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The Silent Invasion: Planktonic Reorganization and the Tropicalization of the Western Mediterranean in the Anthropocene

Environment * Climate Change * Conservation

1. Introduction: The Invisible Barometer of the Mediterranean During the Anthropocene

In the grand theatre of global climate change, the Mediterranean Sea has long been cast as a protagonist -- a "hotspot" where the interactions between atmospheric warming, ocean circulation, and biodiversity loss play out with accelerated intensity.[1] For decades, the narrative of this basin's transformation has been dominated by the visible and the macroscopic: the arrival of alien rabbitfish denuding algal forests in the East, the decline of the iconic *Posidonia* seagrass meadows, or the plight of commercial fisheries facing shifting stocks.[2] However, a landmark study published in early 2026 by Lucas et al. in *Global and Planetary Change* has shifted the focus to the invisible majority that underpins the entire marine ecosystem: the microscopic plankton.[4]

This research, led by the Institute of Environmental Science and Technology at the Universitat Autònoma de Barcelona (ICTA-UAB), provides the first comprehensive evidence that the Western Mediterranean -- long considered a temperate refuge buffered by Atlantic cooling -- is undergoing a profound "tropicalization".[4] This process is not merely an invasion of species but a fundamental restructuring of the biological pump, the engine of marine productivity. By analyzing the fossilized remains of calcifying plankton trapped in sediment cores spanning the last two millennia, the researchers have revealed a silent regime shift: the displacement of native, nutrient-loving species by tropical, oligotrophic specialists adapted to a warmer, more stratified ocean.[6]

1.1 The Concept of Tropicalization in a Temperate Sea

Tropicalization, in the context of marine ecology, refers to the increasing dominance of warm-water species within temperate communities, often accompanied by the retreat or local extinction of cold-temperate taxa. In the Eastern Mediterranean (the Levantine Basin), this phenomenon has been recognized for over a century, driven principally by the "Lessepsian migration" -- the influx of Red Sea species through the Suez Canal.[2] This is a biological invasion in the truest sense, where biota from a tropical Indo-Pacific realm colonize a subtropical basin.

However, the phenomenon documented by Lucas et al. (2026) in the Western Mediterranean (specifically the Alboran Sea and the Strait of Sicily) represents a distinct and perhaps more insidious form of tropicalization.[8] It is driven not by a man-made canal, but by the physical alteration of the ocean itself. As the sea surface temperature (SST) rises and the water column becomes more stratified, the temperate Atlantic waters entering through the Strait of Gibraltar are carrying

tropical passengers -- species like the coccolithophore *Gephyrocapsa oceanica* -- that can now survive and thrive in a basin that was previously too cold for them.[9]

1.2 The "Invisible Majority" as Sentinels

Why focus on plankton? While microscopic, planktonic organisms -- including phytoplankton (algae) and zooplankton (animal drifters) -- constitute the base of the marine food web. They respond rapidly to environmental changes due to their short life cycles, making them arguably the most sensitive indicators of oceanographic shifts.[4]

The 2026 study focuses on two specific groups of calcifying plankton, which serve as dual indicators of ecosystem health and carbon cycling:

- * Coccolithophores: Unicellular algae that surround themselves with microscopic plates of calcite (coccoliths). They are primary producers, harnessing sunlight to create organic matter.[11]

- * Planktonic Foraminifera: Single-celled protists (zooplankton) that build intricate calcite shells. They are primary consumers, grazing on phytoplankton and serving as a critical energy link to higher trophic levels like fish larvae.[12]

Because these organisms build mineralized shells, they leave a permanent record of their existence. When they die, their shells rain down onto the seafloor, accumulating in layers that can be read like the pages of a history book. By analyzing these "natural archives," Lucas and his team have reconstructed the biological history of the Mediterranean over the past 2,000 years, revealing that the changes occurring in the Anthropocene are without precedent in the recent geological record.[8]

This report aims to dissect the findings of this pivotal 2026 study, exploring the mechanisms driving this planktonic reorganization, the specific species involved, and the cascading implications for the Mediterranean's carbon cycle, fisheries, and future biodiversity.

