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Microplastics in blue mussels

Natural environments worldwide are polluted with plastics, as often clearly visible on beaches, along hiking paths or floating on water surfaces. However, not only the big, visible plastics are a problem. Tiny pieces of plastics are spreading in the environment: so-called microplastics, which are only a few millimetres or less in size. They have been detected virtually wherever we look for them: in oceans, rivers, lakes, in soil and in the air. Also many animals in the ocean were found to have microplastics in their bodies. One of them is the blue mussel, which is a widespread inhabitant along Denmark's coasts and which is used as seafood. In my PhD, I was able to show that not only adult mussels take up microplastics, but also their earliest life stages: the larvae. I found that microplastic uptake even has the potential to harm the development of blue mussel larvae. This gives rise to concern since blue mussels are a key species for the ecosystems of our coasts. They filter and thereby clean the surrounding water, they build colonies that protect and stabilise the coast, and they are prey to many species. Still, our understanding of how microplastics affect blue mussels, and more generally marine animals, in their natural environment is very limited.

So what is known about the effects of microplastics on animals? Before we can look at effects, we first need to understand how animals come into contact with microplastics. Mostly this is via particle uptake. Due to their small size, microplastics can be taken up by many different species. This includes some of the smallest animals at the basis of aquatic food webs, like plankton, as well as predators like fish. More than 220 species have been found to take up plastics in their natural environment – a clear sign of the widespread, global plastic pollution. Animals often take up microplastics passively together with their normal food or water. In some cases, they do, however, actively feed on plastic particles because they mistake them for food. In the laboratory, we make experiments to understand how animals handle microplastics in their environment, how much of the particles they take up, which factors determine this and how well animals are able to excrete them again. These questions are not trivial to answer because microplastics are a very diverse group. "Microplastics" is an umbrella term for all pieces of plastics that are smaller than 5 mm. This means that it covers particles that are very different in size, they can have different shapes (spheres, irregular fragments, fibres, films), they are made of different polymers (the main material), they can additionally include a variety of different chemicals, and they have different colours and textures. Research has shown that all these properties can influence whether and to what extent an animal takes up microplastics. In my PhD, I studied uptake of microplastics in blue mussel adults and larvae, though my main interest was in the larvae since it was not known whether and to what extend they take up plastic particles. The larvae live as free-swimming plankton in the water and are extremely important for keeping mussel colonies alive and growing. At the same time, they stand at the basis of the food web in the ocean and are prey to many species. If microplastics enter the food web at this basic level, they have the potential to affect a large number of organisms. This can also be of relevance for the production and consumption of seafood.

In my experiments, I found that blue mussel larvae took up significantly more microplastics in the size range of their normal food in comparison to smaller microplastics. This can be explained by different mechanisms by which big and small particles are taken up. When the plastic particles have a similar size as the food, the animals can actively feed on them by filtering the particles out of the water. In contrast, the smaller particles cannot actively be caught and are rather taken up passively together with water. The larvae showed the ability to excrete the particles again and this process was similar for both tested particle sizes. However, I observed that the time that microplastics stayed in their bodies (from uptake to excretion) was longer than it usually is for their food. This increases the chance that microplastics are passed on to other animals, which feed on mussel larvae.
A decisive factor for the amount of microplastics in the animals' body was also the concentration of microplastics in the water. Generally, there is the tendency to find more plastic particles in an animal, the more plastics is in the surrounding water. However, for the blue mussel larvae that I worked with, this was not proportional. This means that it is not necessarily possible to predict the amount of microplastics in an animal based on the concentration in the surrounding water.
Other researchers have shown that particle shape also matters for uptake and excretion. For instance, an experiment with shrimp showed that the animals took up more irregular fragments in comparison to spheres or fibres. Another study with planktonic animals (water fleas) found that fragments were excreted slower than spheres. Altogether, this means that we need to take many different factors into account when trying to understand how much microplastics different animals take up and subsequently how this may affect them.

An increasing number of studies show that microplastics, once taken up by animals, can negatively affect them in a variety of ways. This includes effects on different biological levels, spanning from cells to tissues and organs, up to whole organisms and even populations. For adult blue mussels, other researchers have for instance observed lower feeding rates in the presence of microplastics. With my studies, I was able to show for the first time that also blue mussel larvae can be negatively affected by microplastics. During two weeks of exposure, the larvae increasingly showed problems in their development; for instance, the shell did not form correctly. This could have implications for the successful settling and development of larvae into adult mussels. The observed effect on development was stronger for higher concentrations of microplastics in the water and if the particles were smaller. Also other studies have observed stronger effects with smaller plastic particles. This leads to the notion that smaller microplastics are more hazardous to organisms.

The extent to which microplastics can affect animals is clearly worrying. However, to date it remains unclear to what degree the effects that have been observed in laboratory studies are translatable to the field. The reason for this is that the conditions in laboratory tests are not very comparable to natural ecosystems. With regards to microplastics this especially refers to particle concentrations and particle types. Laboratory studies have been criticised for using unrealistically high concentrations of microplastics. This is problematic and needs to be improved. However, a current challenge is that it is not yet possible to quantify the smallest fraction of microplastics in environmental samples. This is though exactly the fraction that is most relevant for many animals and that is suspected to be most hazardous. Many studies

work with these sizes but have no realistic concentrations to base their work on. Methods for measuring microplastics are developing and improving quickly. Therefore, we can expect to know much more about realistic conditions in the near future.
The second important aspect is the type of microplastics that is used in laboratory studies in comparison to what has been found in the field. There is a clear discrepancy since the former mostly use spherical beads, while fragments and fibres constitute the majority of microplastics in the environment. Additionally, microplastics quickly become colonized by microorganisms (creating a so-called biofilm) and start degrading once they are in the environment. This changes their properties and makes them less comparable to the clean, new plastics that are usually used in experiments. As pointed out above, the properties of the particles influence the way in which animals interact with them. Therefore, it is important that test particles become more representative of "naturally occurring" microplastics. However, this also brings some new challenges because it means that we need to work with a great variety of particles, differing in many properties. This makes it very difficult to compare the results of different studies. Already now such comparisons are challenging or even impossible because there is little consensus on how microplastic experiments should be done. Therefore, some researchers prefer the use of standardised plastic particles and work towards more standardised and controlled experiments. This appears to be a counter movement to increasing the environmental realism of microplastic experiments, which generally promote less control and standardisation. However, controlled laboratory studies and more environmentally realistic studies both have their values and should be seen as complementary since they answer different questions. We should not only go one way, but improve both.

Even though microplastic pollution has gained enormous attention not only in research but also in society and in politics in recent years, the research field is still relatively young. Therefore, there is a constant need for improvement and development. Our knowledge on the effects of microplastics on organisms and ecosystems is continuously increasing but there are still many questions to be answered. Both on the side of evaluating effects of microplastics on organisms and ecosystems, as well as on the side of determining composition and distribution of microplastics in the environment there are substantial knowledge gaps and uncertainties. Therefore, it can be concluded that it is not yet possible to determine to what degree microplastics are a threat to the environment. These uncertainties need to be acknowledged but should not prevent active support in developing effective policies and measures to reduce plastic pollution. The fact that even species at the very basis of marine food webs, like the blue mussel, contain microplastics in their body and may be negatively affected, is worrying. Furthermore, it is clear that once released to the environment, microplastics will persist for long periods of time – depending on the conditions this could be hundreds of years – and there are no practical means to remove them. In recent years, this topic has received enormous attention in the public and political initiatives are developing quickly. At the same time, we still need more and better research to understand to what degree microplastics pose a threat to ecosystems since this is not yet possible to answer based on current knowledge.