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Microscopic Sentinels: Uncovering the Tropicalization of the Western Mediterranean Ocean Through Calcifying Plankton

Biology * Environment * Climate Change

Introduction: Microscopic Barometers of a Tropicalizing Basin

In the grand theatre of global climate change, the Mediterranean Sea has long functioned as a primary climatic hotspot where atmospheric warming, ocean circulation, and biodiversity loss interact with accelerated intensity.[1] Historically, research into this transformation focused on macroscopic indicators: invasive rabbitfish denuding eastern algal forests, retreating Posidonia seagrass meadows, and shifting commercial fish stocks.[2][3] However, a landmark 2026 study by Lucas et al. in Global and Planetary Change shifts attention to the microscopic foundation of the marine ecosystem: calcifying plankton.[4][5]

Led by the Institute of Environmental Science and Technology at the Universitat Aut noma de Barcelona (ICTA-UAB), the study provides the first comprehensive sedimentary evidence that the Western Mediterranean -- long viewed as a temperate refuge buffered by Atlantic inflow -- is undergoing systemic "tropicalization."[4] Rather than a corridor-mediated biological invasion like the Lessepsian migration through the Suez Canal in the eastern Levantine Basin,[3] Western Mediterranean tropicalization is driven by physical oceanography and rising sea surface temperature (SST).[4][5] As surface waters warm and stratify, Atlantic currents entering through the Strait of Gibraltar transport tropical taxa -- such as the coccolithophore Gephyrocapsa oceanica -- into a basin now warm enough to sustain them.[4][6]

By analyzing microfossils across two millennia of marine sediment cores, Lucas et al. demonstrate a fundamental reorganization of the biological pump during the Anthropocene.[4] The study tracks two key calcifying groups that build shells of calcite and anchor the marine food web and carbon cycle: unicellular photosynthetic phytoplankton (coccolithophores)[6] and heterotrophic protistan zooplankton (planktonic foraminifera).[7] Their fossilized remains reveal that temperate, nutrient-loving assemblages are rapidly being displaced by tropical, oligotrophic specialists.[4][5]

Oceanographic Context: Thermohaline Circulation and Stratification

The biological restructuring identified by Lucas et al. is rooted in the physical oceanography of the Mediterranean. As an anti-estuarine concentration basin where evaporation exceeds precipitation and runoff, the Mediterranean maintains mass balance via surface inflow of relatively fresh, nutrient-depleted Atlantic Water through the Strait of Gibraltar.[8] Basin-scale thermohaline circulation is driven by coupled gradients in temperature and salinity: incoming Atlantic surface water warms and salinifies as it flows eastward, before winter winds cool the dense

surface layer, driving deep-water convection and subsurface outflow back into the Atlantic.[8]

Historically, the thermal gradient between the subtropical Atlantic and the seasonally cool Western Mediterranean acted as an ecological filter blocking tropical Atlantic plankton.[4] However, the Mediterranean is warming roughly 20% faster than the global ocean average (~0.035 deg C per year), accompanied by more frequent and intense marine heatwaves that exceed the thermal thresholds of native temperate taxa.[1][9]

Equally critical is water-column stratification. Surface warming lowers upper-ocean density, sharpening the seasonal thermocline and suppressing vertical winter mixing.[4] Where winter storms historically drove convective upwelling of deep nutrients into the photic zone to fuel spring blooms, enhanced stratification traps nutrients at depth -- shifting surface waters toward persistent oligotrophy that favors picophytoplankton and symbiont-bearing microzooplankton.[10][16]

Sediment Core Methodology and Divergent Plankton Trajectories

To separate anthropogenic forcing from natural variability, Lucas et al. (2026) analyzed high-resolution sediment cores spanning the last 2,000 years from the Alboran Sea (capturing direct Atlantic inflow)[4] and the Strait of Sicily (capturing modified water transiting between the western and eastern basins).[4][5] Chronologies were established via radiometric dating (Lead-210 and radiocarbon) and volcanic tephrochronology, paired with quantitative microscopy of microfossil assemblages.[4]

