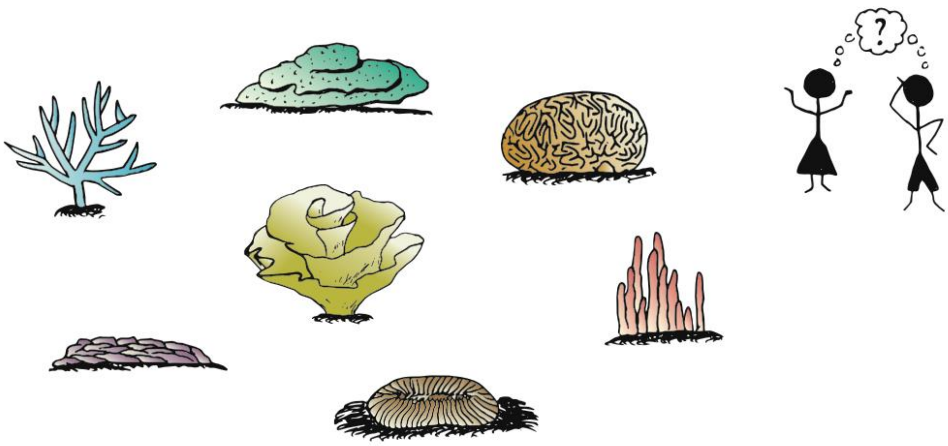
Coral Reefs and their Microbes

Sir: I heard that corals are living creatures, but they just seem like rough rocks to me?



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Coral Reefs

Storyline

Coral reefs are immensely beautiful, complex living structures with enormous ecological and societal importance. By providing habitat and food for a myriad of marine species, coral reefs support an immense biodiversity and are therefore often referred to as "rainforests of the sea". Millions of people worldwide depend on coral reefs for food (fisheries), shoreline protection and livelihoods (tourism). Coral reefs therefore play a major role in delivering the United Nations Sustainable Development Goals (e.g. ending hunger, securing jobs, conserving the oceans).

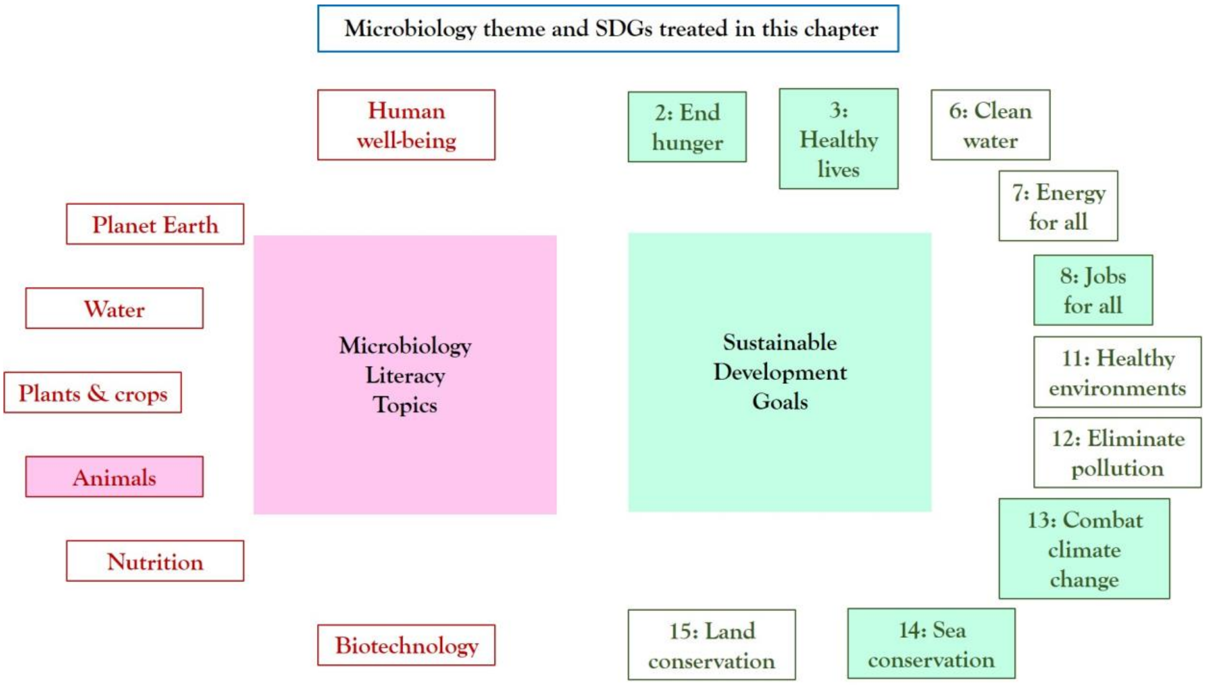
Corals are marine invertebrates related to sea anemones, but which secrete a hard skeleton made of calcium carbonate. It is the accumulation of many corals growing and slowly depositing their skeletons over thousands of years that ultimately forms the large reef structures that are visible from outer space. However, coral growth, reproduction and skeleton generation are processes that require considerable energy. To sustain this demand, the coral animal does not live alone, but instead forms an intimate partnership with various microorganisms. These microbes include very small, single-celled algae that reside within the coral cells, as well as diverse communities of bacteria and viruses. Microorganisms that associate with corals benefit from feeding on the animals' waste products and in return, they perform various essential functions for their host. The small algae use energy from sunlight to synthesize sugars, which are then passed to the coral as its major food source, and bacteria supply their host with essential nutrients and vitamins. Beneficial bacteria can also protect corals from disease-causing microbes by competing for space and food and by producing antimicrobial compounds.

