Society *for* Applied Microbiology

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THE CHANGING ENVIRONMENT

PRESERVING & PROTECTING OUR OCEANS

The marine microbiome

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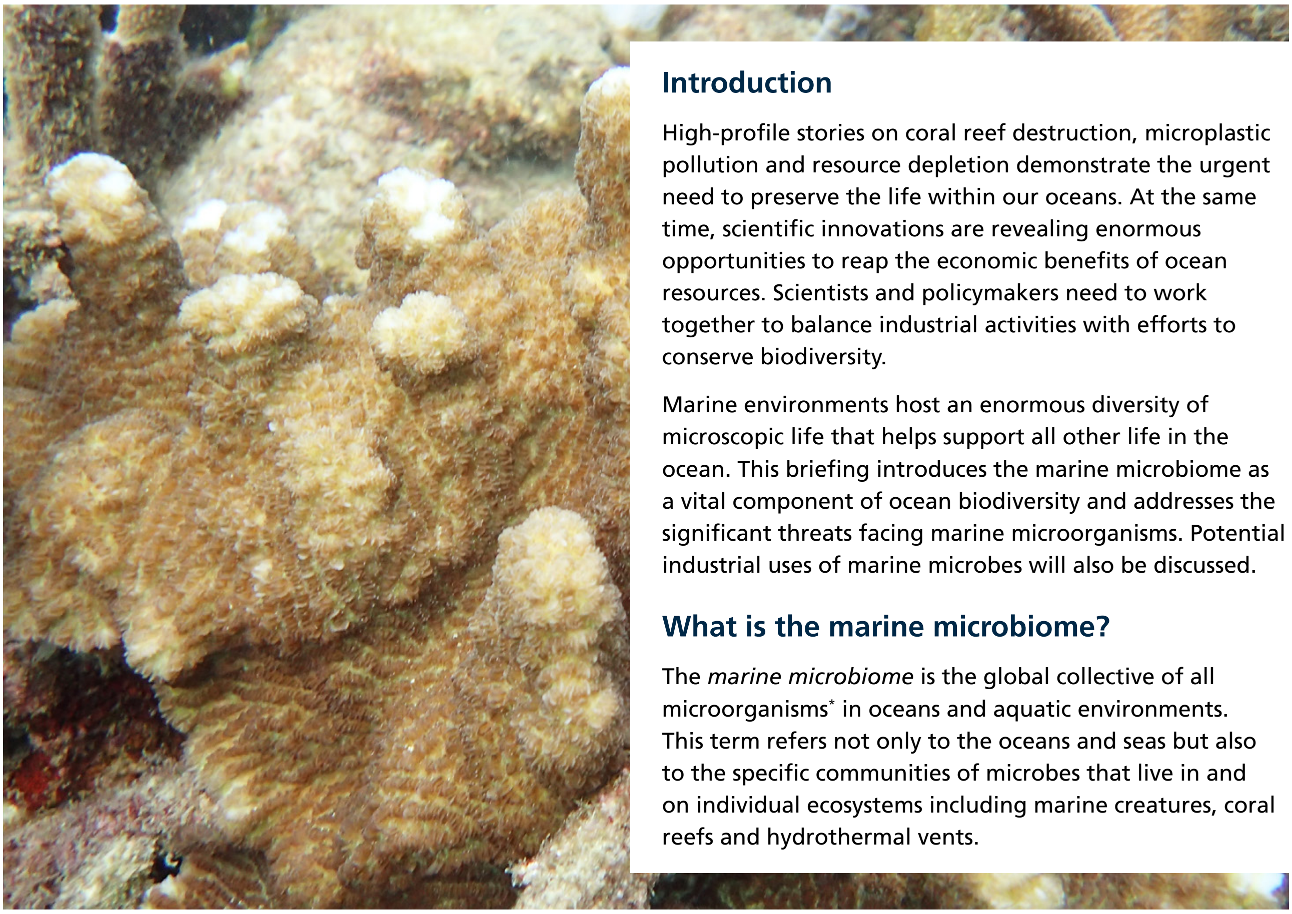
The marine microbiome

Overview

- The ‘marine microbiome’ is the diverse community of microorganisms found in oceans and other marine environments.
- Marine microbes perform vital roles, including the production of most of the world’s oxygen.
- Climate change and pollution pose significant hazards to the marine microbiome, which may introduce new risks to human health and economic growth.
- Marine microbes could hold the key to tackling the threat of pollution. They also have high economic potential as a source of new bioplastics and medicines.



