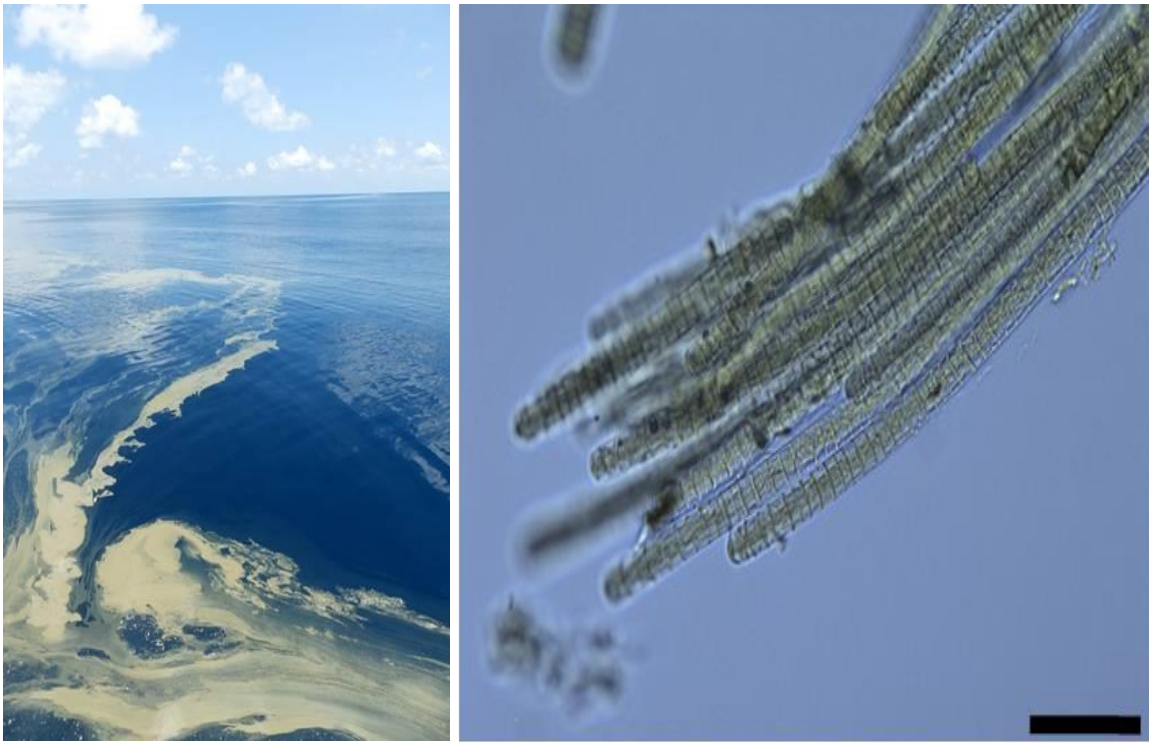
Neuston: microbial life where the sea meets the sky

We love to float on the water at the seaside: do other organisms also like it?



Slicks on the surface of the Pacific Ocean (left image) caused by dense microbial communities dominated by the cyanobacterium *Trichodesmium* (right image). These surface slicks caused by enhanced microbial life and their activities modify the properties of the ocean surface enough to impact global-scale processes.

Michael Cunliffe

Marine Biological Association and School of Biological and Marine Sciences, University of Plymouth, UK