2. Oceanographic Context: The Physics of a Changing Sea

To understand the biological shifts identified by Lucas et al., one must first comprehend the unique physical setting of the Mediterranean Sea and how it is morphing under the pressure of global climate change. The Mediterranean is an "anti-estuarine" concentration basin; evaporation exceeds precipitation and river runoff. This deficit is balanced by the inflow of relatively fresh, nutrient-depleted surface water from the Atlantic Ocean through the Strait of Gibraltar.[15]

2.1 The General Circulation Pattern

The circulation of the Mediterranean is driven by thermohaline forces -- differences in temperature (thermo) and salinity (haline).

- * Inflow: Atlantic Water (AW) enters through the Strait of Gibraltar at the surface. It flows eastward along the North African coast, evolving as it warms and becomes saltier due to evaporation.

* Transformation: In winter, strong, cold winds (such as the Mistral in the Gulf of Lions and the Bora in the Adriatic) cool the surface waters. This cold, salty water becomes dense and sinks, forming Deep Water.

* Outflow: The dense deep water eventually flows back westward and exits into the Atlantic through the Strait of Gibraltar at depth.[15]

This circulation acts as a "conveyor belt" for plankton. The incoming Atlantic Water is the primary vector for introducing new species into the Western Mediterranean. Historically, the temperature contrast between the Atlantic and the Mediterranean acted as a filter; tropical species entering from the Atlantic might survive the transit but would fail to establish permanent populations in the cooler, seasonally dynamic Western Mediterranean. The 2026 study suggests this filter has effectively broken down.[4]

2.2 The Warming Trend: A Hotspot Intensified

The Mediterranean is warming at a rate roughly 20% faster than the global average. Satellite data and in-situ observations spanning the last four decades indicate a steady rise in Sea Surface Temperature (SST).

* Warming Rate: The basin has been warming at approximately 0.035 degrees Celsius per year, with accelerated warming observed in the summer months.[1]

* Western Basin Specifics: While the Eastern Mediterranean has always been warmer, the Western basin is experiencing the most dramatic relative change. The "tropicalization" signal detected by Lucas et al. is most pronounced here because the ecological baseline was historically temperate.[4]

* Marine Heatwaves: Beyond the gradual mean warming, the frequency and duration of Marine Heatwaves (MHWs) have spiked. These extreme events act as "shocks" to the ecosystem, often exceeding the thermal tolerance of native temperate species while creating windows of opportunity for tropical intruders.[17]

2.3 Stratification and Oligotrophication

Perhaps more critical than temperature alone is the effect of warming on the water column's structure. As the surface layer warms, it becomes significantly less dense than the deep water. This creates a strong "stratification" -- a physical barrier that prevents vertical mixing.[4]

* The Nutrient Blockade: In a healthy temperate system, winter storms mix the water column, bringing nutrient-rich deep water to the sunlit surface. This fuels the spring phytoplankton bloom (the "green" ocean).

* The "Blue Desert": Strong stratification acts as a lid, trapping nutrients at depth. The surface becomes nutrient-starved, or "oligotrophic." This favors small cells (picoplankton) and organisms adapted to scavenging or symbiosis, rather than the large, bloom-forming plankton that support rich fisheries.[18]

The Lucas et al. study posits that the observed plankton shifts are a direct biological response to this physical transition toward a warmer, more stratified, and nutrient-poor state.[9]

3. Methodology: Reading the Archives of the Deep

The conclusions drawn by Lucas et al. (2026) are robust because they are not based merely on short-term snapshots of modern water, but on a continuous, high-resolution record spanning centuries. This section details the methodology used to reconstruct the Mediterranean's biological past.

3.1 Sediment Cores as Chronometers

Marine sediment cores are cylindrical samples of the seafloor. In the deep, quiet parts of the ocean, sediment accumulates slowly and continuously, primarily composed of the microscopic shells of dead plankton (calcium carbonate from foraminifera and coccolithophores, and silica from diatoms) mixed with wind-blown dust and river clay.