Introduction

High-profile stories on coral reef destruction, microplastic pollution and resource depletion demonstrate the urgent need to preserve the life within our oceans. At the same time, scientific innovations are revealing enormous opportunities to reap the economic benefits of ocean resources. Scientists and policymakers need to work together to balance industrial activities with efforts to conserve biodiversity.

Marine environments host an enormous diversity of microscopic life that helps support all other life in the ocean. This briefing introduces the marine microbiome as a vital component of ocean biodiversity and addresses the significant threats facing marine microorganisms. Potential industrial uses of marine microbes will also be discussed.

What is the marine microbiome?

The *marine microbiome* is the global collective of all microorganisms* in oceans and aquatic environments. This term refers not only to the oceans and seas but also to the specific communities of microbes that live in and on individual ecosystems including marine creatures, coral reefs and hydrothermal vents.

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* Microorganisms (also known as microbes) include bacteria, viruses, fungi and some algae.

Our oceans are teeming with incredible numbers of different microorganisms; a drop of seawater may contain up to a million microbes[1] and microbial communities are estimated to make up around 70% of total marine biomass.[2] Researchers are only just scratching the surface of the diversity within these enormous communities (**Box 1**).

Marine microbes are the main energy source for all ocean life and carry out many of the basic functions that support entire ecosystems. Phytoplankton, for example, are particularly important as they produce an estimated 50%–80%[3, 4] of all global oxygen (rainforests are estimated to provide around 28%).[5]

Box 1: Measuring marine microbiomes

The Tara Oceans programme used genome sequencing technology to analyse samples from 68 global locations, revealing over 35,000 microbial species.[6] For comparison, Earth is estimated to be home to over 1 trillion microbial species,[7] meaning much more exploration is required to describe this vast diversity. Microbiologists are making use of new technologies, including autonomous vehicles, to investigate ever-greater depths (for example the Mariana Trench).[8]

Researchers are also looking at microbes in unique ecosystems. The Global Coral Microbiome Project,[9] for instance, aims to describe the microorganisms found in coral reefs to help understand the links between microbes and coral health, disease and environmental pressures.

Which factors affect the marine microbiome?

1. Climate change

Excess carbon dioxide (CO_2) emissions from human activity are causing global ocean temperatures and acidity to increase, posing significant challenges for the marine microbiome and the ocean life it supports.

1.1. Human and animal disease

Pathogenic (disease-causing) organisms may spread to new, previously low-risk areas as a result of warmer ocean temperatures. For example, heatwave events have been linked to rising cases of *Vibrio*-related infection in Northern Europe (**Box 2**).[10] Climate change also increases the likelihood that exotic diseases will spread to marine and freshwater fish populations, threatening fish farms.[11]

Box 2: *Vibrio vulnificus*

Vibrio vulnificus is a bacterium associated with shellfish that is responsible for over 95% of seafood-related deaths in the USA.[12] When ingested, it can cause acute gastroenteritis and septicaemia. This pathogen is rarely found in waters below 13°C; however, rising sea surface temperatures in the North Atlantic over the past 50 years have been linked to an increase of human disease caused by *Vibrio* species (including *Vibrio vulnificus*).[13]

Warmer waters also increase the risk of more frequent harmful 'algal bloom' events, where microorganisms grow rapidly in large quantities. Algal blooms can produce toxins and deplete vital nutrients, presenting a hazard to aquatic life, seabirds and humans. This can result in significant environmental and economic costs and may require extensive clean-up activities.[14] In 2015, a *Pseudonitzschia* bloom on the US West Coast resulted in an estimated loss of US$9.2 million for the local razor clam fishery industry.

