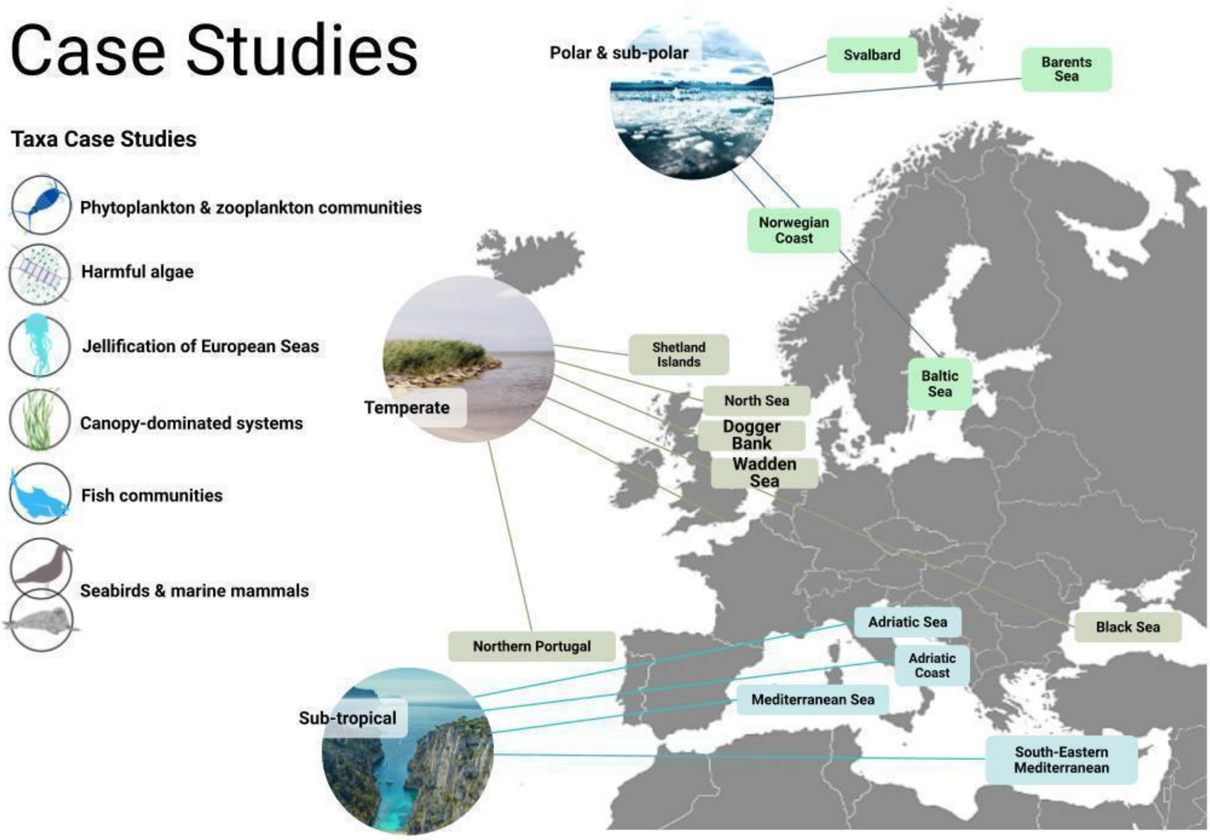
# Case Study 13
# Taxa

# Phytoplankton and Zooplankton Communities, including Harmful Algal Blooms (HABs)




## ACTNOW

ACTNOW is an EU-funded research project aimed at understanding the cumulative impacts on European marine biodiversity, ecosystem functions, and services for human wellbeing. The project equips regulators and decision-makers with essential knowledge and tools to combat biodiversity loss in coastal and marine habitats threatened by climate change and other regional drivers.

Conducted across various Case Study Regions in Europe, ACTNOW focuses on delivering scientific support for adaptation and mitigation measures, sustainable blue economy expansion, and contributions to the UNFCCC.

The project is structured into six Workpackages: WP1 (Data, Indicators and Scenarios), WP2 (Marine Organisms under Multiple Drivers), WP3 (Community, Food-Web and Ecosystem), WP4 (Cumulative Risks & Biodiversity Assessments), WP5 (Synthesis, Impacts & Solutions Options), and WP6 (Communication and Dialogue).

