Symbioses - effective communities of unequal partners

The interaction that can occur between two different types of species comes in different forms, ranging from relationships that can be beneficial for both or just one of the partners, or that can cause damage and in extreme cases lead to the death of one of the partners. Some symbiotic relationships between plants and microbes, for example, have economic uses while others can be used for analyses or as models for industrial applications.

The term symbiosis was defined by the German biologist and mycologist Heinrich Anton de Bary in 1887 as "the living together of unlike organisms". This relatively non-contentious definition did not mention anything about the harm-benefit ratio of the organisms involved. Subsequent research into symbiotic interactions has revealed that biological species can become involved in different types of symbiotic interactions. A mutualistic relationship is the win-win type of symbiosis in which both organisms benefit from the interaction. In addition to the many and varied cleaning and protection symbioses in the animal world, pollination is one of the most well known and ecologically important mutualistic relationships. The plant benefits from the relationship by having its pollen transferred to another plant, and the pollinator, which is usually an insect or bird, receives food in the form or pollen and nectar. Seed distribution is another type of mutualistic relationship: plant seeds are distributed by animals in exchange for food in the form of fruit and seeds. The seeds (e.g. burrs) can be spread by clinging to the animals' coat or by way of the animals' excretions that contain undigested seeds.

Mycorrhiza – a well-known type of symbiosis

Thanks to its mycorrhizal partner, the chlorophyll-deficient Bird's nest orchid (Neottia) can still live in dark forests. Source: BerndH / Wikimedia Commons | CC BY-SA 3.0 / https://commons.wikimedia.org/wiki/File:Neottia_nidus-avis_plants.jpg

Orchids are true multi-talents as far as mutualistic relationships are concerned – they can undergo highly specialized pollination symbioses as well as forming "mycorrhizas" with fungi. The term mycorrhiza comes from the Greek and means "fungus root". Orchids live in endotrophic mycorrhizal associations where the fungus lives inside the plants' roots. The fungus benefits from the association by being able to use the plants' assimilates for its metabolism while the orchids gain access to minerals and nutrients that are taken up from the soil by the mycorrhizal fungi. However, the associations between orchids and fungi are not always mutually beneficial: chlorophyll-deficient orchids such as Bird's-nest orchids (Neottia) are parasitic plants that depend on their mycorrhizal fungus throughout their entire life (mycotrophic). This type of interaction is also referred to as antagonistic symbiosis as it is the plant that benefits from the association rather than both partners benefiting equally. Mycorrhizas are very common in Central Europe; around three-quarters of all Central European flowering plants live in mycorrhizal relationships. The BIOPRO article Sebacinales everywhere – fungi that live in special symbioses shows how common symbioses involving Sebacinales fungi are.

Central European forest trees live in obligatory ectotrophic mycorrhizal associations. The fungal hyphae develop on the plants' roots rather than growing inside them. They grow around the plants' roots and penetrate the intercellular spaces between the epidermal and cortical cells where they form what is known as a Hartig net. The hyphal network takes up nutrients and water from the soil, so the plants do not need to grow typical root hairs. Instead the roots of plants living in such ectomycorrhizal associations hardly have any root hairs and become rather thick. The hyphal network can become rather extensive; hyphae from mycorrhizae on one tree can connect with hyphae from mycorrhizae from one or more trees. The fact that a tree like this benefits greatly from co-habiting with mycorrhiza becomes clear when the fungus is absent: the tree no longer grows effectively, is unable to grow as tall as neighbouring trees that live in obligatory mycorrhizal associations and sometimes even dies.

In some mycorrhizal associations, the fungus provides "its" plant with specific chemical compounds, for example growth factors and cytokines that act as phytohormones. Other products of the fungal metabolism are an effective protection against pests. It therefore does not come as a surprise that people are also seeking to benefit from such phenomena. In agriculture, some plant species are grown alongside mycorrhizal fungi in order to achieve better plant growth. Research into the exact molecular and biochemical relationships of mycorrhiza is being carried out in order to obtain detailed insights into improved pest control and the development of resistance in crops.