Coral reefs globally are in crisis, being severely threatened by global scale human-induced climate change and other local scale disturbances. The greatest threat to corals is global warming, because the microalgal symbionts are expelled from the coral when seawater temperatures increase just 1-2°C above ambient conditions for a prolonged period or during acute heatwaves. Loss of the microalgal symbionts inevitably leads to coral starvation and death if new symbionts are not regained fast enough. Further, stressors caused by human activities (e.g. climate change, pollution, overfishing) can negatively disrupt the coral-associated bacterial communities which can compromise coral survival. Considering the critical roles microbes play in coral health, assessments of how coral reefs contribute to the Sustainable Development Goals must also consider coral reef microorganisms.

The Microbiology and Societal Context

The microbiology: coral-associated microorganisms; symbiosis; holobiont; microalgae, zooxanthellae; photosynthesis; coral bleaching; bacteria; nutrient-cycling; protection from pathogens; shifts in bacterial community composition; coral disease; microbial manipulation.

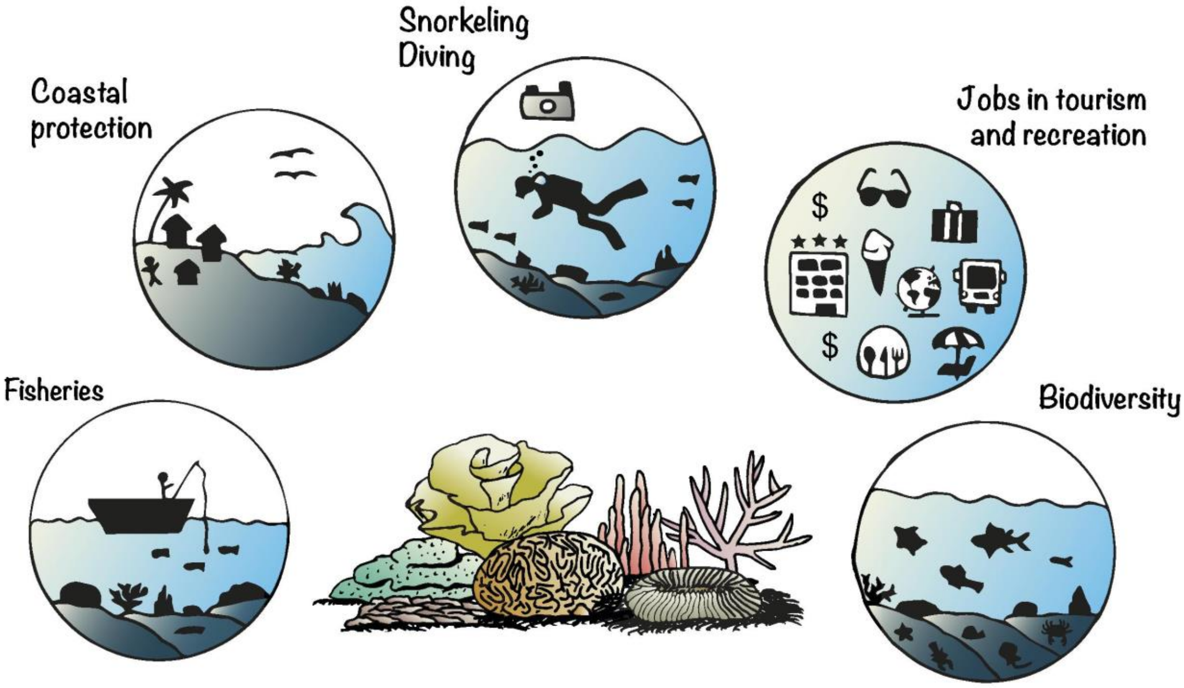
Societal context: services provided by coral reefs; fisheries; economy; global warming; pollution; overfishing; greenhouse gas effects.



Coral Reefs: The Microbiology

1. ***General Importance of Coral Reefs***. Tropical coral reefs occur in 79 countries and cover an area of ~275,000 km^2. In comparison, this area is slightly larger than that of The United Kingdom and represents < 0.1% of the oceans' surface area. However, the ecological, social and economic importance of coral reefs is immense. The estimated value of all goods, services, and livelihoods derived from coral reefs (including tourism, fisheries and protection) exceeds 30 billion US dollars. Reef-associated fisheries are particularly important as they are a primary source of food for an estimated 275 million people worldwide. These reef ecosystems also have deep cultural value and form an important part of national identity. Reef-related tourism contributes ~USD $11.5 billion/year to the global economy. For instance, reefs off southeast Florida support almost 28 million person-days of recreational diving, fishing and viewing activities, translating into USD $4.4 billion in local sales, almost USD $2 billion in local income and >70,000 jobs. Another example, the Great Barrier Reef (GBR), which is the world's largest living structure and one of the seven natural wonders of the world (the others are: Mount Everest, Harbor of Rio De Janeiro, Victoria Falls, Paricutin Volcano, Grand Canyon and the Northern Lights). The GBR contributes more than $6 billion a year to Australia's economy and supports an estimated 64,000 jobs. Further, coral reefs provide coastal protection for land resources and human infrastructure, which is particularly important during storms, cyclones and tsunamis. Coastal protection provided by coral reefs is valued at almost $11 billion dollars, which can be considered as a natural alternative to the cost of building seawalls along coasts. Coral reefs also produce large amounts of exploitable sand and rock (derived from skeletons of dead coral), which is of immense value to many coastal communities, especially those living on coral islands with no

alternative sources of these materials. Finally, coral reefs are the largest reservoirs of biodiversity on earth, hosting approximately one-third of all marine biodiversity. While tropical coral reefs are often the primary focus of marine research, scientists have also recently discovered an astonishing abundance of cold- and deep-water coral reefs. The latter are widely distributed across the Earth's oceans, offering habitat to hundreds of species of fishes and invertebrates, including shrimps, crabs and other animals that are commercially important for humans.



2. The Coral Animal. Despite being permanently fixed to the sea floor and their misleading resemblance to rocks or plants, corals are in fact living animals with fascinating characteristics. Hard corals (also known as reef-building corals, or scleractinian corals) form the 3-dimensional structure of the reef by depositing skeletons of calcium carbonate. Their shapes vary from simple and uniform boulders to more intricate structures with column-like features, table-like layers or complex branches. Hard corals have been thriving on the planet for over 200 million years and have diversified into over 1,600 currently recognized species (Figure 1A).