Objectives include developing 'what if' scenarios, understanding combined impacts on ecosystems, employing advanced biologging and molecular methods, and enhancing awareness of the links between marine biodiversity and human health.

ACTNOW has 17 CSs, 11 are regional CSs while 6 are pan-European (group / taxon) CSs. All are designed to deliver a cause-and-effect understanding, build predictive capacity in models, and to develop indicators and tools for decision-makers charged with the stewardship of European marine biodiversity under threats from multiple drivers (stressors in call) (see fig below). In each case, drivers examined represent the local/regional priorities from regulators who co-create what-if scenarios of interacting drivers including envisioned management actions.

## - Case Study 13: Phytoplankton and Zooplankton Communities

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### Description

Plankton form the base of marine life serving as pelagic primary producers (phytoplankton) and crucial links between lower and higher trophic levels (zooplankton). Phytoplankton are responsible for nearly 50% of global oxygen production and play a key role in carbon sequestration by taking up atmospheric carbon dioxide and transporting it to the seafloor. Zooplankton is a main food source for planktivorous fish supporting pelagic food webs.

Ongoing climate warming and human activities cause compositional changes in plankton communities leading to the loss of biodiversity on multiple trophic levels with widespread implications for ecosystem services, including carbon sequestration and fisheries.

ACTNOW applies statistical and modelling approaches to long-term data on phyto- and zooplankton community composition across all European seas to assess spatial and temporal biodiversity patterns and stability of plankton communities in response to cumulative drivers (climate change, nutrient pollution from land etc.). Modelling work within ACTNOW is complemented by laboratory experiments to provide information on species traits and response mechanisms.

### Services

Ecosystem services provided by plankton include:

- **Regulating services** (climate regulation and carbon storage) - phytoplankton as primary producers are a major contributor to carbon sequestration, transporting organic carbon from the surface euphotic layer to the seafloor as they sink (Huang et al. 2023). Phytoplankton are also known to emit VOCs (volatile organic compounds), such as DMSO (dimethyl sulfoxide), contributing to the formation of clouds with potentially cooling effect on climate (Malin et al. 1992).

- **Provisioning services** (biofuel, food supplements, cosmetics) - phytoplankton are currently being used as biofuel. Some plankton species, e.g. *Nannochloropsis* spp. are also in commercial use as food supplements and in the cosmetic industry due to the high content of Omega 3 fatty acids, vitamin D etc.. They also serve the aquaculture industry.
- **Cultural services** (recreation, health and wellbeing, artistic inspiration and creativity) - Water quality for recreation, such as swimming and surfing is affected by phytoplankton concentrations, with potentially negative health effects caused by toxic species. Biodiversity of plankton communities and some particular plankton traits, e.g. bioluminescence, have been an inspiration for artistic work for many years, beginning with Ernst Haeckel (Dolan, 2019), to modern art by Susanne Winterling (https://planetarysensing.com/), Joey Holder (https://xmuseum.org/en/exhibition/joey-holder-cryptid/) and many others.
- **Supporting services** (biogeochemical nutrient cycling, pelagic and benthic food webs) - Plankton are the basis of marine food webs being consumed by fish, marine mammals and benthic macrofauna. Plankton play a central role in marine carbon and nutrient cycling, including phosphorus, nitrogen and silica.

## Interacting Drivers of Biodiversity Change

Sea surface temperature (SST) has been considered the largest determinant of global plankton biodiversity patterns, but the direction of the response depends on species and their individual traits. Other interacting drivers include:

- nutrient concentrations and stoichiometric ratios
- mixed layer depth and related variables, such as light availability (incl. light spectrum) and water turbulence
- ocean acidification (OA)
- sea surface salinity (SSS)
- trophic interactions within planktonic food web and top-down control by fish
- chemical pollution from land (e.g. pharmaceutics)
- microplastic (both, toxicity of plastic compounds and mechanical damage by assimilated particles)
- invasions by non-native species (e.g. species transported with ballast water)

## Regional Context

Plankton distribution is widespread and strongly affected by global climate change and hydrodynamics. Therefore plankton biodiversity has to be tackled across geographical borders, but with respect to the region-specific drivers.

**The North Atlantic** (including polar seas, the North Sea, the Wadden Sea and the Dogger Bank) is one of the best studied regions in terms of the plankton dynamics. It has been shown that plankton species in the North Atlantic shift polewards in response to global warming (Barton et al. 2016) and phytoplankton biomass declines as a result of increasing temperature and water column stratification (Boyce et al. 2010).