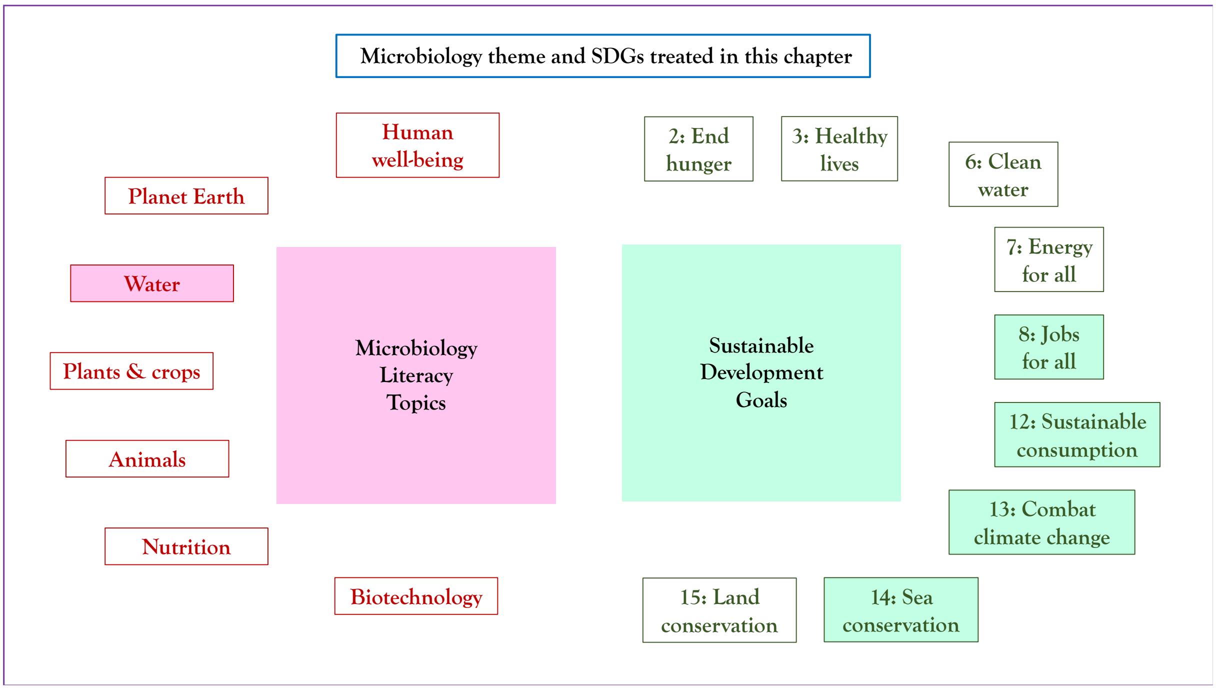
Microbial life where the sea meets the sky

Storyline

The thin surface layer of the ocean in contact with the atmosphere is a unique ecosystem that is distinct from the underlying water column and is often called the sea surface microlayer. Organisms in the sea surface microlayer are called neuston instead of the plankton that live in the water column below. Microbial life, including bacteria and microbial eukaryotes, thrives in the surface layer. These neustonic organisms shape the properties of the surface layer through their activity and have important impacts on a range of processes that influence the wider biosphere including humans.

The Microbiology and Societal Context

The microbiology: ocean microbiome, life at interfaces, microbial interactions, biogeochemistry, microbes in earth system processes. *Sustainability issues:* Conserve and sustainably use the oceans, seas and marine resources for sustainable development, action to combat climate change and its impacts.



Neuston: the Microbiology

1. ***The ocean contains many different habitats.*** When we look at the sea, we usually think of the water above the seabed as a single environment that is home to fish and other sea creatures. But instead of there being just two environments, there are in fact many distinct ones. In addition to the water body itself, called the water column, and the seabed sediment, there are many interfaces – contact points between the seawater and other distinct media – which constitute unique environments having special properties. These include the interface between the lower water column and seabed surface, and interfaces between water and sea animals and plants, between water and sea ice, water and shoreline rocks, and so on. One such special interface is between the upper water column and air: the *neuston*.

2. ***The microlayer habitat.*** Most of our planet's surface is marine, approximately 70% of the surface area, and wherever seawater is not frozen there will be surface microlayer habitat, from coastal waters to the open ocean and from polar (when not frozen) regions to the tropics.

We can generally consider that the surface microlayer is within the top 1mm of the ocean. However, microlayer depth is often operationally defined by the method used to sample the layer (see further below). A common feature of marine microlayers is that they are enriched with gelatinous polysaccharide-containing material, including transparent exopolymer particles (TEP), relative to underlying water that give the surface layer gel-like properties.

3. ***Bacteria in the microlayer.*** Bacteria that live in the surface microlayer are referred to as bacterioneuston to mark their distinction from bacterioplankton in the underlying water column. Assessments of the diversity of bacterioneuston communities has shown that they have different community structures than bacterioplankton in underlying water. But, so far, no unique bacterial species have been found in the marine surface microlayer, suggesting that they are recruited from the water column.