While closely related to jellyfish and sea anemones, most corals are colonial organisms, composed of multiple clonal individuals that are physically connected to one another. These individuals are termed polyps and their size can range from a few millimetres to several centimetres in diameter, depending on the species (Figure 1B). Skeletons protect coral polyps from predators and serve as substrate on which to grow. Coral polyps are composed of different tissue types and possess separate nervous, muscular and reproductive systems.

Coral polyps use their tentacles to capture small animals that swim in the water column and serve as a nutritious food source. Prey is captured using specialised stinging cells (called cnidocytes) that are located on the outer surface of the tentacles. Jellyfish and sea anemones possess the same type of stinging cell which can be painful for humans who inadvertently encounter them. Once prey is captured, it is drawn into the polyp's mouth and digested in the stomach. Waste is then expelled through the same opening as the mouth.

Even though corals possess a sophisticated system for capturing prey, they usually live in waters that are very poor in nutrients. Consequently, the amount of energy that polyps gain by feeding on other organisms (i.e heterotrophic nutrition) is insufficient to supply their needs. Since growing, reproducing, and secreting a skeleton require substantial quantities of energy, hard corals have developed additional ways to obtain food and energy, and this has allowed them to prosper for millions of years in challenging environments.

3. ***Corals are Diverse Holobionts.*** To gain food and energy, most corals form very intimate relationships - symbiosis - with single-celled algae called zooxanthellae. These microalgae live inside the coral cells and give corals their brown colour (Figure 1B, 1C). This symbiosis is crucial to the survival of the coral host, because zooxanthellae (consistent with other algae and plants) are able to absorb energy from the sun and use this energy to produce nutrients, such as sugars (the process of photosynthesis). Nutrients generated by symbiotic microalgae are transferred to the coral host, supplying corals with as much as 90 percent of their energy needs. In turn, zooxanthellae benefit from living in coral cells because they obtain a safe and stable shelter, in addition to having a reliable food source by metabolising some of the waste products secreted by the coral. Since both the coral animal and the microalgae benefit from their association, the symbiosis is mutualistic.

Whilst the relationship between corals and zooxanthellae is the most well-known form of coral symbiosis, corals also form partnerships with bacteria, archaea, fungi and viruses which are all thought to undertake essential roles for the coral animal. Since corals and their microbial partners are highly dependent on each other to survive and function, they have to be considered as a whole and not as separate entities. Hence, the term holobiont is used to describe the grand organism formed by the coral animal, its symbiotic zooxanthellae and the entire suite of microorganisms that interact with them.