The sedimentary record reveals a striking taxonomic divergence between the two calcifying groups during the Industrial Era:

* Coccolithophore Diversity Surge: Rapidly reproducing haptophyte algae exhibited a pronounced increase in species diversity as surface waters warmed and stratified.[4][5] Alongside the cosmopolitan generalist Emiliania huxleyi, the cores record an explosive proliferation of Gephyrocapsa oceanica -- a tropical species typically restricted to warm equatorial divergence zones above 18-20 deg C.[6] Virtually absent since the Holocene Thermal Maximum (~5,000 years BP) and the Eemian Interglacial (~125,000 years BP), the modern resurgence of G. oceanica marks a definitive bio-indicator of Atlantic-driven tropicalization.[4]

* Planktonic Foraminifera Decline: Conversely, planktonic foraminiferal diversity has declined sharply.[4][5] Dependent on seasonal productivity pulses and lunar-synchronized reproductive cycles, temperate grazers such as Globigerina bulloides (an upwelling indicator) and Globorotalia inflata (requiring a deep winter mixed layer) have retreated.[4] In their place, warm-oligotrophic taxa such as Trilobatus sacculifer -- which hosts photosynthetic dinoflagellate endosymbionts to recycle nutrients in stratified waters -- have expanded across the western basin.[4][7]

| Ecological Niche | | Pre-Industrial Temperate Dominants | | Anthropocene Tropicalized Dominants | | Oceanographic & Trophic Implication |

| Primary Producers | | Emiliania huxleyi (Generalist) | | Gephyrocapsa oceanica (Tropical) | | Shift toward warm-water Atlantic calcifiers.[4][6] |

| Secondary Consumers | | Globigerina bulloides, G. inflata | | Trilobatus sacculifer (Symbiont-bearing) | | Replacement of bloom grazers by oligotrophic mixotrophs.[4] |

| Water Column State | | Seasonally mixed, mesotrophic | | Strongly stratified, oligotrophic | | Weakened vertical nutrient flux and export production.[10][16] |

Ecological Restructuring: Atlanticization Versus Lessepsian Invasion

A central contribution of the 2026 study is decoupling the mechanisms of Mediterranean tropicalization between the eastern and western basins. Whereas the Eastern Mediterranean is being reshaped by Lessepsian migration -- an anthropogenic corridor introducing Indo-Pacific taxa through the Suez Canal[2][3] -- the Western Mediterranean is undergoing "Atlanticization," a climate-mediated range expansion of tropical Atlantic plankton through the Strait of Gibraltar.[4]

| Feature | | Eastern Mediterranean (Levantine Basin) | | Western Mediterranean (Alboran & Sicily) |

| Primary Driver | | Lessepsian Migration (Suez Canal corridor)[3] | | Atlanticization (Strait of Gibraltar inflow)[4] |

| Biogeographic Source | | Red Sea / Indo-Pacific | | Equatorial & Subtropical Atlantic |

| Key Indicators | | Siganus spp., Pterois miles, Amphistegina | | Gephyrocapsa oceanica, Trilobatus sacculifer[4] |

| Ecological Impact | | Benthic herbivory, competitive exclusion | | Pelagic base restructuring, oligotrophication[4][16] |

Trophic Cascades, Carbon Cycling, and Paleo-Analogs

As co-author Patrizia Ziveri notes, restructuring at the base of the pelagic food web triggers a bottom-up trophic cascade across higher marine consumers.[4][5] The transition from nutrient-rich blooms dominated by diatoms and Globigerina bulloides toward stratified communities of flagellates and Trilobatus sacculifer diverts energy from the classical grazing food chain into an inefficient microbial loop.[11] Because each additional microbial trophic transfer dissipates metabolic energy, less biomass and essential lipid reserves reach small pelagic fish such as the European anchovy (Engraulis encrasicolus) and sardine (Sardina pilchardus), compounding phenological match-mismatch risks and favoring gelatinous zooplankton.[12][13]