Bacterioneuston have different functional roles, yet at present these still remain poorly understood and warrant future research. Some groups of bacterioneuston species are known polysaccharide-degraders and are likely involved in controlling the gel-like properties of the neuston. Other groups are involved in processing gases that pass through the microlayer, such as methanotrophs that use methane as a growth substrate.

Methane is produced in and released from anoxic – low oxygen – sediments on the sea floor and rises to the sea surface where it is released to the atmosphere. Methane is of course a powerful greenhouse gas. But on the journey of methane to the surface, it is continuously metabolised by methanotrophic microbes – the aquatic methane biofilter – which thereby reduce the amount released to the atmosphere. The methanotrophs of the neuston are the final layer of the aquatic methane biofilter.

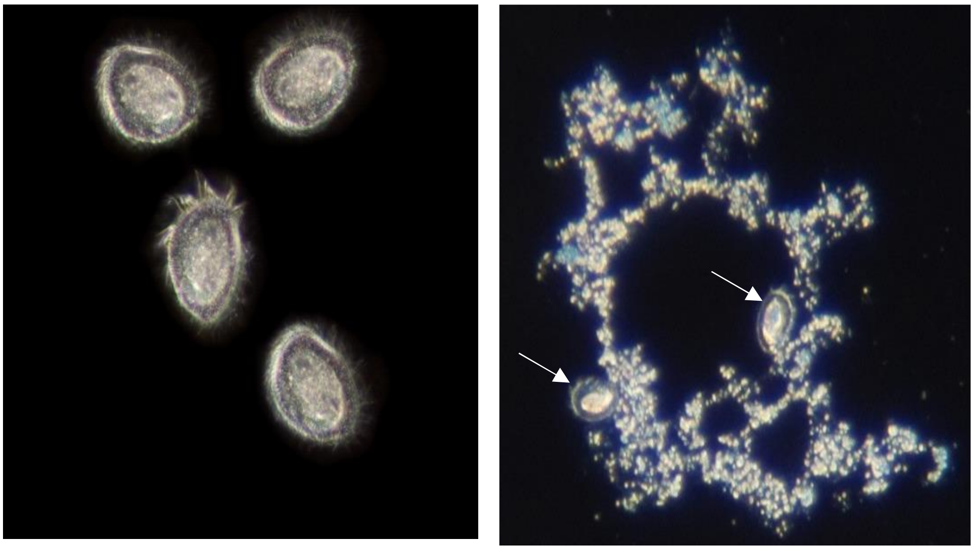
Importantly, bacterioneuston communities in locations that are distantly separated from each other are more like each other than the bacterioplankton communities just below the surface. This similarity in microlayer communities suggests that specific ecological processes are controlling the selection of the specific communities and that their formation is not random. These community structuring processes could include microlayer-specific selective grazing by protists (discussed further below) or response to environmental factors such exposure to high ultraviolet (UV) light from the sun.

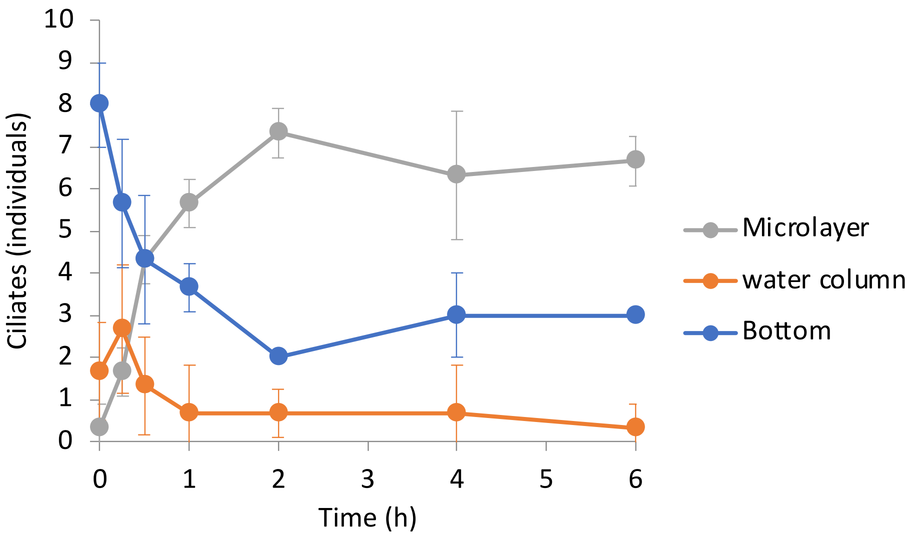
4. ***Microbial eukaryotes (protists) and fungi in the microlayer.*** Microbial eukaryotes (protists) and fungi – "higher (= more complex) forms of life than bacteria and archaea - also