1.2. Health of corals and shelled organisms

Ocean acidity increases as more CO_2 is absorbed by seawater. Many corals and shelled aquatic organisms struggle to maintain their skeletons and shells in these conditions, as calcium carbonate (a required mineral) is less available. This endangers these organisms and the ecosystems they are part of.

Researchers are finding that acid- and temperature-stressed corals and shelled organisms have less diverse microbiomes, increasing their vulnerability to further damage and disease.[15] More studies are needed to understand the long-term impacts, although microbes may hold the answer (see section: *What are the potential uses of marine microbes?*).

1.3. Nutrients and food

Ocean warming lowers the amount of dissolved oxygen in seawater and affects the availability of certain nutrients. This may alter the growth of microbes such as plankton, which are an important food source for other marine life.[16]

In polar environments, many creatures at the seafloor rely on organic matter in the sediment as a ‘food bank’. As temperatures increase at the poles,[17] seafloor microbes may become more active, consuming this organic material and leaving less food for other animals.[18]

2. Industry activity and pollution

2.1. Plastic and microplastics

Plastic pollution is colonized by specific bacterial species that are not usually found in the surrounding water.[19] High numbers of these bacteria, in heavily polluted regions, may negatively alter marine microbiomes. For example, plastic waste can introduce harmful bacteria to coral reefs, increasing the likelihood of coral disease from 4% to 89%.[20]

2.2. Agricultural and aquaculture pollution

Poorly planned and managed intensive agriculture and aquaculture can result in an over-abundance of nutrients leaching or being dumped into aquatic environments. This can cause algal bloom events, eutrophication and oxygen-depleted 'dead zones'.[21] Dead zones in Europe's oceans are projected to expand unless nutrient intake decreases.[22]

Research projects such as TAPAS (Tools for Assessment and Planning of Aquaculture Sustainability) are studying aquaculture sites across Europe to develop recommendations to monitor and reduce the environmental impacts of aquaculture.[23]

2.3. Industrial pollution

Oil spills: Oil pollution has a well-documented negative effect on marine animals and birds. However, the impact of oil on microbial communities is complex. Natural oil-degrading bacteria play a fundamental role in the breakdown and removal of oil in the ocean and on land. Large amounts of oil provide ample food for these bacteria, resulting in growth of their numbers, which may affect other microorganisms. For instance, in soil and permafrost, increased populations of oil-eating bacteria have been linked to a reduction in overall microbial biodiversity.[24]

The full impacts of oil pollution on ocean microbes is not fully understood. This knowledge will be important since we rely on natural bacteria to help clear oil spills. This process, when controlled and optimized, is known as *bioremediation*. It is evident that the ecological impact of pollution clean-up strategies must be understood down to the microbiological level, as human efforts may have unexpected consequences (**Box 3**).

Box 3: Deepwater Horizon (2010)

During the Deepwater Horizon catastrophe, response teams attempted to encourage natural bacteria to remove the oil more quickly. The responders applied a 'chemical dispersant' (Corexit 9500) to surface oil slicks and directly to the leaky wellhead. This separates the oil into small droplets, making them more accessible to microbes for degradation. Over 7 million litres of this dispersant were used.

This action unexpectedly encouraged the growth of bacteria that degraded the Corexit instead, and it has been reported that this may have impeded the action of oil-degrading bacteria. The long-term effects of this event to the Gulf of Mexico are still under debate.[25]

Deep-sea mining: Metal-rich crusts and polymetallic nodules on the ocean floor have become a recent target for the mining industry. These metal-rich areas play host to unique microorganisms, which are thought to contribute to the very formation of the crusts and nodules on which they live.[26] Deep-sea mining activities will disrupt these ecosystems by directly displacing microbes and altering the vital ecosystem functions they carry out. For example, deposited sediment from mining may restrict the growth of bacteria, which are a key food source for marine organisms (e.g. worms).[27] Since some mine claim areas are extremely large (75,000 sq. km), deep-sea mining will have wide-ranging ecological impacts.