The researchers analyzed cores from two strategic locations:

- * The Alboran Sea: Situated just east of Gibraltar, this site captures the immediate influence of the Atlantic inflow. It is the "entry gate" for Atlantic plankton.[4]
- * The Strait of Sicily: The central chokepoint of the Mediterranean. This site reflects the evolved water masses moving from West to East and captures the oceanographic dynamics of the central basin.[8]

3.2 Dating and Chronology

To interpret a core, one must establish a timeline. The study likely utilized a combination of radiometric dating techniques:

- * Lead-210 (Pb-210): Used to date the very recent past (last ~100-150 years), providing high resolution for the Industrial Era.
- * Carbon-14 (Radiocarbon): Used to date older layers, spanning back the full 2,000 years of the study period.
- * Tephrochronology: The identification of volcanic ash layers (tephra) from known eruptions (e.g., from Vesuvius or Etna) can serve as precise "time-markers" to calibrate the radiocarbon dates.

3.3 Micropaleontological Analysis

The core material was sliced into thin layers, each representing a specific window of time. The researchers then performed quantitative counts of the microfossils:

- * Coccolithophores: Analyzed using polarized light microscopy or Scanning Electron Microscopy (SEM). Species like *Gephyrocapsa oceanica* are identified by the specific morphology of their calcite plates.[4]
- * Foraminifera: The shells (tests) are sieved from the sediment and identified under a stereomicroscope. The relative abundance of species (e.g., *Globigerina bulloides* vs. *Trilobatus sacculifer*) is calculated to reconstruct past environmental conditions.[8]

This "micropaleontological" approach allows for the direct comparison of biodiversity and community structure between the Pre-Industrial Era (before 1850) and the Anthropocene (1950-2026), revealing trends that modern monitoring programs

(which only started a few decades ago) would miss.

4. The Protagonists: A Tale of Two Plankton Groups

The "Great Restructuring" identified by Lucas et al. involves a divergence in the fates of the two dominant calcifying groups. While they both build shells of calcite, their biological responses to the warming Mediterranean have been remarkably different.

4.1 Coccolithophores: The Opportunistic Architects

Coccolithophores are unicellular algae belonging to the haptophytes. They are famous for their ability to form massive blooms visible from space, turning the ocean a milky turquoise.

- * Ecological Role: They are primary producers (fixing carbon via photosynthesis) and calcifiers (fixing carbon via shell building).

- * The Trend: The study found a rapid increase in coccolithophore diversity during the Industrial Era. As the water warms and stratifies, the diversity of these algae has gone up.[8]

- * Key Species:

- * *Emiliana huxleyi*: The ubiquitous "weed" of the ocean, found from the poles to the equator.

- * *Gephyrocapsa oceanica*: The "tropical intruder." This species is the focal point of the tropicalization signal.[20]

4.2 Planktonic Foraminifera: The Sensitive Grazers

Foraminifera (or "forams") are protists, generally larger than coccolithophores (size range: 100 microns to 1 mm). They float in the water column, extending sticky pseudopodia to capture prey.

- * Ecological Role: They are secondary producers. They link the primary production (algae) to higher consumers.

- * The Trend: In stark contrast to the coccolithophores, foraminiferal diversity has declined. The community is becoming less diverse and more dominated by a few specialized species.[8]

- * Key Species:

- * *Globigerina bulloides*: A temperate species associated with high productivity and upwelling.

- * *Trilobatus sacculifer*: A tropical species associated with low nutrients and warm waters.[12]

4.3 The Divergence Explained

Why did diversity go up for algae but down for zooplankton? The authors suggest this is linked to their life cycles and resource requirements. Coccolithophores have rapid turnover rates and can exploit short-lived pulses of nutrients or stratifying conditions. Foraminifera, being higher up the food chain and having more complex

life histories (some with monthly reproduction cycles keyed to the moon), are more sensitive to the disruption of the seasonal cycle (phenology) and the overall reduction in productivity (oligotrophication).[8]

5. The Great Restructuring: Evidence of Tropicalization

The core finding of the Lucas et al. (2026) report is the identification of a specific biological signature of tropicalization in the Western Mediterranean. This is not a subtle shift; it is a replacement of the ecosystem's foundation.

5.1 The Rise of *Gephyrocapsa oceanica*

The most significant indicator identified in the sediment cores is the explosion in the abundance of *Gephyrocapsa oceanica*.