inhabit the sea surface microlayer, including photosynthetic microbes and protist predators that graze on other protists and bacteria.

Phytoneuston are microbial single cell algae that are found in the sea surface microlayer. As with bacterioneuston, the community structure of phytoneuston in the microlayer can be different to phytoplankton communities in the underlying water column.

There are other types of microbial eukaryotes in the marine environment that are predators of other microbes. These microbial predators have important roles in regulating the abundance of their prey through grazing, and form links in the marine food web from microbial groups to higher trophic levels that ultimately lead to fish and other marine animals. Again, the communities of microbial predator protists in the microlayer can also be different to those in the underlying water column.



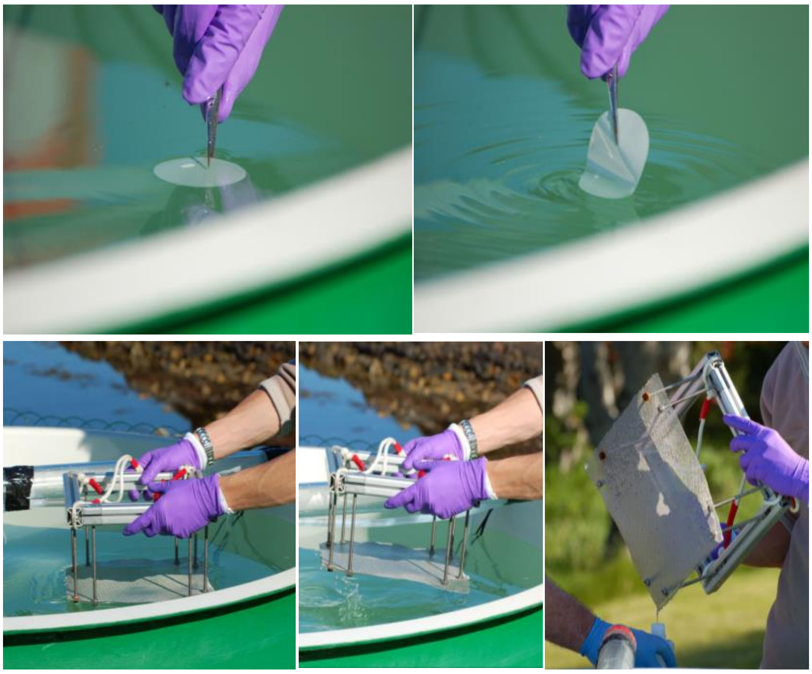


A microbial eukaryote called a ciliate that was isolated from the coastal sea surface microlayer near Plymouth (UK). The ciliate is a predator and grazes on other microbes living on the gel particles in the microlayer (left image). In an experiment, we added 10 ciliates to a petri dish containing seawater. Initially, when first added to the petri dish most ciliates crawl on the bottom of the dish, however after a few hours, most ciliates are in the neuston where they stay.

5. ***Sampling microbial life in the microlayer***. A variety of approaches are available for sampling the sea surface microlayer. Simpler approaches use hand-held tools to collect microlayer

samplers, such as glass plates, mesh screens and membranes. Some sampling devices, such as glass plates and mesh screens, are placed in the seawater below the microlayer and then lifted out of the sea through the microlayer. As the sampler passes through the microlayer the microlayer water is collected on the sampling device. The microlayer sample is then transferred from the device to a sampling bottle for further analysis.

Membrane samplers are carefully placed on the surface and when removed lift off the underlying microlayer. Different sampling techniques sample the microlayer at different depths. For example, mesh screen samplers collect a microlayer sampling depth of approximately 400 µm (0.4 mm), conversely membrane samplers collect microlayer samples of approximately 40 µm (0.04 mm). At the microbial scale, these differences in sampling depth are large and should be considered in microlayer studies.



