español de Oceanografía, Centro Oceanográfico de Málaga, Spain (GSAs 1-2) • IEO - Instituto Español de Oceanografía, Centro Oceanográfico de Baleares, Spain (GSA 5) • IEO - Instituto Español de Oceanografía, Centro Oceanográfico de Murcia, Spain (GSA6) • MARBEC - Marine Biodiversity, Exploitation and Conservation, Ifremer, France (GSAs 7-8, Jadaud and Certain, 1994) • CIBM - Consorzio per il Centro Interuniversitario di Biologia Marina ed Ecologia Applicata G. Bacci (GSA 9) • COISPA - Tecnologia & Ricerca (GSA 10) • CNR IRBIM - Institute for Biological Resources and Marine Biotechnologies, Messina - Italy (GSA 10) • Dipartimento di Scienze della Vita e dell'Ambiente, Università di Cagliari, Italy (GSA 11) • Ministry for Sustainable Development, the Environment and Climate Change, Malta (GSA 15) • CNR IRBIM - Institute for Biological Resources and Marine Biotechnologies, Mazara del Vallo, Italy (GSA 16) • Department of Biological, Geological and Environmental Sciences, Laboratory of Marine Biology and Fisheries, University of Bologna, Italy (GSA17) • Fishery Research Institute of Slovenia (GSA 17) • IOR - Institute of Oceanography and Fisheries, Croatia (GSA 17) • COISPA - Tecnologia & Ricerca, Italy (GSA 18) • Department of Biosciences, Biotechnology and Environment, University of Bari, Italy (GSA 19) • HCMR - Hellenic Centre of Marine Research, Greece (GSAs 20, 22 and 23) • FRI - Fisheries Research Institute, Greece, (GSA 22) • DFMR - Department of Fisheries and Marine Research, Ministry of Agriculture, Rural Development and Environment, Cyprus (GSA 25) Free access obtained through the EU DG MARE as part of the Data Collection legal framework (DCF Regulation (EU) 2017/1004)	DG MARE – MEDITS Database	P = 1420 A = 7824
15	MEDITS	Trawl (2009–2010)	Terribile et al. (2016)		P = 86 A = 90
7	NOURMED	Traw (2018–2019)	Vaz (2018a)	Ifremer	P = 14 A = 187
7	EPIBENGOL	Trawl (2018)	Vaz (2018b)	Ifremer	P = 6 A = 4
7	GOLDYS	Trawl (2022)	Vaz et al. (2023)	Ifremer	P = 85 A = 91
7	MEDSEACAN	ROV (2009–2010)	Fabri and Pedel (2020), Fourt et al. (2017)	Ifremer	P = 12 A = 89
8	CORSEACAN	ROV (2010)	Fourt et al. (2017)	Ifremer	P = 19 A = 70
17	SOLEMON	Trawl (2011–2021)	AdriaMed (2011)	CNR	P = 43 A = 689
22	HCMR surveys	Trawl (1994–2016)	Salomidi et al. (2022)	HCMR	P = 29 A = 0
22-23	HCMR surveys	Video (1996–2010)	Smith et al. (2022)	HCMR	P = 30 A = 0
20-22-23-25	Various surveys	Literature-	Otero and Mytilineou (2022)		P = 41 A = 0
–	OBIS	–	https://obis.org/		P = 47 A = 0
–	GBIF	–	https://www.gbif.org/fr/		P = 5 A = 0

Table B2. Metadata of candidate environmental predictors explored for this study. Variables selected for the final ensemble modeling process are highlighted in grey. Abbr. = Abbreviation; Native res. = Native resolution; Ecol. sel. = Ecological selection; Cor. sel. = Correlation selection; and BIC GAM = BIC selection on GAM. Native resolution given in decimal degrees. Mean = Long-term average of monthly bottom values for the period 2010-2020. Long-term minimum = Long-term average of the minimum value of the bottom variable per year for the period 2010–2020. Long-term maximum = Long-term average of the maximum value of the bottom variable per year for the period 2010–2020. Range = Range of the bottom variable for the period 2010–2020 (i.e., average of the absolute difference between the minimum and maximum value of the variable per year).