The Managing Impacts of Deep-Sea Resource Exploitation (MIDAS) research programme developed recommendations for the mining industry to help reduce the environmental impact of deep-sea activities.[28] The programme indicated that more research is needed to understand the long-term disturbance effects on sea floor microbiomes.

What are the potential uses of marine microbes?

Marine microbes are a rich source of industrially relevant products that may also hold the key to addressing climate change and pollution. Studying and exploiting these organisms has been historically difficult as the extreme conditions they require to survive are hard to replicate in a laboratory. However, recent advances in automation and DNA sequencing technology are opening up opportunities to harness the potential of these unique organisms.

1. Tackling pollution

Ocean plastic pollution is an increasingly devastating crisis; however, bacteria-based solutions may be around the corner. Bacteria that grow and feed on plastics may be used in a controlled way to break down and remove plastic pollution on a large scale.[29] Researchers are also investigating marine microbes as a source of new sustainable bioplastics.[30] The idea of 'microbial upcycling' is an emerging vision, in which engineered bacteria convert non-biodegradable plastics into biodegradable products. If the costs associated with these processes can be reduced, marine microbes may be part of a sustainable solution to future plastic use and recycling.

Microbes already play a vital role in oil clean-up strategies (see above). They also have the potential to break down other environmental pollutants, such as bromine-containing pesticides and flame retardants.[31]

2. Combating climate change

Scientists are also exploring how microorganisms might tackle the causes and effects of climate change. Deep-ocean microbes have been estimated to capture enormous amounts of CO_2 (1 billion tons annually).[32] Researchers are looking at ways of using bacteria to convert CO_2 to the mineral calcium carbonate, for example through the CO2SOLSTOCK project.[33] An alternative approach involves adding iron to the ocean to promote algal growth, which consumes CO_2.[34] However, the practicality of this method is uncertain as it will also remove oxygen from the interior of the ocean, leading to negative impacts.

Microbes could also be applied to make coral reefs more resilient to disease and to increasing ocean temperature and acidity.[35] Potential approaches include 'inoculating' corals with specific microbes and transplanting different and healthy species of coral (which contain different microbes) into unhealthy reefs.[36]

3. Biotechnology

Marine microbes have adapted to survive in extreme conditions, meaning they have incredibly diverse genes. This genetic material (DNA) could be exploited to lead to the discovery of products with high economic value.[37] Marine microbes could produce new biofuels,[38] enzymes, foods, medicines and cosmetics.[39] The international PharmaSea project, for example, searched microbes in deep-sea trenches for new antibiotics, identifying two drug leads from over 1000 different strains of bacteria.[40]

Marine biotechnology research presents a powerful opportunity for the UK bioeconomy. A 2016 Commonwealth report estimated the global marine biotechnology market to be worth US$6.7–29 billion.[41] In addition, a recent analysis found that 84% of patents related to marine genetic resources were registered by companies (12% registered by universities), further highlighting their economic potential.[42] However, future international regulations may change how microbes beyond UK waters are used in research and development (**Box 4**).

The UK is home to many experienced research facilities such as the Scottish Association for Marine Science (SAMS), the National Oceanography Centre (NOC), Plymouth Marine Laboratory (PML), the Lyell Centre for Earth and Marine Science and Technology (Heriot-Watt University), the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) and the Marine Biological Association (MBA).[43] This strong marine science base will play a crucial role in determining the benefits we receive from protecting and utilizing marine microorganisms.

Box 4: Resources in the high seas

Unlike for ocean mineral deposits, there are no international rules on access to genetic material (e.g. bacterial DNA) in Areas Beyond Natural Jurisdiction (ABNJ). An agreement is currently in development under the UN Convention on the Law of the Sea (UNCLOS) for the conservation and sustainable use of ocean biodiversity.[44]

Such an agreement could open up opportunities including shared training and technology transfer, as well as enhanced information-sharing systems. However, additional support is needed for basic science and to standardize data collection.[45]

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The Society *for* Applied Microbiology (S*f*AM) is the oldest microbiology society in the UK, representing a global scientific community that is passionate about the application of microbiology for the benefit of the public. Our members work to address issues involving the environment, human and animal health, food production and industry.

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