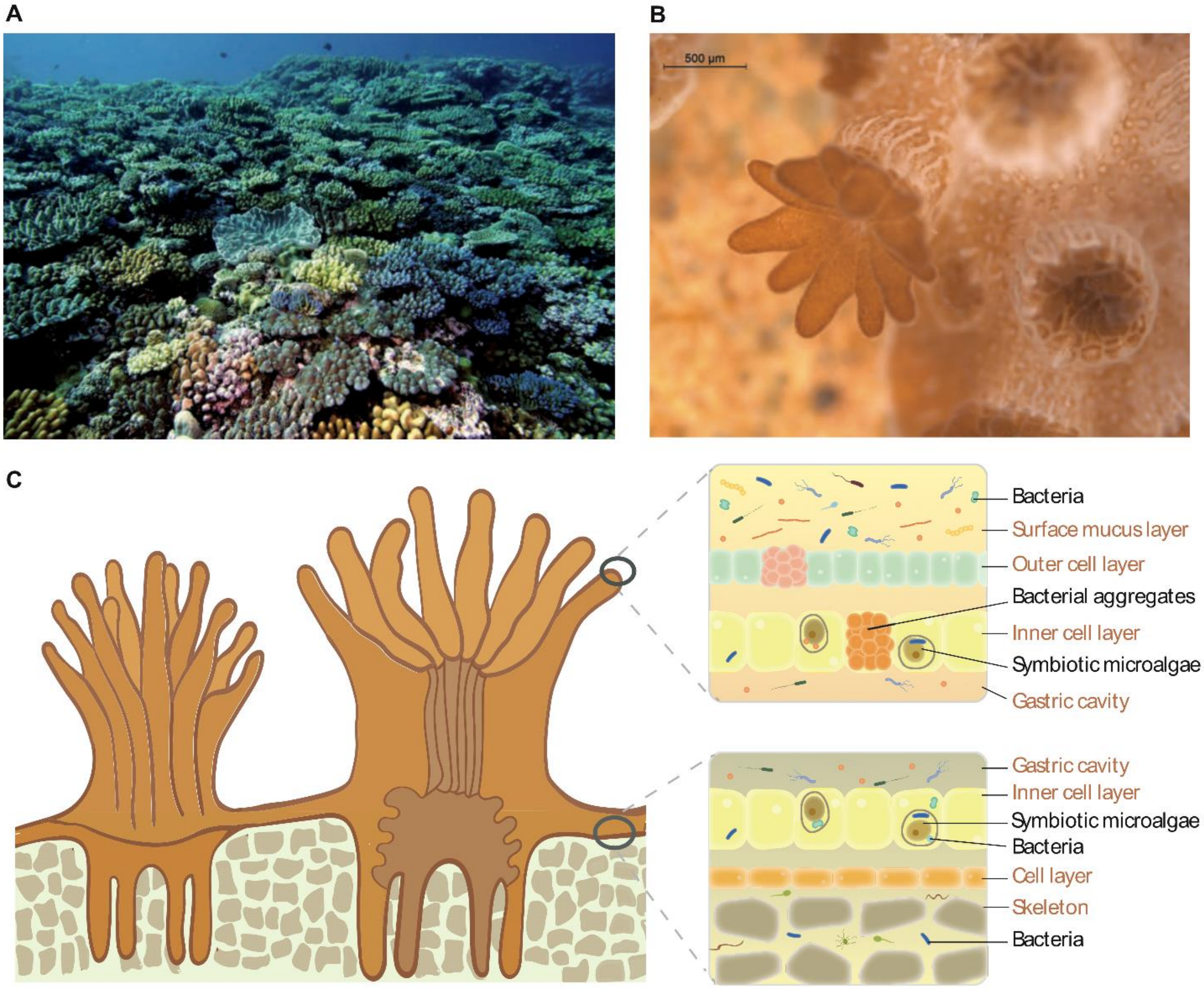
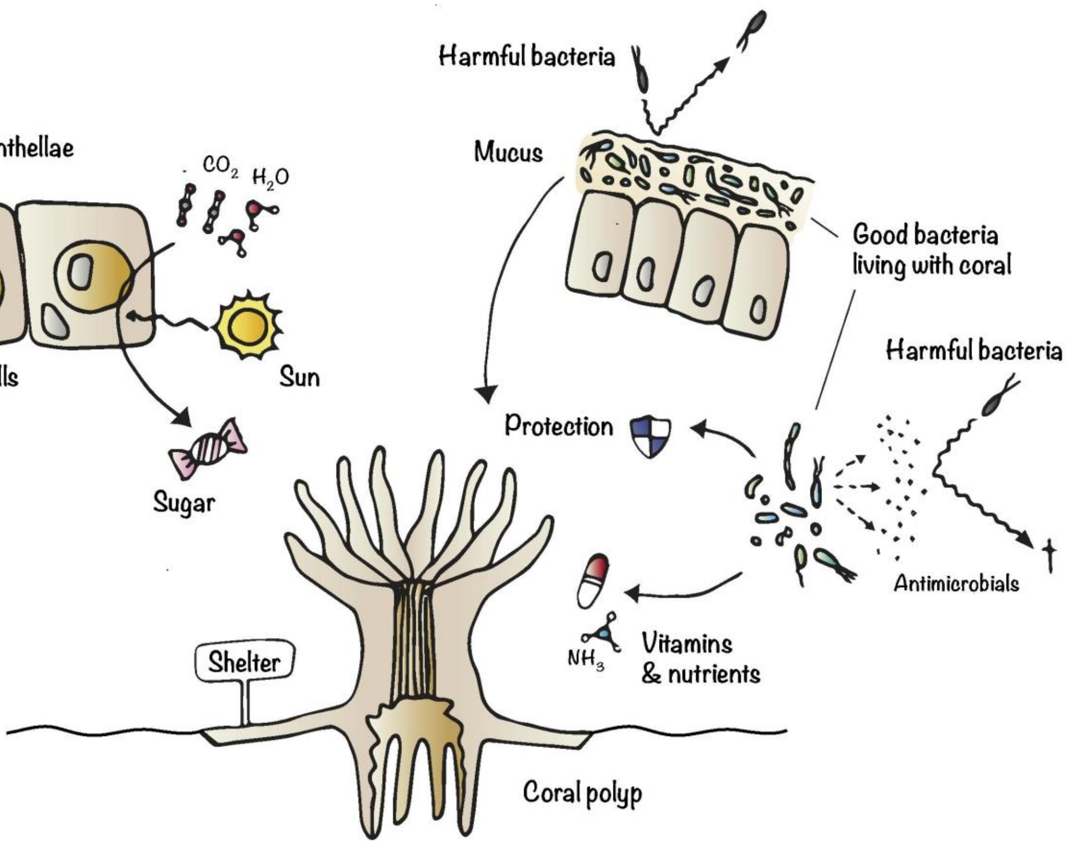


Figure 1. A. Photograph of a healthy reef showing multiple coral colonies of different species and growth forms. Vibrant colours seen on some corals are due to fluorescent proteins which polyps produce themselves. Image courtesy of the Australian Institute of Marine Science, Australia. **B**. Photograph of a 3-month old coral (species Acropora tenuis) showing several polyps that are interconnected by a tissue layer and have started building a skeleton. Zooxanthellae (symbiotic microalgae) inhabit inner tissues and are visible as brown pigments. The polyp on the far left has extended its twelve tentacles to feed, with its mouth situated in the centre. **C**. Schematic of the coral holobiont depicting two polyps on the left with close-ups of their different compartments on the right (identified by brown legends). Microorganisms (black legends) are present within all compartments: bacteria inhabit the outer mucus layer, the gastric cavity, the skeleton and are also present inside coral cells. Symbiotic microalgae are located within inner cell layers. Figure courtesy of Inka Vanwonterghem, adapted from Vanwonterghem and Webster (2020).

4. ***The Importance of Coral-Associated Bacteria.*** Understanding the composition and function of coral-associated bacteria has been the focus of significant research in recent years. It is estimated that corals harbour thousands of different bacterial 'species' across multiple

compartments in their body (Figure 1C). Bacteria are especially abundant in the thin mucus layer that is secreted by coral cells and covers the outer surface of polyps. Bacteria have also been observed inside coral cells (both in the outer tissue layer and in the inner tissue layer where zooxanthellae reside), in the gastric cavity and in the skeleton (Figure 1C). Similar to humans who possess different bacterial communities in their gut, their skin and their mouths, coral-associated bacteria are generally specific to individual host compartments, where they undertake specialised functions that match their physical niche.

For instance, bacteria present in the coral surface mucus layer secrete antimicrobial compounds (e.g. antibiotics) that can act against invading pathogens and hence protect corals from infectious diseases. Because resident bacteria are very densely populated in the mucus, they can also prevent pathogens from reaching the coral by outcompeting them for space and food. Some viruses are also thought to contribute to disease prevention by infecting harmful bacteria or regulating the numbers of resident bacteria.