Smooth transitions make it difficult to accurately define the benefits of symbiotic relationships

Lichens: symbiotic organisms composed of fungi and algae. Living as a symbiont in a lichen enables the fungus to derive essential nutrients. The algae possess chlorophyll and can produce glucose, which the fungus needs. In return, the fungus provides the algae with a place to live, protects them against dehydration and enables the algae to live in environments where they would not normally be able to subsist.
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The division of symbioses into mutualistic and antagonistic/parasitic is associated with the problem that there are numerous intermediary forms that are difficult to allocate. The transition from one to the other can be very smooth and/or temporarily different. Let's go back to the example of orchids to explain the difference: in the early development stage, all orchid species are mycotrophic, i.e. depend on the fungus; however, older chlorophyll-containing orchid species no longer live in mycotrophic relationships as they can carry out photosynthesis and generate the necessary organic compounds themselves. In other forms of interactions little is still known about whether and how the partners benefit from each other or are detrimental for each other.

One such example is dinoflagellates, marine unicellular organisms that constitute a large part of marine phytoplankton. Dinoflagellates can take up phototrophic or eukaryotic unicellular organisms and live in endocytobiosis for their entire lives. This type of symbioses, which seems to affect the formation of algal blooms, is currently being investigated by researchers at the University of Stuttgart. The researchers are also focusing on the economic aspects of endocytobioses with the aim of assessing whether endocytobioses might in the future also be applicable to biotechnological uses such as the bioproduction of materials.

Endocytobioses are also key in the endosymbiotic theory according to which cell organelles such as mitochondria and plastids arose as a result of the endocytobiosis of a photosynthetic unicellular prokaryote into a eukaryotic host. The partners lived in a symbiotic relationship that resulted in mutual adaptation and dependence. The article "Symbiogenesis of mitochondria and plastids" provides information about the research being carried out at Universität Heidelberg and EMBL (European Molecular Biology Laboratory).

Economically relevant bacterial symbioses – for better or for worse

The symbiotic association between legumes (peas, beans, clover, etc.) and rhizobia has been studied in great detail and is a classic example of mutualism. These soil bacteria are rather common; they are motile and move forward by using their flagella. Moreover, they are unique in their preference for legumes (Fabaceae). They enter the root hairs of legumes where they initiate the formation of root nodules. Rhizobia require a plant host; they cannot independently fix nitrogen. The partners are only able to fix elementary nitrogen jointly and make it bio-available to either one of them. The bacteria supply ammonia and amino acids to the plant and in return receive organic acids from the plant. The rhizobia-legume symbiosis is also highly advantageous for agriculture as the ability to fix nitrogen enables the legumes to grow well on poor soil. Unlike the nitrogen-fixing symbionts, tumour-producing Agrobacterium and fire blight causing Erwinia bacteria are pathogenic and do not benefit the plant. These interactions are not regarded as typical symbioses, but rather as antagonistic symbioses in which only the bacterial partner benefits and the plant gets damaged or dies.

Bacteria can also enter symbiotic relationships with other bacteria, algae and fungi. Communities of this kind, especially those that lead to the formation of biofilm, have a rather negative effect on human beings. Bacteria that secrete extracellular polymeric substances (EPS) can, for example, form a biofilm on dental implants. Oral biofilms promote tooth decay and gum disease. Biofilms protect the microbial cells within them and facilitate growth. Articles focusing on sediment formation, which is being worked on by researchers from the University of Stuttgart (see also Underground career – bacteria as the builders of sediments), show how the association of different types of microorganisms promotes the formation of EPS. In this case, the formation of EPS is rather beneficial, at least from a human point of view, as EPS contribute to the stabilisation of sediments and the stability of aquatic ecosystems.

Strong together: When fungi form symbiotic relationships with algae

Extreme ecosystems require symbiosis specialists: when algae and fungi join forces to become lichens they are able to inhabit extreme environments (cold areas, nutrient- and water-deficient areas) and derive essential nutrients, something neither algae nor fungi would be able to do on their own. Around 98 per cent of lichens consist of ascomycetes (sac or cap fungi) and around 13,500 fungal species are known to form lichens with algae, in particular green algae, cyanobacteria or both. Lichens produce dyes and acids that only the symbiotic partners together can produce. The diet of reindeer, which are an important economic factor in northern areas of the globe, is 90 per cent lichen. Lichens are also used as food by many different human cultures across the world. In addition, they are useful bioindicators: they are very sensitive to pollutants in the air and in rain and are thus accurate air quality monitors. A high degree of pollution causes the lichens to change colour, and in extreme cases can lead to their death. In Germany, lichen monitoring has been standard practice since 2005 and is carried out according to the VDI regulation 3975.

Dossier

16-Apr-2012
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