**The Baltic Sea** is a highly eutrophic brackish ecosystem with a unique combination of marine and freshwater plankton species. The Baltic Sea is threatened by multiple stressors to the extent that other seas might experience in the future, which presents a great opportunity to study species tolerance limits and plankton dominance shifts. The zooplankton community in the Baltic Sea has been shown to shift from more complex copepods to less complex and fast growing cladocerans and rotifers, creating a mismatch with the phytoplankton bloom dynamic (Jansson et al. 2020). The richness of phytoplankton is strongly affected by the salinity gradient of the Baltic Sea reaching the minimum number of species at 7-9 psu (Olli et al. 2019).

**The Mediterranean Sea** (including the Adriatic) is characterised by a rich and complex physical dynamics with distinctive traits, especially in regard to the thermohaline circulation. Recent investigations have basically confirmed the long-recognised oligotrophic nature of this sea, which increases along both the west-east and the north-south directions.Plankton distribution also follows the aforementioned gradient (e.g. Nowaczyk et al., 2011; Siokou et al., 2019), with higher abundances concentrated in the upper 100 m layer, sharply decreasing with depth. The basin is largely dominated by small autotrophs, microheterotrophs and egg-carrying copepod species. The microorganisms (phytoplankton, viruses, bacteria, flagellates and ciliates) and zooplankton components reveal a considerable diversity and variability over spatial and temporal scales. Research has demonstrated significant impacts of climate change on plankton distribution and abundance in the Mediterranean. Long-term studies have shown that rising temperatures and shifts in hydrological regimes are altering zooplankton communities, particularly in regions like the Levantine basin. These changes underscore the complex interplay between climate-driven hydrological shifts and zooplankton dynamics. Despite uncertainties in modelling future scenarios, the resilience of zooplankton communities, supported by functional diversity, suggests some capacity to adapt to environmental changes (Benedetti et al., 2018). However, these adaptations may still have profound implications for ecosystem structure and function.

**The Black Sea** has been one of the most eutrophicated and mismanaged semi-enclosed seas in the world. Therefore, a general consensus of recent assessments of changing environmental conditions of the Black Sea is that the northwestern shelf (NWS) has improved in the last decade due to decreasing nutrient loads from the rivers (e.g.Parr et al. 2005).There have been fewer algal blooms, lower algal biomass, increasing plankton biodiversity, decreasing opportunistic and gelatinous species, and reappearance of cladocerans and copepods (Shiganova et al. 2008).

Plankton communities in the Black Sea have been profoundly affected by climate change, alongside other anthropogenic pressures such as eutrophication and overfishing. Rising sea temperatures and changes in salinity, driven by both natural climatic variability and human-induced factors, have led to significant shifts in plankton distribution and composition. In terms of zooplankton, studies have documented changes in species composition, with warmer conditions favouring smaller, warm-water species over larger, cold-water ones. This shift can reduce the overall energy transfer efficiency within the marine food web, as smaller zooplankton are often less nutritious for predators. Additionally, hypoxia, exacerbated by warmer temperatures and stratification, has affected deeper water layers, leading to habitat loss for some zooplankton species and altering their vertical distribution (Oguz & Velikova, 2010).

**The North Sea** is a highly productive shallow shelf sea supporting substantial biodiversity, including globally significant populations of seabirds, grey seals and harbour seals, that are of global significance. It is also an area harbouring unique assemblages of seabed fauna mediating globally significant ecosystem processes such as carbon and nitrogen cycling, that affect the ability of the ocean to serve as a sink for greenhouse gases. The region is also subjected to a range of anthropogenic activities including intense fishing, oil exploitation, offshore wind industries and others. Concurrently, the North Sea is one of the world’s warming hotspots, and concomitant changes in its species distributions are well underway. These changes affect our ability to sustain effective biodiversity conservation in the region affecting marine protected areas and jeopardising advances made in fisheries management. These impacts in turn limit the ability to continue to use the region to support food security, climate regulation and biodiversity in the medium and long-term. A key study site – the Dogger Bank in the Central North Sea– present areas of remarkably high biodiversity with high abundances of forage fish, and apex predators (including cetaceans, birds and seals) which aggregate in order to exploit this area. This is also an area of intensive past, present and forecast change in human activity, moving from previously crucial fishing grounds to with plans for large-scale construction of many new wind turbines, and offshore hydrogen generation.