* Biogeography: *G. oceanica* is traditionally restricted to the Equatorial Atlantic Divergence Zone and other warm, tropical waters. It requires temperatures generally above 18-20 deg C to thrive and outcompete other species.[6]

* The "Lazarus" Signal: In the Mediterranean fossil record, *G. oceanica* was abundant during past warm intervals, such as the Eemian Interglacial (125,000 years ago) and the Holocene Thermal Maximum (~5,000 years ago). During the cooler periods that followed, it virtually disappeared. Its sudden resurgence in the 20th and 21st centuries is a clear "bio-indicator" that the Mediterranean thermal regime has returned to a tropical state.[4]

* Mechanism: The study argues that this is driven by the "increasing intrusion and eastward expansion" of the species from the Strait of Gibraltar. As the Atlantic surface water warms, it acts as a conveyor belt, delivering *G. oceanica* into a Mediterranean that is now warm enough to sustain it.[9]

5.2 The Decline of the Temperate "Old Guard"

As tropical species rise, the native temperate assemblages are faltering. The sediment records show a decline in the traditional dominants of the Western Mediterranean productivity.

* *Globigerina bulloides* Decline: This species is a proxy for "classical" marine productivity. It thrives in turbulent, nutrient-rich waters (blooms). Its decline signals that the Western Mediterranean is losing its seasonal vigor -- the winter mixing that fertilizes the surface is weakening.[6]

* *Globorotalia inflata* Retreat: This species reproduces in the deep mixed layer during winter. The warming winters and reduced mixing depth are shrinking its reproductive habitat.[22]

5.3 The Oligotrophic Shift: Enter the Symbionts

Replacing the high-productivity grazers are species adapted to the "blue desert." The study notes a rise in warm-oligotrophic species such as:

* *Trilobatus sacculifer*: This foraminifer hosts photosynthetic symbionts (dinoflagellates) within its cell. This adaptation allows it to survive in nutrient-poor waters by recycling the waste products of its symbionts. Its expansion

is a classic sign of oligotrophication.[6]

* Globigerinella spp.: Another group often associated with subtropical, stratified waters.

Table 1: The Shift in Western Mediterranean Plankton Assemblages

Ecological Niche	Native/Pre-Industrial Dominants	Anthropocene/Tropicalized Dominants	Implication
Primary Production	Emiliania huxleyi (Generalist)	Gephyrocapsa oceanica (Tropical)	Shift toward warm-water calcifiers.
Secondary Production	Globigerina bulloides (High nutrient)	Trilobatus sacculifer (Low nutrient)	Shift toward symbiont-bearing, low-energy species.
Water Column	Mixed, Seasonal, Eutrophic/Mesotrophic	Stratified, Stable, Oligotrophic	Reduced energy transfer to higher trophic levels.
Origin	Native / North Atlantic Temperate	Tropical Atlantic / Equatorial	"Atlantification" of the Mediterranean.

6. A Tale of Two Tropicalizations: East vs. West

A critical nuance highlighted by the research material is the distinction between the tropicalization occurring in the Western basin versus the Eastern basin. While the outcome (a warmer, more tropical sea) is similar, the mechanisms and biological agents are distinct.

6.1 The Eastern Basin: Lessepsian Migration

In the Levantine Basin (East), tropicalization is driven primarily by the Suez Canal.

- * Mechanism: Biological Invasion (Human-mediated corridor).
- * Direction: South-to-North (Red Sea to Mediterranean).
- * Agents: Indo-Pacific species (e.g., Rabbitfish, Lionfish, Amphistegina foraminifera).
- * Nature: These are "Alien" species, often with no evolutionary history in the Mediterranean. They are colonizers filling empty niches or displacing natives through aggression or competitive exclusion.[2]

6.2 The Western Basin: Atlantification

In the Alboran and Tyrrhenian Seas (West), tropicalization is driven by Gibraltar and Climate.

- * Mechanism: Oceanographic Expansion (Climate-mediated range shift).
- * Direction: West-to-East (Atlantic to Mediterranean).
- * Agents: Tropical Atlantic species (e.g., Gephyrocapsa oceanica, Trilobatus sacculifer).
- * Nature: These are "Native" or "Neighboring" species that historically existed in the Atlantic reservoir. They are expanding their range as the "thermal curtain" of

the Western Mediterranean lifts. This is a "natural" process accelerated by anthropogenic warming.[4]

The Lucas et al. study is significant precisely because it decouples these two phenomena, proving that even without the Suez Canal, the Mediterranean would still be tropicalizing due to global warming allowing Atlantic tropicals to enter.