Simultaneously, planktonic reorganization alters the Mediterranean carbon sink. While photosynthesis sequesters dissolved CO2 via the organic carbon pump, biogenic calcification operates as a carbonate counter-pump in the surface ocean while providing dense mineral ballast that accelerates the sinking of particulate organic carbon to the abyssal seafloor.[14] The decline of heavy foraminiferal tests -- compounded by ocean acidification, which has already reduced industrial-era shell weights by 32-40% in Globorotalia truncatulinoides and 18-24% in Globigerina bulloides across the northwestern Mediterranean[14] -- threatens to weaken organic carbon ballasting and deep-sea sequestration.[4] Furthermore, the return of an Eemian-like (MIS 5e) G. oceanica assemblage warns of progressive deep-water

stagnation akin to the prehistoric conditions that produced anoxic Mediterranean sapropels.[15]

| System Component | | Observed / Projected Shift | | Ecosystem & Biogeochemical Consequence |

| Pelagic Base | | Diatoms / G. bulloides -> Flagellates / G. oceanica | | Shift from classical food web to lower-efficiency microbial loop.[11] |

| Small Pelagic Fisheries | | Prey lipid depletion & phenological mismatch | | Reduced body condition and recruitment in anchovy and sardine stocks.[12][13] |

| Carbonate Ballasting | | Decline in foraminifera; up to 32-40% shell thinning | | Weakened biological pump efficiency and positive climate feedback.[14] |

Conclusion: Managing an Oligotrophic Mediterranean

The 2026 findings of Lucas et al. demonstrate that the Western Mediterranean biosphere has crossed a historic ecological threshold. The proliferation of Gephyrocapsa oceanica and replacement of temperate upwelling foraminifera by symbiont-bearing tropical taxa confirm that Atlantic-driven tropicalization is already reshaping the basin's foundational productivity.[4] Effective marine policy must integrate these micropaleontological baselines: regional fisheries management must recalibrate catch limits for a permanently lower, oligotrophic carrying capacity, while Earth system models must incorporate divergent coccolithophore and foraminiferal calcification responses to project Mediterranean carbon sequestration accurately.[14][16]

Updates... (Nov 16, 2026): Refined species-specific industrial-era shell weight reductions from B jard et al. (2023) (32-40% in Globorotalia truncatulinoides and 18-24% in Globigerina bulloides), removed numbered section headings, and replaced ResearchGate, Reddit, HTTP 403/500, and uncited links with 16 verified peer-reviewed CrossRef DOIs and UAB repository records with strict 1-to-1 inline parity.

References & Primary Sources

* [1] Pastor, F., Valiente, J. A., & Khodayar, S. (Aug 20, 2020). A Warming Mediterranean: 38 Years of Increasing Sea Surface Temperature. Remote Sensing, 12(17), 2687. -- https://doi.org/10.3390/rs12172687

* [2] Tsadok, R., Zemah-Shamir, Z., Shemesh, E., Martinez, S., Ramon, D., Kolski, I., Tsemel, A., & Tchernov, D. (Nov 8, 2023). Dietary habits change of Lessepsian migrants' fish from the Red Sea to the Eastern Mediterranean Sea. Aquatic Invasions, 18(4). -- https://doi.org/10.3391/ai.2023.18.4.113532

* [3] Katsanevakis, S., Nikolaou, A., Tsirintanis, K., & Rilov, G. (Mar 2025). Lessepsian migration in the Mediterranean Sea in an era of climate change: Plague or boon? Science Talks, 13, 100412. -- https://doi.org/10.1016/j.sctalk.2024.100412

* [4] Lucas, A., Pallacks, S., Incarbona, A., Mortyn, P. G., & Ziveri, P. (Apr 2026). Tropicalization and biodiversity restructuring of calcifying plankton in a rapidly warming Mediterranean Sea. Global and Planetary Change, 259, 105314. -- https://doi.org/10.1016/j.gloplacha.2026.105314

* [5] Lucas, A., Pallacks, S., Incarbona, A., Mortyn, P. G., & Ziveri, P. (2026).

