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Editorial: The role of dimethylsulfide and other sulfur substances on the climate and ecology of coral reefs

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Editorial on the Research Topic
The role of dimethylsulphide, and other sulphur substances, on the climate and ecology of coral reefs

Whilst ground-breaking research on dimethylsulfide (DMS) on coral reefs was published over 25 years ago (Jones et al., 1994; Hill et al., 1995), the goal of this special topic is to highlight more recent research on the climatic and ecological role of DMS, its biological precursor dimethylsulfoniopropionate (DMSP), and related compounds in tropical coral reef environments. Forty-three researchers contributed eleven high quality manuscripts from the Australian Great Barrier Reef (GBR), French Polynesia, and Okinawan reefs off Japan. Contributions include case studies and review articles covering atmospheric science, remote sensing, biogeochemistry, microbiology, coral physiology and ecology, and genetic research.

McGowan et al. compare observations of coral reef-atmospheric interactions during summer monsoon conditions on the Great Barrier Reef with those of a desert fringing coral reef in the Gulf of Eilat, Red Sea. While in the Gulf of Eilat the stability of the atmospheric boundary layer inhibits the impact of the reef on the overlying atmosphere, GBR reefs during the summer monsoon are characterized by convective exchange of heat and moisture, which may allow the vertical transport of DMS and other aerosol and cloud droplet precursors. In a mini review, Swan discusses the potential for coral reef-derived, atmospheric DMS oxidation products to regulate the regional climate of the GBR (Figure 1). He describes how low wind speeds over tidally exposed coral reefs cause plumes of atmospheric DMS and sulfate aerosols. Upon subsequent growth, these aerosols can affect cloud microphysics and regulate regional cloud albedo. Massive coral bleaching events may currently weaken such regulation. Jackson et al. investigated this further using an Australian Community Climate and Earth System Model. Incorporation in the model of the coral-to-air DMS emission, during aerial exposure at low tide, revealed that the GBR is an important regional source of atmospheric sulfur. However, no influence on sulfate aerosol mass or number concentration was detected, in contrast to observational studies that suggest otherwise. In a companion paper, Jackson

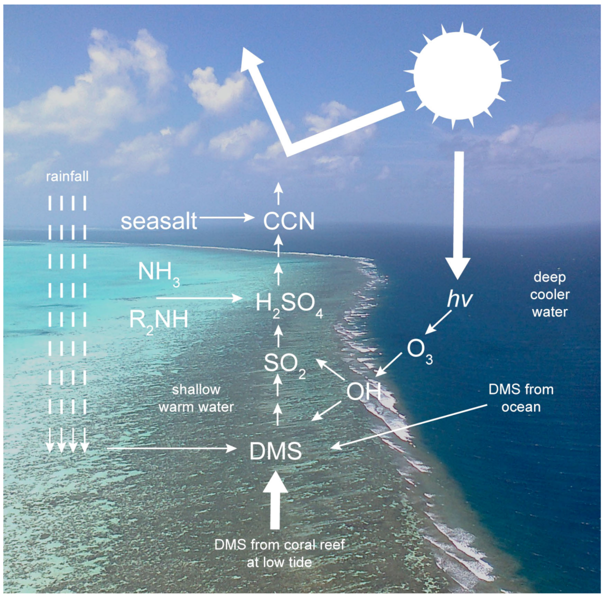

FIGURE 1
An aerial photograph of Wistari Reef near Heron Island in the Capricorn–Bunker group of coral reefs southern Great Barrier Reef, Australia (23.13° S, 151.85° E to 23.92° S, 152.60° E). Superimposed on this image is a conceptual model of factors controlling hygroscopic sulfate aerosol production (H_2SO_4) over the GBR. Ocean-derived atmospheric DMS and pulses of atmospheric DMS from the coral reef at low tide are oxidised by photochemically produced hydroxyl radical (OH) forming sulfate aerosol that can grow to cloud condensation nuclei (CCN). This process can assist formation of high-albedo low-level marine clouds that influence solar radiation over the GBR. Source: Hilton B. Swan, Graham B. Jones, Elisabeth S. M. Deschaseaux, and Bradley D. Eyre. Biogeosciences, 14, 229–239, 2017 www.biogeosciences.net/14/229/2017/doi:10.5194/bg-14-229-2017 © Authors 2017. CC Attribution 3.0 License.

et al. used a CMIP6 model to investigate the influence of predicted increases in sea surface temperature and photosynthetically active radiation on DMS emissions from the GBR by the end of the century. They conclude that the predicted 10-14% increase in DMS emission is unlikely to significantly influence the regional atmosphere of the GBR, though further research is needed. Whilst DMS is considered a climate-cooling gas, methane is a powerful greenhouse gas with warming effects. Deschaseaux et al. report a correlation of DMS emission fluxes with methane fluxes from the Heron Island Reef, GBR. DMS emissions were also positively correlated with the abundance of intermediate and large diameter aerosols, suggesting that DMS significantly contributes to the growth of existing atmospheric particles.