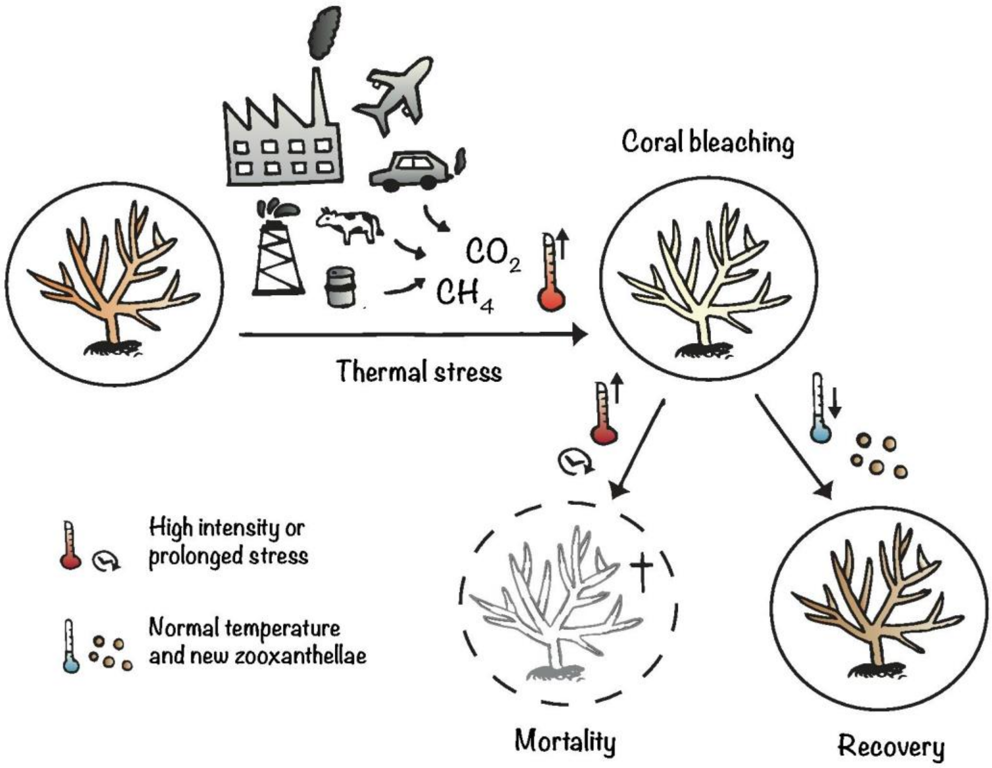


Coral-associated bacteria can also provide nutrients to their coral host and its zooxanthellae. In particular, bacteria can metabolise compounds that cannot be used by higher organisms, converting them into forms that are readily assimilated by the host. Thus, bacteria are believed to provide corals with precious sources of carbon, nitrogen, sulfur and phosphorus, as well as delivering essential minerals and vitamins. These products can then be used by corals and zooxanthellae to build tissues, gain energy and sustain critical physiological functions. The functional importance of bacteria associated with cold-water corals may be even more significant, as these corals frequently inhabit depths where sunlight cannot penetrate, and therefore do not possess zooxanthellae. Without microalgal symbionts, it is believed that cold-water corals (as well as other reef invertebrates) primarily rely on bacteria to obtain certain nutrients and survive in this challenging environment.

Bacterial communities associated with corals are usually dynamic: their composition and activity can vary with time, location and environmental conditions. For instance, if the seawater surrounding the coral changes in temperature, acidity or nutrient content, the bacterial communities can rapidly change to better suit these new conditions. Some of these microbial changes may have negative consequences for the coral host, whereas other effects may be positive, thereby underpinning the adaptation and survival of the coral in the face of environmental change.

5. ***Effects of Global Human Impacts on Corals and Their Symbionts.*** Like other organisms, the coral holobiont tolerates natural fluctuations in environmental conditions (such as those encountered with seasonal cycles) and can withstand or recover from temporary weather disturbances (e.g. cyclones, floods and heatwaves). However, if these anomalies are extreme or last for extended periods of time, corals become stressed and can die. The greatest threat to corals is elevated seawater temperatures, which are caused by excessive greenhouse gas emissions and global warming.

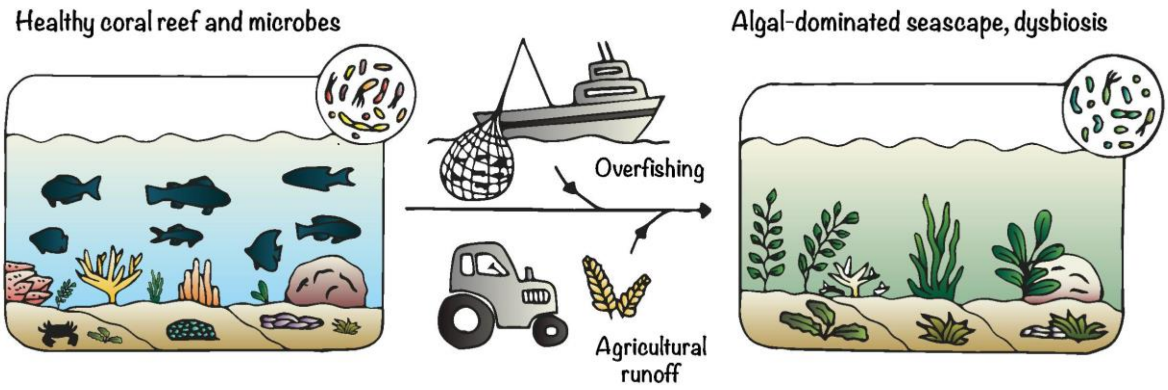
Corals can start becoming stressed when seawater temperature exceeds the maximum average summer temperature by just 1°C. If elevated seawater temperatures persist for weeks, a phenomenon called coral bleaching can occur, a process whereby the coral loses its symbiotic microalgae (primarily by expulsion). Because the pigmented zooxanthellae are no longer present in coral tissues, the latter become transparent and the white skeleton becomes visible underneath (hence the designation coral "bleaching", Figure 2). Bleached coral can survive for a limited amount of time but have very low energy levels because they lack their principal food source (i.e. nutrients delivered by zooxanthellae following photosynthesis). If cooler temperatures rapidly return, corals can capture new zooxanthellae cells from the environment, re-initiate the vital symbiosis and recover. However, if the stress is sustained (which can result from very high temperatures over successive days or slightly warmer temperatures over several weeks) many corals will die (Figure 2). In addition to inducing global warming, the excessive quantities of carbon dioxide present in the atmosphere become absorbed into the seawater, making the oceans more acidic. Increased seawater acidity makes it harder for corals to form new skeleton, further compromising their survival.