7. Cascading Effects: The Unraveling of the Food Web

The microscopic shift detailed in the 2026 study is not an isolated curiosity; it has profound implications for the macroscopic world. Patrizia Ziveri, co-author of the study, warns that "alterations at the base of the food web can propagate to higher trophic levels, affecting the overall balance of the marine ecosystem".[4]

7.1 From Classical Web to Microbial Loop

The shift from *Globigerina bulloides* (associated with diatoms and high nutrients) to *Trilobatus sacculifer* (associated with stratification) represents a shift in the energetic efficiency of the food web.

* Classical Food Web: Diatoms Copepods Small Fish (Anchovy). This is a short, efficient chain. Energy transfer is high.

* Microbial Loop: Picoplankton Flagellates Ciliates Micro-zooplankton Fish. This is a long, inefficient chain. At each step, metabolic energy is lost.

The "oligotrophication" of the Western Mediterranean implies a transition toward the Microbial Loop. While the biodiversity of tiny flagellates might be high, the biomass available for fish is lower.[23]

7.2 The Threat to Small Pelagic Fisheries

The Mediterranean fishery is culturally and economically dependent on small pelagic fish: the European Anchovy (*Engraulis encrasicolus*) and the Sardine (*Sardina pilchardus*).

* The "Match-Mismatch" Hypothesis: Fish larvae spawn at specific times, evolving to match the bloom of their zooplankton prey. If warming shifts the timing (phenology) of the plankton bloom, or changes the species composition of the bloom, the larvae may hatch into a "desert."

* Nutritional Quality: Not all plankton are created equal. *Globigerina bulloides* blooms are often associated with lipid-rich copepods essential for fish growth. A community dominated by *Gephyrocapsa oceanica* and gelatinous zooplankton may not provide the necessary fatty acids for larval survival.[25]

* Current Indicators: Fisheries data from the Western Mediterranean (e.g., Gulf of Lions) has already shown a "sardine mystery" -- fish are becoming smaller and leaner. The plankton restructuring identified by Lucas et al. provides a plausible bottom-up mechanism for this decline: the carrying capacity of the ecosystem is shrinking.[26]

7.3 Gelatinous Futures

Another consequence of stratification and warming is the rise of gelatinous zooplankton (jellyfish and ctenophores). These organisms thrive in warm, stratified waters where fish larvae struggle. They compete with fish for plankton and, in some cases, predate on fish eggs. The shift toward a "tropical" plankton community often presages a shift toward a jellyfish-dominated ecosystem, a phenomenon already observed in parts of the Mediterranean.[27]

8. Biogeochemical Feedbacks: The Carbon Cycle at Risk

Beyond the food web, calcifying plankton are the engineers of the ocean's carbon cycle. The restructuring of these communities has biogeochemical consequences that could feedback into the global climate system.

8.1 The Rain Ratio and the Carbon Pumps

The ocean regulates atmospheric CO₂ through two main "pumps":

- * The Organic Pump: Photosynthesis captures CO₂. Dead organic matter sinks, sequestering carbon.
- * The Carbonate Counter-Pump: The formation of calcium carbonate (CaCO₃) shells by foraminifera and coccolithophores actually releases CO₂ in the short term (due to chemical shifts in alkalinity) but sequesters carbon in the long term (geological storage).[28]

The ratio of organic carbon to inorganic carbonate rain (the "Rain Ratio") determines the ocean's efficiency as a carbon sink. The shift identified by Lucas et al. -- increasing coccolithophores (carbonate producers) but decreasing foraminifera (major flux carriers) -- complicates this picture.

- * Heavier Ballast: Foraminifera shells are heavy and sink fast, helping to transport organic carbon to the deep sea ("ballasting"). Their decline could slow down the organic pump, leaving more CO₂ in the surface layers.[29]

8.2 Ocean Acidification and Calcification

The Mediterranean is not just warming; it is absorbing anthropogenic CO₂, leading to Ocean Acidification (OA).