## Research Needs

There is a major gap in application of plankton biodiversity data to inform policy and ecosystem management, which are still based on simplified lists of indicators, e.g. proportion of diatoms to dinoflagellates, presence of potentially toxic species, the number of species (richness), and the bulk plankton variables (e.g. total zooplankton abundance, chlorophyll *a* concentration). To advance our understanding of the effects of multiple drivers on plankton biodiversity and better predict the consequences of plankton biodiversity change for ecosystem functioning, we need to go beyond these indicator lists and their limitations by including the information on species traits, community dynamics and interactions. Thus, the goal of ACTNOW is building up an effective and comparable framework to accurately assess biodiversity and stability of plankton communities in the era of global change.

## Research Planned in ACTNOW

● T1.2 Development of indicators relevant to address biodiversity of plankton communities

Develop a regionally tuned new Phytoplankton Functional Type (PFT) algorithm for the Mediterranean Sea (NKUA). Estimates of phytoplankton size structure, an ecological indicator, will be derived using an abundance-based phytoplankton size class size model (Brewin et al., 2010), parameterised using available in situ HPLC algal pigment datasets.

● T1.3 Compiling phytoplankton and zooplankton long-term datasets

● T2.1 Collecting phytoplankton and zooplankton data on cruises, including analysis of eDNA and metabarcoding, HABs and phytoplankton toxins, and metabolic rates of zooplankton

During the ACTNOW cruise in the Dogger Bank phytoplankton community composition samples were collected for taxonomy, flow cytometry, stable isotope and lipid analyses. The analyses are still underway and planned to be finalized in 2025.

DTU staff has undertaken experimental studies assessing potential cumulative impacts on feeding and survival of Arctic copepods to the single and joint effects of climate change (i.e., in terms of temperature and salinity) and exposure to crude oil. The results are published in Rist et al. 2024 (https://doi.org/10.1021/acs.est.3c09582) and follow-up studies on egg production and early-life survival under similar cumulative stressors are underway.

Collecting size-fractionated suspended particulate matter and mesozooplankton samples (from 0.7 to >200μm), during six bimonthly HCMR cruises in the Saronikos Gulf (Eastern Mediterranean), to investigate changes in the nutritional quality (biochemical content) and assess mesozooplankton growth rate, respiration and redox status seasonal variations. Analyses of these samples are still underway and planned to be finalised in 2025.

● T2.3 Literature review and laboratory experiments on the impact of multiple stressors on zooplankton respiration and fitness

● T2.4 Compiling information on phytoplankton and zooplankton traits from literature and own experimental work within WP2

DTU has participated in several online meetings discussing and planning comparative analysis (including meta-analysis) of cumulative impacts across different studies and organisms groups. As a proof-of-concept study DTU are in the process of compiling available data from cumulative impact studies on zooplankton (i.e., including both published and unpublished data) carried out by DTU staff. The aim is to test a comparative analysis of joint responses to climate change and other stressors (i.e., mainly oil and microplastics).

● T3.1 Modelling responses of phytoplankton and zooplankton communities to multiple stressors across different temporal and spatial scales

● T3.2 Parameterising plankton interactions within marine food webs

● T3.3 Assessing the importance of plankton community shifts for functioning of ecosystems

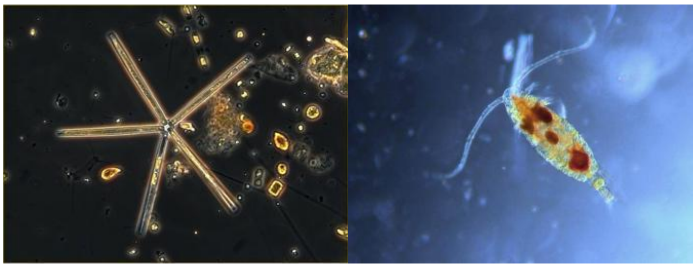
● T4.1 Testing the performance of existing plankton biodiversity assessments

● T4.3 Informing new and improved biodiversity status and risk assessments

● T5.1 Making predictions on plankton biodiversity change in response to multiple stressors

● T5.4 Contributing to the project synthesis products

## Pictures, graphs and maps



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