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Natural Capital and Ecosystem Assessment

Mixoplankton in the context of Natural Capital and Policy

HIGHLIGHTS



- Traditional monitoring and management tools for oceans, seas, and coasts rely on outdated conceptual frameworks.
- Many phytoplankton and up to half of protist-zooplankton combine plant-like photosynthesis with animallike consumption within a single cell.
- These dual-function organisms, called **mixoplankton**, challenge marine ecological classifications and require nuanced approaches in studies and management.
- Research over the past two decades has revealed mixoplankton's vital role in structuring and supporting marine food webs.
- The emerging **mixoplankton paradigm** underscores the need for modernized ecological frameworks and management approaches.

Mixoplankton are fundamental to the health of marine food webs in UK waters, and understanding their natural capital value offers new insights into ecosystem resilience and sustainability

A new paradigm in marine ecology

Our monitoring and management tools relating to fisheries production and global change, operate within a paradigm that builds on a simple division between 'plantlike' phytoplankton and their consumers, the 'animal-like' zooplankton at the base of the marine food web.

It is now recognised that most phytoplankton and as much as half the protist-zooplankton combine both plant-like photosynthesis and animal-like consumer activity synergistically within the same single-cell. These are the mixoplankton.

Mixoplankton are not hybrids of phytoplankton or zooplankton, neither did they originate from phytoplankton. Rather, phytoplankton evolved from mixoplankton. The recently published Mixoplankton Database reveals that various marine mixoplankton were previously mislabelled as phytoplankton or zooplankton.

Mixoplankton play an important role in structuring, functioning, and provisioning of food webs in coastal and marine waters. This has led to the emergence of a new paradigm in marine ecology — the mixoplankton paradigm, which sees a restructuring of the plankton food web.

In UK coastal and marine waters, records from the Ocean Biogeographic Information System (OBIS) database reveal the occurrence of 126 species of mixoplankton.

These exhibit a size range over many orders of magnitude (akin to that of mouse to elephant) and express diverse prey preferences (e.g., virus, bacteria, cyanobacteria, diatoms, multicellular animals such as copepods, shrimps, snail larvae etc.). Mixoplankton thus defy attempts to pigeonhole them into a one-size fits all scenario configuration.

A healthy marine ecosystem, particularly in shelf-coastal regions, depends greatly on the proliferation of diverse populations of mixoplankton. However, under certain environmental conditions, the proliferation of noxious mixoplankton can lead to harmful algal blooms, diminishing the value of this ecosystem asset to both ecological health and people.

Road map for mixoplankton

The emerging understanding of mixoplankton as pivotal components of marine ecosystems challenges longstanding paradigms and highlights their ecological and management importance. Effective policy development must account for the unique ecological roles and impacts of mixoplankton. Application of the precautionary principle now places an onus on regulators to take account of the known existence of mixoplankton and of their diverse nutritional mechanisms and ecological interactions. The following recommendations provide a roadmap for this.

Key recommendations for incorporating mixoplankton understanding into policy frameworks

Policies on monitoring and management of UK coastal and marine waters: Current tools classify plankton only as producers or consumers, overlooking mixoplankton, which do both. Their dual role affects food webs differently under varying conditions. Monitoring and management policies should be updated to account for mixoplankton's multi-trophic impacts.



Policies on management of organic eutrophication: Wastes from sewage, farming, and aquaculture contain organic and inorganic nutrients, but current policies focus only on inorganic ones. Policies should address organic nutrient types and sources, as these can promote mixoplankton growth, including harmful algal blooms (HABs).

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Policies on managing phosphorus and nitrogen removal from sewage: Imbalanced N:P:Si ratios in treated sewage promote harmful mixoplankton growth and toxicity. Policies should ensure phosphorus removal is matched by nitrogen removal to maintain balance.



Policies on building marine infrastructures: Marine construction impacts turbulence, flushing rates, and salinity, which influence plankton ecology and may promote harmful mixoplankton blooms. Planning policies should evaluate how construction could harm ecosystem health.



Mixoplankton and Natural Capital

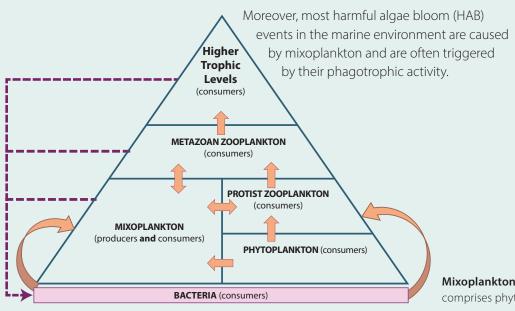
Mixoplankton contribute diverse natural capital attributes that are fundamental to the functioning of many marine food webs and to valued assets of the marine environment, such as fisheries (finfish and shellfish), water bathing quality, biodiversity, and aesthetics. These microbial organisms, mirroring the "three pervasive features" of Nature – "mobility, silence and invisibility," have been left in the shadows. Mixoplankton need to be recognised as both positive and negative assets, with healthy contributions optimized and harmful impacts, such as uni-species blooms, minimized. They urgently need to be considered as key assets in discussions of UK natural capital and thence policy.

Mixoplankton are more than mixotrophs

All phytoplankton are able to photosynthesize and use some form of dissolved or particulate inorganic nutrients.