Layer	Abbr.	Source	Meaning - Unity	Native res.	Ecological importance	Ecol. sel.	Cor. sel.	BIC GAM
Depth	depth	EMODnet	Distance between the surface and the seafloor (in m)	0.001	+: Driver of benthic community =: Constant over time	Yes	Yes	Yes
Slope	slope	EMODnet derived	Slope degree of the seafloor (in degree)	0.001	+: Driver of benthic community -: Correlated with depth	Yes	No	
Rugosity	rough	EMODnet derived	Difference between the maximum and the minimum value of bathymetry (in µm)	0.001	+: Driver of benthic community -: Correlated with depth	Yes	No	
Average grain size	grain_size	EMODnet broad-scale seabed habitat map	Average size of grain fractions including in the sediment (in mm)	0.001	+: Driver of benthic community =: Constant over time -: No significant response	Yes	Yes	No
Mean bottom temperature	temp_mean	Bio-Oracle v3.0	in T°C	0.05	+: Driver of benthic community +: Sensitive to climate change	Yes	Yes	Yes
Long-term minimum bottom temperature	temp_ltmin	Bio-Oracle v3.0	in T°C	0.05	-: No significant response	Yes	Yes	No
Long-term maximum bottom temperature	temp_ltmax	Bio-Oracle v3.0	in T°C	0.05	-: Correlated with mean bottom temperature	Yes	No	
Range of bottom temperature	temp_range	Bio-Oracle v3.0	in T°C	0.05	-: Correlated with depth	Yes	No	
Mean bottom current velocity	current_velocity_mean	Bio-Oracle v3.0	in $m.s^{-1}$	0.05	+: Driver of suspension feeders controlling food supply -: No significant response	Yes	Yes	No
Long-term minimum bottom current velocity	current_velocity_ltmin	Bio-Oracle v3.0	in $m.s^{-1}$	0.05	-: No significant response	Yes	Yes	No
Long-term maximum bottom current velocity	current_velocity_ltmax	Bio-Oracle v3.0	in $m.s^{-1}$	0.05	-: No significant response	Yes	Yes	No
Range of bottom current velocity	current_velocity_range	Bio-Oracle v3.0	in $m.s^{-1}$	0.05	-: No significant response	Yes	Yes	No
Mean bottom salinity	salinity_mean	Bio-Oracle v3.0	in PSS	0.05	-: Correlated with depth	Yes	No	
Long-term minimum bottom salinity	salinity_ltmin	Bio-Oracle v3.0	in PSS	0.05	-: Correlated with depth	Yes	No	
Long-term maximum bottom salinity	salinity_ltmax	Bio-Oracle v3.0	in PSS	0.05	+: Driver of benthic community +: Sensitive to climate change	Yes	Yes	Yes
Range of bottom salinity	salinity_range	Bio-Oracle v3.0	in PSS	0.05	-: Correlated with depth	Yes	No	
Mean bottom oxygen	O2_mean	Bio-Oracle v3.0	in $mmol.m^{-3}$	0.05	+: Driver of benthic communities +: Sensitive to climate change -: Correlated with depth	Yes	No	
Long-term minimum bottom oxygen	O2_ltmin	Bio-Oracle v3.0	in $mmol.m^{-3}$	0.05	+: Driver of benthic communities +: Sensitive to climate change	Yes	Yes	Yes
Long-term maximum bottom oxygen	O2_ltmax	Bio-Oracle v3.0	in $mmol.m^{-3}$	0.05	-: Correlated with depth	Yes	Yes	Yes

Table B2. (continued).

Layer	Abbr.	Source	Meaning - Unity	Native res.	Ecological importance	Ecol. sel.	Cor. sel.	BIC GAM
Range of bottom oxygen	O2_range	Bio-Oracle v3.0	in mmol.m^{-3}	0.05	-: Correlated with depth	Yes	Yes	Yes
Mean bottom chlorophyll A	chl_mean	Bio-Oracle v3.0	in mg.m^{-3}	0.05	+: Proxy of food supply +: Sensitive to climate change -: Correlated with depth	Yes	No	
Long-term minimum bottom chlorophyll A	chl_ltmin	Bio-Oracle v3.0	in mg.m^{-3}	0.05	-: Correlated with depth	Yes	No	
Long-term minimum bottom chlorophyll A	chl_ltmax	Bio-Oracle v3.0	in mg.m^{-3}	0.05	-: Correlated with depth	Yes	No	
Range of bottom chlorophyll A	chl_range	Bio-Oracle v3.0	in mg.m^{-3}	0.05	-: Correlated with depth	Yes	No	
Mean bottom primary productivity	phyc_mean	Bio-Oracle v3.0	in mmol.m^{-3}	0.05	+: Proxy of food supply +: Sensitive to climate change -: Correlated with depth	Yes	No	
Long-term minimum bottom primary productivity	phyc_ltmin	Bio-Oracle v3.0	in mmol.m^{-3}	0.05	-: Correlated with depth	Yes	No	
Long-term maximum bottom primary productivity	phyc_ltmax	Bio-Oracle v3.0	in mmol.m^{-3}	0.05	-: Correlated with depth	Yes	No	
Range of bottom primary productivity	phyc_range	Bio-Oracle v3.0	in mmol.m^{-3}	0.05	-: Correlated with depth	Yes	No	
Mean bottom pH	pH_mean	Bio-Oracle v3.0	–	0.05	+: Drive the metabolism of calcareous organisms +: Sensitive to climate change -: Too scarce range observed in the Mediterranean -: Uncertain effect on poorly calcified species	No		
Long-term minimum bottom pH	pH_ltmin	Bio-Oracle v3.0	–	0.05	-: Too scarce observed range in the Mediterranean	No		
Long-term maximum bottom pH	pH_ltmax	Bio-Oracle v3.0	–	0.05	-: Too scarce observed range in the Mediterranean	No		
Range of bottom pH	pH_range	Bio-Oracle v3.0	–	0.05	-: Too scarce observed range in the Mediterranean	No		

Table B3. Metadata of environmental layers projected in future conditions under IPCC climate scenario used in the study.

Layer	Abbreviation	Source	Meaning	Period	SSP
Mean bottom temperature	temp_mean_2050 temp_mean_2100	Bio-Oracle v3.0	Average data from distinct ESMs (Earth System Grid Federation) provided by the CMIP6	2040–2050 2090–2100	SSP2-4.5
Long-term maximum bottom salinity	salinity_ltmax_2050 salinity_ltmax_2100	Bio-Oracle v3.0	Average data from distinct ESMs (Earth System Grid Federation) provided by the CMIP6	2040–2050 2090–2100	SSP2-4.5
Long-term minimum bottom oxygen	O2_ltmin_2050O2_ltmin_2100	Bio-Oracle v3.0	Average data from distinct ESMs (Earth System Grid Federation) provided by the CMIP6	2040–2050 2090–2100	SSP2-4.5