Tropicalization and biodiversity restructuring of calcifying plankton in a rapidly warming Mediterranean Sea. Universitat Aut noma de Barcelona Research Portal. -- https://portalrecerca.uab.cat/en/publications/tropicalization-and-biodiversity-restructuring-of-calcifying-plan/

* [6] Gafar, N. A., & Schulz, K. G. (Jun 15, 2018). A three-dimensional niche comparison of Emiliania huxleyi and Gephyrocapsa oceanica: reconciling observations with projections. Biogeosciences, 15, 3541-3560. -- https://doi.org/10.5194/bg-15-3541-2018

* [7] Dowsett, H., Robinson, M., Foley, K., Herbert, T., Hunter, S., & Andersson, C. (Mar 2, 2023). The Relative Stability of Planktic Foraminifer Thermal Preferences over the Past 3 Million Years. Geosciences, 13(3), 71. -- https://doi.org/10.3390/geosciences13030071

* [8] Abdellaoui, B., et al. (Mar 22, 2024). Spatial pattern of sea surface temperature and chlorophyll-a trends in relation to hydrodynamic processes in the Albor n Sea. Mediterranean Marine Science. -- https://doi.org/10.12681/mms.30268

* [9] Fern ndez- lvarez, B., et al. (Oct 7, 2025). Mediterranean Sea Warming and Marine Heatwaves in 2024. State of the Planet. -- https://doi.org/10.5194/sp-2025-13

* [10] Skeji , S., et al. (Jul 2, 2024). Phytoplankton Assemblage over a 14-Year Period in the Adriatic Sea: Patterns and Trends. Biology, 13(7), 493. -- https://doi.org/10.3390/biology13070493

* [11] Hagstr m, ., Azam, F., Andersson, A., Wikner, J., & Rassoulzadegan, F. (1988). Microbial loop in an oligotrophic pelagic marine ecosystem: possible roles of cyanobacteria and nanoflagellates in the organic fluxes. Marine Ecology Progress Series, 49, 171-178. -- https://doi.org/10.3354/meps049171

* [12] Morote, E., Olivar, M. P., Villate, F., & Uriarte, I. (Feb 8, 2010). A comparison of anchovy (Engraulis encrasicolus) and sardine (Sardina pilchardus) larvae feeding in the Northwest Mediterranean: influence of prey availability and ontogeny. ICES Journal of Marine Science, 67(5), 897-908. -- https://doi.org/10.1093/icesjms/fsp302

* [13] Costalago, D., Palomera, I., & Tirelli, V. (May 2014). Seasonal comparison of the diets of juvenile European anchovy Engraulis encrasicolus and sardine Sardina pilchardus in the Gulf of Lions. Journal of Sea Research, 89, 64-72. -- https://doi.org/10.1016/j.seares.2014.02.008

* [14] B jard, T. M., Rigual-Hern ndez, A. S., Flores, J. A., Tarruella, J. P., Durrieu de Madron, X., Cacho, I., Haghipour, N., Hunter, A., & Sierro, F. J. (Apr 14, 2023). Calcification response of planktic foraminifera to environmental change in the western Mediterranean Sea during the industrial era. Biogeosciences, 20(7), 1505-1528. -- https://doi.org/10.5194/bg-20-1505-2023

* [15] Incarbona, A., Ziveri, P., Sabatino, N., Manta, D. S., & Sprovieri, M. (Dec 2011). Conflicting coccolithophore and geochemical evidence for productivity levels in the Eastern Mediterranean sapropel S1. Marine Micropaleontology, 81(3-4), 131-143. -- https://doi.org/10.1016/j.marmicro.2011.09.003

* [16] Mentaschi, D., et al. (Feb 2, 2024). Projected climate oligotrophication of the Adriatic marine ecosystems. Frontiers in Climate, 6, 1338374. --

https://doi.org/10.3389/fclim.2024.1338374