- * Shell Thinning: Research indicates that modern Mediterranean foraminifera already possess lighter, thinner shells compared to pre-industrial specimens (up to 30-40% mass loss in some species).[29]
- * The Double Whammy: The "tropical" species *G. oceanica* and *T. sacculifer* are expanding into a chemical environment that is hostile to calcification. While they are thermally adapted to the warmth, the acidification may impose a metabolic cost, making them fragile.[30]
- * Feedback Loop: If the primary calcifiers are stressed or if the community shifts towards lighter shells that dissolve easily, the Mediterranean's ability to store carbon in its sediments may be compromised. The seabed, which has been a carbon locker for millennia, could become less efficient, creating a positive feedback loop

that accelerates atmospheric warming.[4]

9. Paleo-Perspectives: Back to the Future?

The Lucas et al. study is powerful because it contextualizes the current shifts against the backdrop of deep time. The presence of *Gephyrocapsa oceanica* allows scientists to draw parallels with past geological epochs.

9.1 The Eemian Analog (MIS 5e)

Approximately 125,000 years ago, during the Last Interglacial (Eemian), global temperatures were 1-2 deg C higher than pre-industrial levels -- similar to the trajectory of modern warming.

* The Plankton Signal: Sediment cores show that *G. oceanica* was dominant in the Mediterranean during the Eemian.

* The Oceanographic State: The Eemian Mediterranean was highly stratified. This stratification led to the stagnation of deep waters and the formation of sapropels (layers S5, S4, etc.) -- organic-rich black muds deposited under anoxic conditions.[32]

* The Warning: The return of the "Eemian assemblage" of plankton serves as a warning. It suggests the Mediterranean circulation is moving toward a state of stagnation. While we are not yet at the point of sapropel formation (anoxia), the biological precursors are aligning. A stagnant Mediterranean would be a dead zone for deep-sea life and a massive alteration of regional biogeochemistry.

10. Conclusion: The New Normal

The report by Lucas et al. (2026) serves as a critical update to our understanding of the Mediterranean biosphere. It dismantles the assumption that the Western Mediterranean is a resilient temperate fortress. Instead, it paints a picture of a sea in rapid transition, infiltrated by Atlantic tropicals and reshaped by the physics of a warming planet.

The "tropicalization" revealed by the microscopic plankton is an ongoing reality, not a future projection. The "invisible majority" has already reorganized. The intrusion of *Gephyrocapsa oceanica* and the replacement of native foraminifera with tropical nomads like *Trilobatus sacculifer* provide irrefutable evidence that the ecosystem's baseline has shifted.[4]

Implications for Policy and Conservation:

* Fisheries Management: Stock assessments for anchovy and sardine can no longer rely on historical baselines of productivity. Models must account for a permanently oligotrophic, "tropicalized" carrying capacity.

* Climate Modeling: Global climate models often overlook the specific contributions of plankton species. The distinct responses of coccolithophores vs. foraminifera must be integrated to accurately predict future carbon uptake.[34]

* Biodiversity Monitoring: Conservation efforts must expand beyond visible megafauna. Monitoring the microscopic "canaries in the coal mine" provides the earliest warning of systemic collapse or shift.

The Mediterranean of the 21st century is becoming a "Blue Desert" -- beautiful, warm, clear, but fundamentally different from the rich, temperate sea that sustained civilizations for millennia. The plankton have spoken, and their message is clear: the heat is here, and the ecosystem has already changed forever.

Appendix: Summary Data Tables

Table 2: Comparative Analysis of Mediterranean Tropicalization Vectors

Feature	Eastern Mediterranean (Levantine Basin)	Western Mediterranean (Alboran/Tyrrhenian)
Primary Driver	Lessepsian Migration (Anthropogenic Corridor)	Atlanticization (Climate-Driven Expansion)
Source Region	Red Sea / Indo-Pacific	Subtropical / Equatorial Atlantic
Primary Vector	Suez Canal	Strait of Gibraltar (Atlantic Inflow)
Key Biological Indicators	Rabbitfish (Siganus), Lionfish (Pterois), Amphistegina	Gephyrocapsa oceanica, Trilobatus sacculifer
Ecological Impact	Competitive displacement, algal grazing	Trophic restructuring, oligotrophication
Status	Mature Invasion (Established)	Accelerating / Emerging (2026 Finding)

Table 3: Cascading Effects of Plankton Shifts on Ecosystem Services

Trophic Level	Shift Observed/Predicted	Ecosystem Consequence
Base (Plankton)	Shift from Diatoms/G. bulloides to Flagellates/G. oceanica	Reduced energy density; longer food chains.
Primary Consumers	Shift to small copepods & gelatinous zooplankton	"Jellyfishification"; lower food quality for fish.
Fish (Small Pelagics)	Phenological mismatch; lower recruitment	Decline in Anchovy/Sardine stocks (Economic loss).
Carbon Cycle	Decrease in heavy calcifiers (Forams); Thinner shells	Reduced carbon sequestration; potential positive feedback to warming.
Deep Sea	Reduced vertical mixing; stagnation	Risk of hypoxia; loss of deep-water biodiversity.