When corals are exposed to high levels of stress, the beneficial coral-associated bacterial community can shift towards a bacterial community dominated by opportunistic microbes including pathogens. This microbial change can trigger disease in the already weakened coral.

Figure 2 Photographs of a healthy reef (left), the same reef during a bleaching event (centre) and following the death of corals, which were subsequently covered by algae (right), image courtesy of The Ocean Agency (https://theoceanagency.org) which provides stunning free to access imagery and videos in support of ocean conservation efforts.

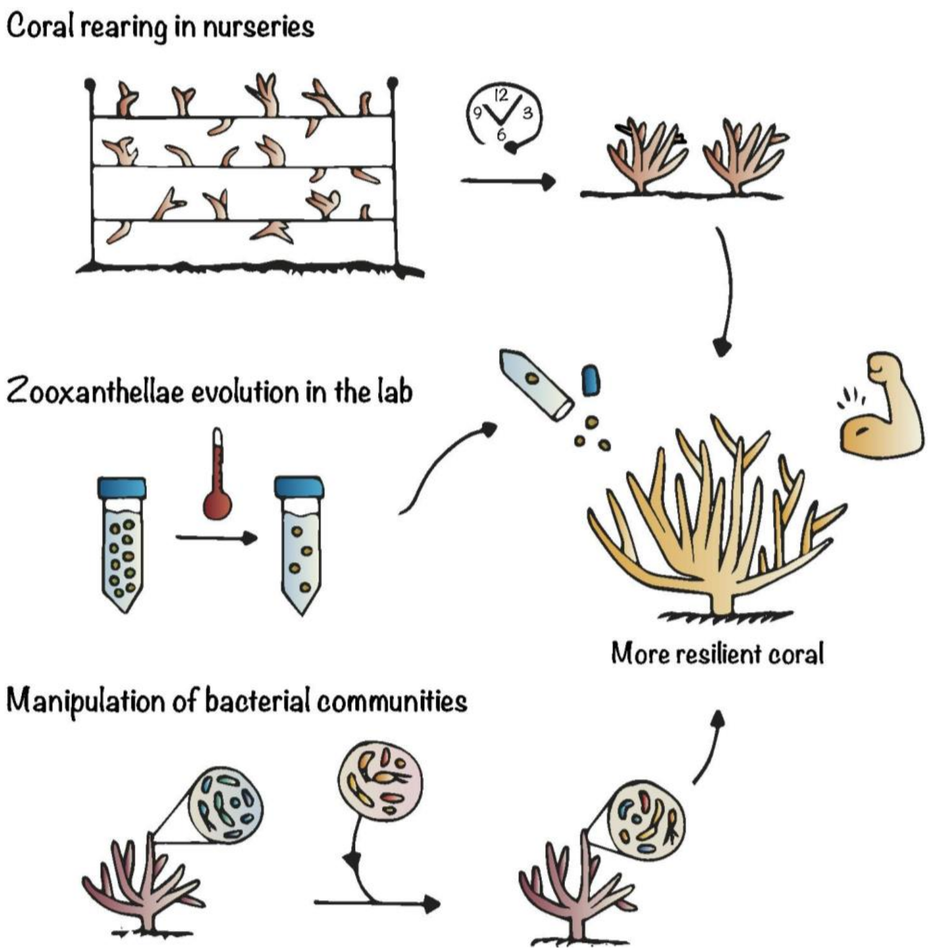
6. ***Effects of Local Human Impacts on Corals and Their Symbionts.*** Human-driven disturbances acting on local scales, such as pollution or overfishing, can exacerbate the effects of global climate change on the coral holobiont. Plastic is the most prevalent debris found in the oceans and represents a significant threat to all marine life. Scientists have recently reported that corals interact with microplastics (small plastic pieces less than 5 mm long) via ingestion and adhesion on their surface, which can lead to coral bleaching and tissue death. Overfishing removes large quantities of fish that graze on seaweed-like algae. These algae thrive in warmer waters, and when grazing pressure is removed, they can easily overgrow and outcompete corals for space. This phenomenon is exacerbated by pollution (typically from agricultural runoff), because chemical and natural fertilisers washed into the oceans can stimulate algal growth. Increasing algal abundance also increases the levels of organic matter present in the seawater which can promote the growth of opportunistic and potentially pathogenic microbes. Hence, overharvesting and pollution can threaten the future of coral reefs, at least in part through their effect on the seawater bacterial community composition.



7. ***Urgent need to mitigate human-derived disturbances and protect coral reef ecosystems***. Scientists have predicted that the cumulative impacts of climate change and other local stressors caused by human activities will significantly alter and degrade coral reefs worldwide by the end of the century. The occurrence of mass bleaching events has increased alarmingly in the past few years. The two consecutive bleaching events that occurred in 2016 and 2017 affected half of the corals on the GBR. Of immense concern, the GBR experienced a third and unprecedently widespread mass bleaching event in March 2020. These increasingly frequent disturbance events are not allowing corals sufficient time to recover before they have to face their next challenge, nor to repopulate the reef with offspring to secure its future. Unless urgent measures are implemented to reduce greenhouse gas emissions, coral reefs as we know them will not persist into the future. Loss of coral reefs means not only the disappearance of a spectacular diversity of corals, which have persisted for millions of years and evolved into remarkably complex organisms, but also the collapse of entire marine ecosystems (comprising fishes, turtles, sea urchins, crabs, sea stars, sponges, octopuses, worms, etc…) that rely on coral reefs. Millions of humans that depend on reefs for food, habitat protection and livelihoods will also suffer. Hence,

it is of utmost importance to preserve the fine balance that is formed by the coral animal and its associated microorganisms: their individual size may be minuscule, but they are pillars of life.