Membrane (top images) and mesh screen (bottom images) sea surface microlayer samplers.

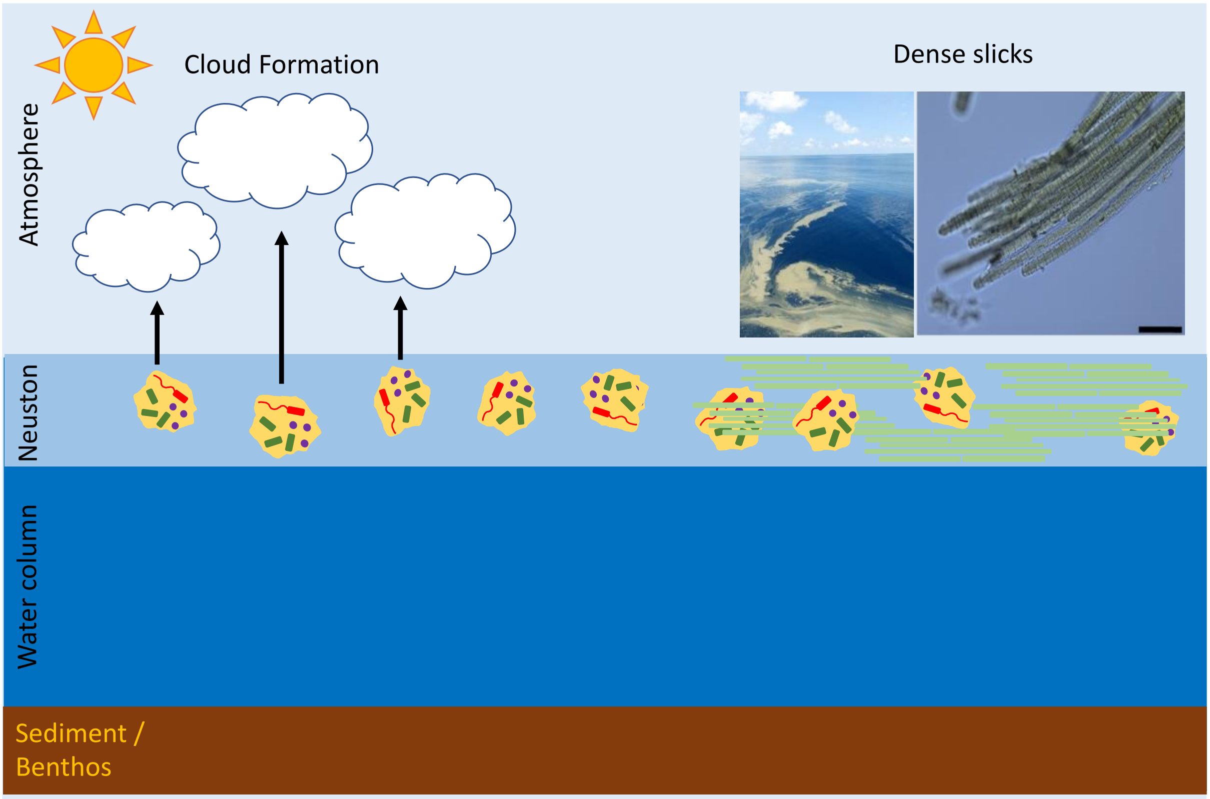
When we go swimming in the sea, we are constantly dipping in and out of the neuston, and its microbial life, and picking it up on our bodies. But it does us no harm and, because our bodies represent a very different environment from the neuston, the microbes we pick up do not grow and establish themselves on our body surfaces. They are just temporary guests!

6. ***Role of microlayers in modification of the surface ocean and cloud formation.*** Microbial life in the sea surface microlayer is interlinked to the chemical composition of the microlayer because microorganisms produce and modify a range of different chemical compounds. Their impact on the chemical composition of the microlayer, such as through the production of surfactants which act like soap, can have a subsequent effect on its physical properties, such as foam production.