Works Cited

* A Warming Mediterranean: 38 Years of Increasing Sea Surface Temperature - MDPI, accessed February 16, 2026, <https://www.mdpi.com/2072-4292/12/17/2687>

* Climate Change and Lessepsian Migration to the Mediterranean Sea - ResearchGate, accessed February 16, 2026, https://www.researchgate.net/publication/388395999_Climate_Change_and_Lessepsian_Migration_to_the_Mediterranean_Sea

* Dietary habits change of Lessepsian migrants' fish from the Red Sea to the Eastern Mediterranean Sea - Aquatic Invasions, accessed February 16, 2026, <https://aquaticinvasions.arphahub.com/article/113532/>

- * Microscopic plankton reveal tropicalization of the Mediterranean ..., accessed February 16, 2026, <https://www.uab.cat/web/sala-de-premsa-icta-uab/detall-noticia/microscopic-plankton-reveal-tropicalization-of-the-mediterranean-sea>
- * EurekAlert! Climate Change - Latest News Releases, accessed February 16, 2026, <https://www.eurekalert.org/specialtopic/climatechange/news>
- * Tropicalization and biodiversity restructuring of calcifying plankton in a rapidly warming Mediterranean Sea - Universitat Autònoma de Barcelona Research Portal, accessed February 16, 2026, <https://portalrecerca.uab.cat/en/publications/tropicalization-and-biodiversity-restructuring-of-calcifying-plankton-in-a-rapidly-warming-mediterranean-sea>
- * spread of Lessepsian fish does not track native temperature conditions - Oxford Academic, accessed February 16, 2026, <https://academic.oup.com/icesjms/article/79/6/1864/6633758>
- * Tropicalization and biodiversity restructuring of calcifying plankton in ..., accessed February 16, 2026, <https://ddd.uab.cat/record/325655?ln=ca>
- * Tropicalization and biodiversity restructuring of calcifying plankton in a rapidly warming Mediterranean Sea - DDD UAB, accessed February 16, 2026, <https://ddd.uab.cat/record/325655/>
- * eastern mediterranean university: Topics by Science.gov, accessed February 16, 2026, <https://www.science.gov/topicpages/e/eastern+mediterranean+university>
- * A three-dimensional niche comparison of *Emiliania huxleyi* and *Gephyrocapsa oceanica*: reconciling observations with projections - BG, accessed February 16, 2026, <https://bg.copernicus.org/articles/15/3541/2018/>
- * The Relative Stability of Planktic Foraminifer Thermal Preferences over the Past 3 Million Years - MDPI, accessed February 16, 2026, <https://www.mdpi.com/2076-3263/13/3/71>
- * Planktonic foraminifera response to the azores high and industrial-era global warming in the central-western Mediterranean Sea, accessed February 16, 2026, https://www.research.unipd.it/retrieve/8b20949b-e346-4cce-9a1e-3a366e10f6d8/Ferraroetal2024_GPC.pdf
- * r/climatechange - Reddit, accessed February 16, 2026, <https://www.reddit.com/r/climatechange/new/>
- * Spatial pattern of sea surface temperature and chlorophyll-a trends in relation to hydrodynamic processes in the Alboran Sea | Mediterranean Marine Science - eJournals, accessed February 16, 2026, <https://ejournals.epublishing.ekt.gr/index.php/hcmr-med-mar-sc/article/view/30268>
- * Planktonic foraminifera response to the azores high and industrial-era global warming in the central-western Mediterranean Sea | Request PDF - ResearchGate, accessed February 16, 2026, https://www.researchgate.net/publication/382634168_Planktonic_foraminifera_response_to_the_azores_high_and_industrial-era_global_warming_in_the_central-western_Mediterranean_Sea
- * r/environment - Reddit, accessed February 16, 2026, <https://www.reddit.com/r/environment/new/>
- * Phytoplankton Assemblage over a 14-Year Period in the Adriatic Sea: Patterns and Trends, accessed February 16, 2026, <https://www.mdpi.com/2079-7737/13/7/493>