8. Current actions and research directions to conserve and protect corals. Coral restoration programs are being established in response to the unprecedented loss of coral reefs globally. These restoration projects aim to propagate coral fragments or sexually derived recruits in 'nursery environments' until they are sufficiently developed to enable transplantation back onto degraded reefs. Researchers are also exploring the possibility of exposing these 'cultivated' corals to sub-lethal stressors that might promote their rapid acclimatization to higher seawater temperature. If successful, this approach would enable 'hardier' corals to be transplanted back to the reef, although currently little is known about the potential trade-offs of enhancing traits such as thermal tolerance. Acclimatization could occur via changes in the physiology of the coral host, but may also occur via changes in the composition and function of associated microbial communities that enhance host fitness.



Scientists are now investigating whether coral stress tolerance could be increased by direct manipulation of their microbial symbionts. For instance, laboratory experiments are being conducted in which zooxanthellae grown in culture flasks are progressively exposed to higher temperatures over time. Some zooxanthellae are not able to withstand these warm temperatures and die. However, after many generations of cell division (zooxanthellae reproduction), some can adapt to the higher temperature. In theory, these heat-tolerant zooxanthellae could be delivered to baby corals during the point at which they first establish their symbiotic relationship, thereby enabling the developing coral to better withstand heat stress. Alternatively, the coral-associated bacterial communities could be targeted to enhance the performance of the coral holobiont.

In the field of human health, such approaches are already well established. For example, patients with inflammatory bowel diseases (i.e. excessive inflammation in the intestinal tract) frequently benefit from receiving an inoculum comprising bacterial communities retrieved from the gut of healthy people. Moreover, some live bacteria selected for favourable properties can be consumed by humans or other animals to which they confer health benefits (such bacteria are called "probiotics"). If beneficial microbes delivered to corals succeed in establishing a symbiotic partnership, this may improve the environmental tolerance of the coral holobiont.

Relevance for Sustainable Development Goals and Grand Challenges

Without their microbial partners, corals could not survive and the extensive reef structures that humanity relies upon would not exist. Hence, the contributions that coral reefs provide to SDGs need to be considered in the context of the coral holobiont and attributed to the coral animal as well as the zooxanthellae, bacteria and other associated microorganisms.

- **Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture** (*end hunger and malnutrition, increase agricultural productivity).* Both tropical and cold-water coral reefs are a huge reservoir of marine biodiversity, serving as habitat for hundreds of species. These encompass invertebrate and fish species directly harvested by humans for food (such as sea urchins, oysters, crabs, shrimps, octopuses, coral trout, groupers, etc.) or that are preyed upon by pelagic fish (such as mackerel or tuna which are in turn also consumed by humans. Given that fish are considered a superfood and a staple of the healthy "Mediterranean diet", and seafood comprises an important and highly nutritious part of the human diet, maintaining the health of coral reefs is critical to delivering SDG 2.

- **Goal 3. Ensure healthy lives and promote well-being for all at all ages** (i*mprove health, reduce preventable disease and premature deaths).* The coral holobiont and the different animals (especially invertebrates) dwelling on coral reefs are an important source of novel pharmaceuticals. Reef species such as sponges, corals and sea squirts produce secondary metabolites that could be used to treat a wide range of diseases for which currently available medications are not effective. Scientists have been isolating reef-derived compounds and developing drugs to target various conditions including cardiovascular disease, bacterial infections, inflammation, and cancers, with promising results. Hence, coral reefs could represent a source of compounds with valuable therapeutic applications for humans, directly contributing to SDG 3.

- **Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all** (p*romote economic growth, productivity and* *innovation, enterprise and employment creation)*. Through fisheries, tourism and recreation, coral reefs make a substantial contribution to delivering SDG 8. Whether visiting coastal areas for scuba diving, snorkeling or fishing excursions or to enjoy the beautiful beaches protected by the reefs, tourists bring money to local hotels, restaurants, tour operators and other businesses which provide work to local populations. Coral reefs provide jobs and income to local economies in the range of billions of US dollars each year.

- **Goal 13. Take urgent action to combat climate change and its impacts** *(reduce greenhouse gas emissions, mitigate consequences of global warming, develop early warning systems for global warming consequences, improve education about greenhouse gas production and global warming)*. Greenhouse gas emissions are posing a significant threat to the survival of coral reefs by driving the higher seawater temperatures that are disrupting the beneficial relationship between the coral animal and its associated microorganisms. To prevent the collapse of entire coral reef ecosystems, it is imperative to reduce global greenhouse gas emissions. Communicating the beauty, wonder and importance of coral reefs may incentivise the population to take action against climate change in order to preserve these fragile ecosystems.

- **Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development** *(reduce pollution of marine systems by toxic chemicals/agricultural nutrients/wastes like plastics, develop mitigation measures for acidification, enhance sustainable use of oceans and their resources)*. Waste (chemical pollutants, microplastics, nondegradable objects) released into the marine environment can be directly toxic to animal and plant life or inadvertently kill animals that ingest or become entangled in it. Nutrient pollution and overfishing also threaten corals by promoting the growth of algae, destabilizing the coral microbiome and rendering corals more sensitive to opportunistic bacterial pathogens. Visual imagery of coral reefs degraded by large amounts of plastic waste has recently been used to successfully campaign against single use plastics, including plastic straws, thereby contributing to marine conservation efforts globally.