When microbial communities in the surface microlayer become dense, they form surface slicks because of the increased organic matter that they are producing. Research conducted on microlayers in the Pacific Ocean has shown that surface slicks formed that are dominated by the cyanobacterium *Trichodesmium* can modify the chemical and physical properties of the sea surface microlayer including changing temperature and salinity compared to non-slick microlayers.

Temperature and salinity of the sea surface are important in global scale processes such as the water cycle.

The organic material produced and modified by microorganisms in the microlayer can be transported from the ocean surface to the atmosphere by wave breaking and bubble bursting. This microlayer material can contribute to the production of clouds by acting as cloud condensation nuclei and ice nucleating particles in polar regions.



Cartoon showing two major functional roles of microbial life in the neuston; production of clouds from organic particles (yellow shapes with attached bacterioneuston) transported from the neuston (left) and enriched slicks (right) that modify the physical and chemical properties of the microlayer, including by the cyanobacterium *Trichodesmium.*

7. ***All surface water bodies have a neuston.*** Neustons are also found in freshwater ecosystems. In fact, the term neuston was first proposed by a freshwater (non-marine) scientist from Sweden at the beginning of the previous century. Compared to marine neuston microbial life, freshwater neuston microbial life is much less studied and therefore we know less about it. The freshwater neuston-specific bacterium called *Nevskia ramose* forms flat rosettes on the surface of shallow freshwater habitats and likely does so as an adaption for living at the interface.

8. ***What can perturb the neuston?*** As with many marine ecosystems, the neuston is vulnerable to pollution. Marine microplastic particles are often found in the surface layer because many plastics float and become enriched there. Microplastics in the marine environment are readily colonised by microorganisms, such as bacteria, so therefore represent a new niche for marine neuston life. The neuston is also perturbed by oil pollution because some of the hydrocarbons in petroleum oil are lighter than water and thus float on the surface, forming the characteristic oil slicks.

Relevance for Sustainable Development Goals and Grand Challenges

- **Goal 8. Decent work for all**. Coastal waters provide important commercial opportunities and employment for many people, including those associated with beach holidays and tourism. A number of seawater surface manifestations, including surface foam, blooms of surface algae, and oil pollution, and the neuston microbes involved, can diminish the attractivity of beach activities and the income and employment associated with such activities.
- **Goal 12. Reduce pollutant release into the environment.** Oil pollution is a chronic problem of marine systems resulting from deliberate and accidental release of oil from commercial and recreational vessels. Lighter oil fractions float on the surface forming visible slicks. Some of the hydrocarbons eventually evaporate or are degraded by neuston microbes, but while in the neuston they perturb both its microbes and their vital functions.
- **Goal 13. Reduce greenhouse gas emissions.** Ocean sediments and subsurface are sources of the powerful greenhouse gas methane. Methane released from the ocean bed rises to the surface to be released into the atmosphere where it causes global warming. During its passage from the bottom to the surface of the sea, methane encounters methanotrophic microbes that capture it and use it as food, thereby reducing the amount eventually escaping to the atmosphere: this is the methanotroph methane biofilter. The neuston also contains methanotrophs and is the uppermost part of the filter, so any perturbation of its activity, e.g. by pollution, reduces its activity and allows more methane to escape to the atmosphere.
- **Goal 14. Reduce pollution of marine systems by toxic chemicals/agricultural nutrients/wastes like plastics.** As indicated above, oil pollution perturbs the neuston. Nitrogen and phosphate fertiliser run-off from coastal farms promote blooms of surface microalgae which also alter the neuston in a major way. And some plastics and especially microplastics float on water and perturb the neuston and its activities.

Pupil Participation

1. *Class discussions of the neuston*

a. When we swim, we swim in the neuston and come out of the water covered in neuston microbiota, as well as microbes from the water column. Should this bother us?

b. We talk above about the ocean neuston. Freshwater ponds and lakes also have a neuston. Will they be similar or different from the sea neuston? If so, why?

c. Do fast-flowing rivers have a neuston? If so, how might it differ from the neustons of calm waters, and why?

d. How might the neuston influence climate?