- * Projected climate oligotrophication of the Adriatic marine ecosystems - Frontiers, accessed February 16, 2026, <https://www.frontiersin.org/journals/climate/articles/10.3389/fclim.2024.1338374/full>
- * Microscopic plankton reveal tropicalization of the Mediterranean Sea - Reddit, accessed February 16, 2026, https://www.reddit.com/r/climatechange/comments/1r5mg6b/microscopic_plankton_reveal_tropicalization_of/
- * Coupled Coccolith-Based Temperature and Productivity High-Resolution Reconstructions in the Eastern Equatorial Pacific During the Last Deglaciation and the Holocene - Frontiers, accessed February 16, 2026, <https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2022.865846/full>
- * Low planktic foraminiferal diversity and abundance observed in a spring 2013 west-east Mediterranean Sea plankton tow transect - BG, accessed February 16, 2026, <https://bg.copernicus.org/articles/14/2245/2017/bg-14-2245-2017.pdf>
- * Population Connections, Community Dynamics, and Climate Variability, accessed February 16, 2026, <https://meetings.pices.int/publications/book-of-abstracts/2011-5th-zoopl-symp-book-of-abstracts.pdf>
- * (PDF) Microbial Components - ResearchGate, accessed February 16, 2026, https://www.researchgate.net/publication/259762685_Microbial_Components
- * comparison of anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) larvae feeding in the Northwest Mediterranean: influence of prey availability and ontogeny - Oxford Academic, accessed February 16, 2026, <https://academic.oup.com/icesjms/article/67/5/897/609506>
- * Spatiotemporal variability in the feeding habits of anchovy and sardine: a comparison of upwelling and river-runoff driven ecosystems - Frontiers, accessed February 16, 2026, <https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2025.1602042/full>
- * Phytoplankton size changes and diversity loss in the southwestern Mediterranean Sea in relation to long-term hydrographic variability | Request PDF - ResearchGate, accessed February 16, 2026, https://www.researchgate.net/publication/338407961_Phytoplankton_size_changes_and_diversity_loss_in_the_southwestern_Mediterranean
- * Conflicting coccolithophore and geochemical evidence for productivity levels in the Eastern Mediterranean Sapropel S1 | Request PDF - ResearchGate, accessed February 16, 2026, https://www.researchgate.net/publication/234057773_Conflicting_coccolithophore_and_geochemical_evidence_for_productivity_levels_in_the_Eastern_Mediterranean_Sapropel_S1
- * (PDF) Calcification response of planktic foraminifera to ..., accessed February 16, 2026, https://www.researchgate.net/publication/370022534_Calcification_response_of_planktic_foraminifera_to_environmental_change_in_the_Mediterranean
- * Decrease in coccolithophore calcification and CO₂ since the middle Miocene - PMC, accessed February 16, 2026, <https://pmc.ncbi.nlm.nih.gov/articles/PMC4735581/>
- * Full article: Living in a high CO₂ world: impacts of global climate change on marine phytoplankton - Taylor & Francis Online, accessed February 16, 2026, <https://www.tandfonline.com/doi/full/10.1080/17550870903271363>

- * The glacial and interglacial history of the Black Sea during the last 134 ka: About meltwater events, abrupt temperature changes - Publication Server of the University of Greifswald, accessed February 16, 2026, https://epub.ub.uni-greifswald.de/frontdoor/deliver/index/docId/1675/file/diss_Wegwerth_Antje.pdf
- * Middle-Late Pleistocene Eastern Mediterranean nutricline depth and coccolith preservation linked to Monsoon activity and Atlanti - ePrints Soton, accessed February 16, 2026, https://eprints.soton.ac.uk/471082/1/2022_Incarbona_et_al_GLOPLACHA_D_22_00217_R1.pdf
- * Press releases Archives - Ocean Acidification, accessed February 16, 2026, <https://news-oceanacidification-icc.org/category/press-releases/>