Xue et al. measured concentrations of DMSP and its breakdown product acrylate in a coral reef-open ocean transect in Mo'orea, French Polynesia. While concentrations showed little change along the transect, the microbial consumption of both compounds was much faster in the reef, suggesting that rapid biological turnover maintains the reef-borne dissolved concentrations of these two compounds at low levels similar to those of the open ocean. In the same Mo'orean reefs, Masdeu-Navarro et al. measured DMSP-related compounds (DMSPCs, i.e., DMSP, DMS, acrylate and DMSO) and volatile organic compounds (VOCs). Dominant corals were sources of DMSPCs, while a dominant seaweed was a source of DMSPCs and VOCs such as carbonyl sulfide and poly-halomethanes. The diel cycle of DMSPCs concentrations near the polyps of *Acropora pulchra* paralleled changes in sunlight intensity, and rDNA meta-barcoding and metagenomic analyses suggested that solar radiation-induced oxidative stress caused the release of DMSPCs by the coral holobiont, either directly or through symbiont expulsion. With similar ecophysiological objectives, Gardner et al. exposed *Acropora millepora* to thermal stress experiments and observed a large increase in coral DMSP concentrations. The distinct bacterial communities of the coral mucus showed increases in the abundance of two DMSP catabolic genes, *dmdA* (demethylation) and *dddP* (cleavage to DMS), under thermal stress, and a shift occurred to cleavage as the DMSP concentration increased. This helps explain why DMS emission is enhanced in heat-stressed corals.

Corals are holobionts where the distinct roles of each of the components (i.e., the cnidarian host and the symbiotic algae, as well as the other members of the associated microbiome) in the physiology of the entire coral are not easy to tease out. For instance, bacteria do not only catabolise DMSP but can also synthesize it. Kuek et al. confirmed this by finding the DMSP-synthesis gene *dsyB* in 9% of 157 isolates of bacteria associated with four common coral species. Genome sequencing of one of the isolates, *Shimia aestuarii* AMM-P-2, revealed the complete genetic machineries to assimilate sulfate and synthesise sulfur-containing aminoacids and DMSP, and demethylate and cleave DMSP, as well as utilise or detoxify acrylate. Intracellular DMSP increased two-fold under both hypersaline conditions and high UV exposure. Chiu and Schinzato carried out molecular identification of DMSP lyase-like genes in *Acropora digitifera* tissue, and saw that multiple variants were expressed. A comprehensive survey of available transcriptomic databases revealed that DMSP lyase-like genes occur across Cnidaria: in Hexacorallia and Octocorallia (Anthozoa), and even in a jellyfish (Hydrozoa), and evolved from a gene in the last common ancestor of Cnidaria, dating to the Precambrian. Given that DMSP lyase-like gene-harbouring cnidarians thrive in coral reefs and shallow, warm waters, these genes may be essential for animals to survive in such environments and adapt to environmental changes. Quaternary ammonium compounds (QACs) – e.g., betaines – have a chemical structure analogous to that of the tertiary sulfonium compounds such as DMSP. In coral tissues, QACs are suggested to protect the photosystem machinery of the algal symbiont against photon and thermal stresses by stabilizing photosystem proteins and scavenging reactive-oxygen-species. Hill reviews the available evidence on the roles of QACs, and calls for more studies of QAC-related ecophysiology in corals.

All in all, the contributions in this Research Topic provide further evidence for the critical role of DMSP, DMS and related compounds in the evolution of tropical corals and their adaptation to the conditions of high temperatures and irradiances that characterise their distribution. Most importantly, they highlight the need to look at the coral as a holobiont, where the different components all contribute to the ecophysiological aspects of sulfur cycling. A consequence of these ecophysiological aspects is the increased emission of DMS from reefs where high irradiances, high temperature and aerial exposure by low tides converge. In combination with atmospheric convective uplifts, DMS emissions represent an important injection of sulfur up into the atmosphere where low level clouds form. Whether this injection has significant impact on regional climate is still controversial and requires further evaluation.

Author contributions

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