Posidonia oceanica bleaching: the Mediterranean Sea as a case study

Patrizia Stipcich[1,2*], Lazaro Marín-Guirao[3], Damiano Baldan[4], Erika Fabbrizzi[1,2], Adriana Alagna[5], Eugenia Apostolaki[6], Baris Akcali[7], Patrick Astruch[8], Fabio Badalamenti[2,9], Elena Balestri[10], Elena Bañares[11], Bruno Belloni[8], Jaime Bernardeau-Esteller[3], Carlo Nike Bianchi[12], Fabio Blanco Murillo[13], Jordi Boada[14,15], Charles-François Boudouresque[16], Fabio Bulleri[10], Edoardo Casoli[17], Eric Charbonnel[18], Edouard Chéré[19], Antonia Chiarore[19], Giovanni Chimienti[20], Alberto Colletti[1], Alessia Crobu[21], Ivan Cvitković[22], Giovanni D'Anna[9], Marija Despalatović[22], Maria Cristina Gambi[23], Vasilis Gerakaris[6], Daniele Grech[24], Ivan Guala[24], Onur Karayali[7], Demetris Kletou[25], Claudio Lardicci[26], Victoria Litsi[6], Vesna Mačić[27], Julia Máñez Crespo[28], Silvia Mazzucca[29]; Beatriz Marin-Diaz[28], Virginia Menicagli[10], Alice Mirasole[19], Carla Morri[12], Simone Maria Santo Musumeci[1], Heike Molenaar[30], Briac Monnier[31], Pedro C. Navarro-Martínez[3], Irene Olive[13], Arianna Pansini[21], Paolo Marras[5], Christine Pergent-Martini[32], Alexis Pey[33], Federico Pinna[34], Amalia Piro[29], Isabella Provera[13], Alessandra Puccini[34], Vasilis Resaikos[35], Beatrice Romagnoli, Natalia Ruiz-Valero[3], José L. Sánchez Lizaso[36], Antonio Santonastaso[34], Faustino Scarcelli[29], Núria Teixidó[15], Jorge Terrados[28], Fiona Tomas[28], Yolanda Fernández Torquemada[36], Andrea Tursi[36], Ante Žuljević[4], Claudia Pezzilli[37] , Simonetta Fraschetti[1,2]