2. *Exercises*

a. Think about how large the surface of the ocean is. How many bacteria do you think are living in the global ocean neuston microbiome?

b. Do you think we could modify the neuston to improve its role in combating climate change? What type of microorganisms could we add and what would their effect be? What wider impacts might this have?

c. Looking at the SDGs, how important is it to conserve marine microbial life, including in the neuston? How much should we care about marine microbes?

d. What types of experiments could you design to study microbial life living in microlayers?

The Evidence Base, Further Reading and Teaching Aids

General video on marine microbiomes:
https://www.youtube.com/watch?v=xOQoWcMbbOI

Video on *Trichodesmium* from cruise to study sea surface microlayer:
https://www.youtube.com/watch?v=wPkDWiha-bA

The microlayer habitat
Engel A et al (2017) The ocean's vital skin: Toward an integrated understanding of the sea surface microlayer. *Frontiers in Marine Science* 165.
Cunliffe M et al (2013) Sea surface microlayers: a unified physicochemical and biological view of the air-ocean interface. *Progress in Oceanography* 109: 104-116.
Cunliffe M, Upstill-Goddard RC & Murrell JC (2011) Microbiology of aquatic surface microlayers. *FEMS Microbiology Reviews* 35: 233-246.

Bacteria in the microlayer
Zäncker B, Cunliffe M & Engel A (2018) Bacterial community composition in the sea surface microlayer off the Peruvian coast. *Frontiers in Microbiology* 9: 2699.
Cunliffe M et al (2009). Comparison of bacterioneuston and bacterioplankton dynamics during a phytoplankton bloom in a fjord mesocosm. *Applied and Environmental Microbiology* 75: 7173-7181.
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Microbial eukaryotes (protists) and fungi in the microlayer
Zäncker B, Cunliffe M & Engel A (2021) Eukaryotic community composition in the sea surface microlayer across an east–west transect in the Mediterranean Sea. *Biogeosciences* 18: 2107-2118.
Taylor JD & Cunliffe M (2014) High-throughput sequencing reveals neustonic and planktonic microbial eukaryote diversity in coastal waters. *Journal of Phycology* 50: 960-965.
Cunliffe M & Murrell JC (2010) Eukarya 18S rRNA gene diversity in the sea surface microlayer: implications for the structure of the neustonic microbial loop. *ISME J* 4: 455-458.

Sampling the sea surface microlayer
Cunliffe M & Wurl O (2014) *Guide to Best Practices to Study the Ocean's Surface*. Plymouth, Occasional publications of the Marine Biological Association of the United Kingdom. https://plymsea.ac.uk/id/eprint/6523/
Cunliffe M et al (2009) Comparison and validation of sampling strategies for the molecular microbial analysis of surface microlayers. *Aquatic Microbial Ecology* 57: 69-77.

Microlayers, modification of surface ocean and cloud formation
Wurl et al (2018) Warming and inhibition of salinization at the ocean's surface by cyanobacteria. *Geophysical Research Letters* 45: 4230-4237.
Wilson T et al (2015) A marine biogenic source of atmospheric ice-nucleating particles. *Nature* 525: 234-238.

Quinn P & Bates T (2011) The case against climate regulation via oceanic phytoplankton sulphur emissions. *Nature* 480: 51-56.

Glossary

Biosphere – the areas of our planet where life exists.
Cloud condensation nuclei – also called 'cloud seeds', small particles around which water vapour condenses and clouds form.
Cyanobacterium – single for Cyanobacteria, a major group of bacteria that are photosynthetic and abundant in the oceans.
Ecosystem - communities of interacting organisms and their environment.
Ice nucleating particles – like cloud condensation nuclei, small particles around which ice crystals form.
Microbial eukaryotes (protists) - ubiquitous, generally single-celled organisms with diverse life strategies (e.g. photosynthetic, predators).
Neuston – organisms that live in surface microlayers.
Plankton – organisms that float in water column that are unable to swim against currents.
Salinity – the concentration of salt. On average, seawater contains 35 grams of salt in one litre.
Surfactants – chemical compounds that decrease the surface tension.
Transparent exopolymer particles – gel-like particles made of complex sugars (polysaccharides) and produced by different microbial groups, including algae.
Trichodesmium – an important cyanobacterium in the oceans.
Water cycle – the movement via a range of processes of water from the ocean, to the atmosphere and then on land, before returning to the ocean.