Potential Implications for Decisions

1. ***Individual***
    a. Avoid single-use plastics to reduce pollution in the marine environment
    b. Appropriately recycle all items suitable for recycling
    c. Buy reasonable quantities of goods to avoid material and food waste, which could end up in the oceans and impact corals and their associated microorganisms
    d. Encourage peers to follow sustainable consumption practices
    e. Decrease air travel and prioritize public transport over the use of personal vehicles
    f. Restrict meat consumption as cattle produce considerable amounts of methane, which is a potent greenhouse gas
    g. When consuming marine products, select those certified as sustainable
    h. Respect marine protected areas by adhering to guidelines
    i. Avoid touching and collecting marine animals when snorkeling/diving

2. ***Community policies***
    a. Install numerous waste and recycling bins through towns to ensure appropriate waste disposal
    b. Promote local fishing over mass harvesting

c. Educate population about the importance of coral reef ecosystems (for example, install explanatory panels along walkways)
d. Provide financial support to take-away food shops that offer reduced prices for consumers bringing their own cups and containers
e. Organize clean-ups of local reefs and beaches

3. ***National policies relating to coral reefs***
   a. Education campaigns about the value of coral reefs and the need to protect them
   b. Promote renewable energy sources (such as hydraulic or solar) over fossil fuels and provide required infrastructures (e.g. solar grids)
   c. Impose a carbon tax, especially for large industries
   d. Levying of an environmental tax for the consumption of marine products that do not follow sustainable guidelines (e.g. originating from industrial fishing)
   e. Limit dredging and shipping as much as possible (to avoid physical destruction of reefs and oil spills into the marine environment)
   f. Utilize networks of marine protected areas to ensure sustainable use of the marine environment.

Pupil Participation

1. ***Class discussion of the issues associated with corals***
   a. Raise awareness about the importance of coral reefs by discussing the services they provide to humans and to the marine ecosystem.
   b. Discuss the important roles that microbes perform within the coral holobiont
   c. What would seascapes look like with degraded reefs and how would this impact entire marine animal food chains?

2. ***Pupil stakeholder awareness***
   a. In a scenario where most coral reefs disappear, how would the life of the millions of people who directly depend on the reef change? How could it affect your daily life?
   b. Reflect on how your daily activities can be modified to keep reefs healthy. How can we as individuals and as a community reduce carbon dioxide emissions, practice sustainable consumption, promote recycling and limit the amount of pollution?

Activities

- Watching videos or documentaries about coral reefs and marine ecosystems will provide useful illustrations and powerful insights into their functioning. The documentary *Chasing Coral* is of great relevance (available on Netflix: https://www.netflix.com/au/title/80168188). The National Geographic short documentary *Coral Reefs 101* provides a brief but informative summary (https://video.nationalgeographic.com/video/101-videos/0000015f-9331-d8e7-a7ff-f77d2dfb0000).

- Organise a class excursion to a local Natural History museum to look at their coral collection. Pay attention to the different coral morphs and the intricacy of their skeleton and try to identify the corallites (little skeletal cups) where individual polyps used to grow. Actual skeletons could be compared with images of corals to emphasise that these are not rocks but fascinating animals.

Exercises

c. Present to pupils several images of healthy, partially bleached, entirely bleached and dead coral reefs. Notice how dead reefs become overgrown with algae, start to degrade and can no longer sustain a rich and diverse marine life.
d. Match these photos with *Coral Watch* colour chart (https://coralwatch.org/index.php/monitoring/using-the-chart/) to assess the degree of bleaching and try to relate it with the degree of human impact.

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Glossary

Adaptation: process by which organisms change over time to become better suited to their environment. Adaptation occurs over multiple generations and relates to biological traits that can be inherited.

Acclimatization: process by which individual organisms adjust to changes in their environment; acclimatization occurs within a single organism's lifetime.

Archaea: single-celled microorganisms that often resemble Bacteria in shape and size, but have different molecular characteristics. Some Archaea are known to live in extreme environments (e.g. very high temperature, salinity or acidity).

Bacteria: single-celled microorganisms that live in a wide diversity of environments. Bacteria can exist as free-living or associated with higher organisms. While some cause disease, most Bacteria exert beneficial functions for other life forms.

Cnidocytes: a specialized cell type harbored by corals (and some other marine invertebrates including sea anemones and jellyfish) that can deliver a sting for defense and to capture prey.

Colonial organism: organism formed by many individuals that are clones of each other and physically interconnected.

Coral bleaching: process by which corals expel the little symbiotic algae living in their tissues in response to stress. This causes corals to turn white, as their skeleton becomes visible under their transparent tissues.

Dysbiosis: an imbalance in an organisms natural microbial community. This imbalance disturbs the symbiotic relationship between the host and its microorganisms, and frequently results in disease.

Greenhouse gases: gases in the atmosphere (such as carbon dioxide – CO_2, and methane – CH_4) that trap heat similar to a glass roof on a greenhouse. Increased human emissions of greenhouse gases are causing global warming.

Heterotrophic nutrition: mode of nutrition in which organisms cannot make their own food and are therefore dependent on other organisms to survive.

Holobiont: a biological entity comprised of a host and all associated microorganisms.

Inoculum: substance introduced into the body of an organism to increase its resistance.

Mutualistic: a symbiosis (i.e. relationship between two organisms) is mutualistic when it benefits both partners.

Pathogen: a microorganism (such a bacterium or a virus) that can cause a disease.

Polyp: a coral polyp is a soft-bodied organism related to sea anemones and jellyfish. Usually, clones of a single polyp are connected to each other and form a coral colony.

Probiotics: live microorganisms that, when administered to a host, provide a health benefit.

Scleractinian coral: corals that secrete a skeleton and contribute to forming coral reefs (they are also known as "hard corals").

Symbiosis: relationship between two different organisms living in close physical association.

Zooxanthellae: yellow-brown single-celled algae that can live in symbiosis with different marine invertebrates. Zooxanthellae live within the cells of their animal host and provide them with essential nutrients.