[1]University of Naples Federico II, Department of Biology, Naples, Italy; [2]National Biodiversity Future Center, Palermo, Italy; [3]Spanish Institute of Oceanography (IEO, CSIC), Oceanographic Center of Murcia, Spain; [4]National Institute of Oceanography and Applied Geophysics (OGS), Trieste, Italy; [5]Sicily Marine Centre, Stazione Zoologica Anton Dohrn, Palermo, Italy; [6]Institute of Oceanography, Hellenic Centre for Marine Research, Heraklion, Crete, Greece; [7]DEU, Institute of Marine Sciences & Technology, Izmir, Turkiye; [8]GIS Posidonie, Aix-Marseille University, OSU Pytheas, campus of Luminy, 13288 Marseille cedex 9, France; [9]CNR-IAS, Castellammare del Golfo, Italy; [10]University of Pisa, Department of Biology, Pisa, Italy; [11]Universidad de Malaga, Andalucía Tech, Departamento de Botanica y Fisiología Vegetal, Malaga, Spain; [12]Zoologica Anton Dohrn, Department of Integrative Marine Ecology, Genoa Marine Centre, 16126, Genoa, Italy; [13]Department of Integrative Marine Ecology, Stazione Zoologica Anton Dohrn, Naples, Italy; [14] Centre d'Estudis Avançats de Blanes (CEAB-CSIC), Blanes, Spain; [15]Stazione Zoologica Anton Dohrn, Department of Integrative Marine Ecology, Ischia Marine Centre, Ischia, Naples, Italy; [16]Aix-Marseille University and University of Toulon, MIO (Mediterranean Institute of Oceanography), IRD, CNRS, Marseille France; [17] Sapienza University of Rome, Department of Environmental Biology, Rome, Italy; [18]Parc Marin de la Côte Bleue, Observatoire, BP 42, 13620 Carry-le-Rouet, France; [19]Ville d'Agde, Direction Gestion du milieu marin, Aire Marine Protégée de la côte agathoise, 34300, Agde, France; [20]Department of Biosciences, Biotechnology and Environment, University of Bari, Italy; [21]Department of Chemical Physical Mathematical and Natural Sciences, University of Sassari, Sassari, Italy; [22] Institute of Oceanography and Fisheries, Split, Croatia; [23]National Institute of Oceanography and Applied Geophysics, OGS, Borgo Grotta Gigante, Sgonico, Trieste, Italy; [24]IMC - International Marine Centre, Loc. Sa Mardini, Torregrande - 09170 Oristano, Italy; [25]Marine & Environmental Research (MER) Lab, Limassol, 4533, Cyprus; [26]Department of Earth Sciences, University of Pisa, Pisa, Italy; [27]Institute of marine biology, University of Montenegro; [28]Instituto Mediterráneo de Estudios Avanzados (IMEDEA), CSIC-UIB, Esporles, Balearic Islands, Spain; [29]Laboratory of Plant Biology and Plant Proteomics (Lab.Bio.Pro.Ve), Department of Chemistry and Chemical Technologies, Università della Calabria, Italy; [30]Laboratoire d'Environnement Marin Littoral, Université de Nice, 06108 Nice, Cedex 02, France; [31]Université de Corse Pasquale Paoli, UMR CNRS SPE 6134, Campus Grimaldi BP52, 20250 Corte, France; [32]University of Corsica, BP 52, 20250 Corte; [33]THALASSA Marine Research & Environmental Awareness, 286 F route d'Aspremont, 06690 Tourrette-Levens, France; [34]Stazione Zoologica Anton Dohrn, Department of Integrative Marine Ecology, Genoa Marine Centre, 16126, Genoa, Italy; [34]Department of Architecture, Design and Urban Planning, University of Sassari, Sassari, Italy; [35]Enalia Physis Environmental Research Centre, Acropoleos 2, Aglantzia, Nicosia 2101, Cyprus; [36]Department of Marine Sciences, University of Alicante, 03690 San Vicente del Raspeig, Alicante, Spain; [37] University of Genoa (DiSTAV)

*patrizia.stipcich@unina.it

Posidonia oceanica seagrass is facing multiple stressors that can alter ecosystem functioning and plant traits. Among these, leaf bleaching, a senescence-related depigmentation process, has been observed in some areas of the Mediterranean Sea. Bleaching was related to processes that lead to a low structural investment, but the main drivers that distinguish it from brown necrosis remain unclear. This study aimed to identify the environmental factors influencing leaf bleaching across the Mediterranean Sea through a correlative and mensurative approach. In summer 2025, over 70 researchers collected 419 observations on the presence/absence of bleached meadows, while environmental variables were obtained from Copernicus Marine datasets. Morphological and structural data, including leaf area, brown necrotic and bleached area, and leaf mass per area (LMA), were collected from shoots in 32 sites. CLM used to correlate environmental satellite data to bleaching occurrence, indicated that higher depth, chlorophyll-a concentrations and salinity were associated with reduced bleaching incidence, while high temperature and nitrate concentrations increased bleaching. The interaction between nitrates and temperature suggested a weakening of nitrate effects under warmer conditions, highlighting complex stressor interactions. GLMMs, used to correlate bleached leaf area to structural and morphological variables, showed that bleaching decreased with higher LMA, indicating that leaves with greater structural investment are less susceptible. Spatial variability among sites explained a substantial proportion of the observed variance. In contrast, brown necrosis did not show significant relationships with the explanatory variables, suggesting different underlying mechanisms from bleaching. Overall, leaf bleaching was more frequent in shallow meadows and under stressful environmental conditions such as low salinity, eutrophication, and high temperature, and was associated with structurally weaker leaves. Leaf bleaching may affect plant resilience to multiple stressors and understanding both individual and interactive environmental drivers for the conservation and management of this key Mediterranean species become pivotal.