Mixoplankton are chlorophyll-containing protist microbes capable of predation. As mixotrophs, they combine photosynthesis, the ability to use dissolved organic nutrients (e.g., amino acids, sugars), and grazing, The dissolved inorganic nitrogen (DIN) excreted from prey digestion within a mixoplankton cell is recycled internally to drive photosynthesis.

Mixoplankton have very different consequences for food web structure as they can convert a wide range of nutrient forms into plankton abundance and directly influence trophic dynamics by consuming other organisms, including competitors and even their own predators. This complexity impacts many marine ecosystem services such as harvestable fish biomass, climate regulation, and water quality maintenance, which are heavily influenced by plankton species that are now defined as mixoplankton.



Mixoplankton paradigm

The mixoplankton paradigm is the third major shift in marine ecology, following the *microbial loop* — a trophic pathway where dissolved organic carbon (DOC) is returned to higher trophic levels via its incorporation into bacterial biomass, and then coupled with the 'classic food chain' formed by phytoplankton to zooplankton to nekton; and the viral shunt — a mechanism that prevents marine microbial particulate organic matter from migrating up trophic levels by recycling them into dissolved organic matter, which can be readily taken up by microorganisms.

The mixoplankton paradigm compliments the microbial loop and viral shunt while adding complexity and stability to biological communities and food web.

Mixoplankton paradigm where the base of the food web comprises phytoplankton and mixoplankton.

Mixoplankton types

Mixoplankton span size ranges of many orders of magnitude and express diverse prey preferences. Mixoplankton thus defy attempts to pigeonhole them into a one-size fits all scenario configuration.

Constitutive Mixoplankton (CM) : innate ability to photosynthesise and consume contributing to primary production, carbon drawdown and nutrient recycling	Specialist Non-Constitutive Mixoplankton (NCM) : gained photosynthetic ability from specific prey taxonomic groups
Non-Constitutive Mixoplankton (NCM): acquires phototrophic ability from prey, contributing to primary production temporarily	plastidic Specialist Non-Constitutive Mixoplankton (NCM): gained ability to photosynthesise by keeping chloroplasts from specific prey
Generalist Non-Constitutive Mixoplankton (NCM): gained ability to photosynthesise by keeping chloroplasts from diverse prey	endosymbiotic Specialist Non-Constitutive Mixoplankton (NCM): gained ability to photosynthesise by keeping specific prey as symbionts



ARKdynamics

This newsletter has been jointly produced by the Cardiff University, ARK dynamics and the Environment Agency as part of the NCEA Programme. It reflects the collaborative efforts of these organisations in advancing the understanding and management of mixoplankton in UK waters.

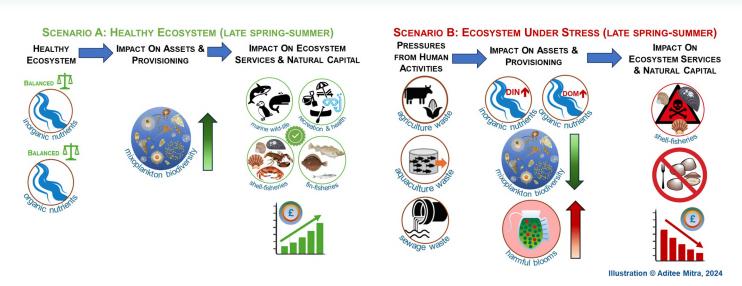


Occurrence of mixoplankton in UK waters

At least126 mixoplankton species are currently found in UK waters. This represents about 20 per cent of our traditional phytoplankton taxa. They are a significant portion of the taxa responsible for harmful algal blooms.

Requirement to optimise the positive assets of mixplankton and minimise the negatives

The natural capital of mixoplankton, and of plankton in general, equates to the sum of all the asset values of the organisms that feed directly or indirectly upon them, plus that of societal assets linked to the marine ecosystem. Mixoplankton are an important influence in both healthy scenarios — where the dissolved inorganic and organic nutrients (DIN and DOM, respectively) support biodiversity in mixoplankton communities which in turn support the different ecosystem services; and unhealthy scenarios which are often associated with human disturbances resulting in harmful events.



Mixoplankton are important intermediates in the food web, converting inorganic nutrients to larger plankton. They are therefore key indicators of human nutrient activity, as increasing pressures from human activities can lead to an imbalanced system.

Recommendations to recognise the uniqueness of mixoplankton -

- Normalise the usage of 'mixoplankton' in any/all discussions concerning plankton
- Recognise the eco-physiological variation within mixoplankton types
- Recognise the challenges present in monitoring and managing the asset value of mixoplankton

Conclusions and way forward

Monitoring and management methodologies and policies are revised such that the multi-trophic impacts of mixoplankton are recognised.

Concentration, types and sources of organic nutrients (sewage, farm, aquaculture) should be considered in policies relating to the management of eutrophication of marine and coastal waters. Such organic eutrophication can support the growth of mixoplankton, including HAB species.

Removal of phosphorus from sewage and effluent treatment needs to be balanced by the removal of nitrogen.

Planning policies should conduct assessments on how such constructions could risk marine ecosystem health through potentially supporting mixoplankton blooms.