AgriCos e-Newsletter
ISSN: 2582-7049
AgriCos e-Newsletter
Open Access Multidisciplinary Monthly Online Magazine
Volume: 05 Issue: 12 December 2024 Article No: 05

Sponges Powering Coral Reef Health through Biogeochemical Balance

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SUMMARY

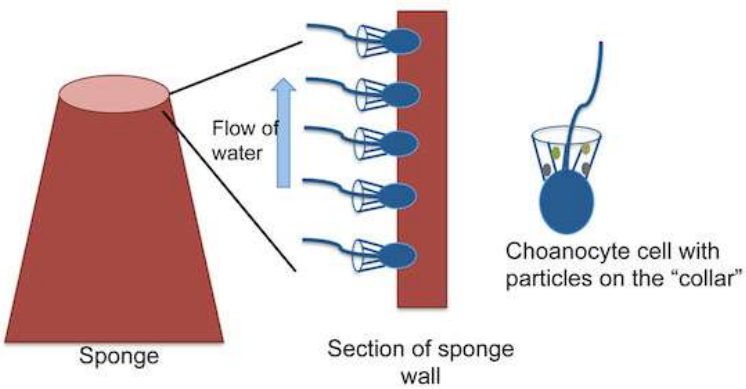
Sponges play a crucial role in maintaining the biogeochemical balance of coral reef ecosystems. Acting as natural filters, they absorb dissolved organic matter and recycle nutrients, enhancing water quality and supporting diverse marine life. Through symbiotic relationships with microorganisms, sponges contribute to nitrogen cycling, carbon sequestration, and mineral deposition. Their activity sustains coral health, promotes resilience against stressors, and bolsters reef productivity. Understanding sponge functions in nutrient dynamics is essential to conserving these vibrant marine habitats.

INTRODUCTION

Sponges are one of the oldest and most essential inhabitants of coral reef ecosystems, playing a pivotal role in maintaining the balance and productivity of these vibrant underwater landscapes. Known as “nature’s filters,” sponges pump large volumes of water through their porous bodies, capturing organic particles, microorganisms, and nutrients, which they recycle back into the environment. This process not only improves water quality but also supports the nutrient needs of surrounding marine organisms, including corals. Moreover, sponges harbor diverse communities of symbiotic microorganisms that enhance their biogeochemical functions, contributing to key processes like nitrogen cycling, carbon sequestration, and mineral deposition. As coral reefs face increasing stress from climate change, pollution, and overfishing, understanding the biogeochemical importance of sponges offers valuable insights into reef resilience and conservation. This exploration of sponge ecology sheds light on their role as a foundation of reef health and stability.

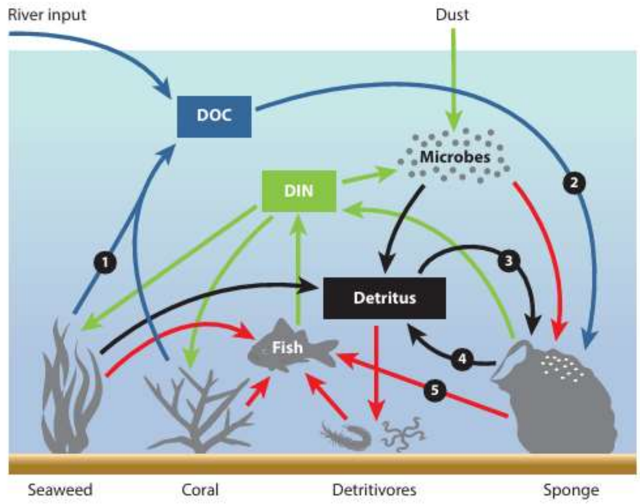
Biogeochemical Cycling:

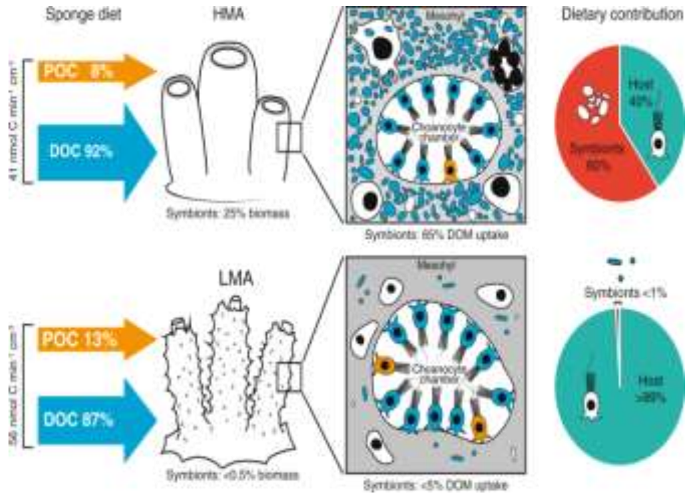
Sponges emerged as significant mediators of biogeochemical fluxes in coastal zones by respiring organic matter and facilitating both the consumption and release of nutrients. Zoo geochemistry to characterize the effects that terrestrial animals have on the carbon cycle by altering CO_2 uptake and loss, carbon sequestration in plants and soils (Schmitz et al. 2018). The process of storage and exchange of carbon in ecosystems is vital for carbon cycle models and to assess the potential for natural carbon storage as changes continue to Earth’s climate. The oceans contain the largest pool of cycled organic carbon on earth as dissolved organic carbon and among marine organisms, sponges are unsurpassed in their ability to pump large volumes of seawater and to simultaneously remove dissolved organic carbon. There is increasing interest in ability of sponges to overturn the water column as they pump seawater through the extremely high surface area of their aquiferous system transforming the chemistry of Seawater.



Carbon Cycling and the Sponge-Loop Hypothesis

The sponge loop is a dominant component in the carbon cycling of coral reef ecosystems. Coral reef ecosystems thrive as some of the most productive and diverse habitats on Earth, despite existing in nutrient-poor, oligotrophic waters. One of the critical processes sustaining this productivity is the "sponge loop," a unique microbial loop that allows carbon to be retained within the reef ecosystem. In this loop, sponges absorb dissolved organic carbon (DOC) released by seaweeds and corals, converting it into particulate organic carbon (POC) by shedding cellular detritus through their collar cells. This detritus, rich in nutrients, is then consumed by benthic detritivores and suspension feeders, transferring energy to higher trophic levels. Encrusting and cryptic sponges play a particularly important role, as their conversion of DOC to POC is nearly equivalent to the daily gross primary production of the entire reef. Through this process, sponges help maintain the nutrient flow and support the resilience and productivity of coral reef ecosystems.





The capacity of sponges to remove DOC from the water column is in the early laboratory studies and the identification of large discrepancies between POC uptake and respiratory carbon demand. Greater internal surface area and an increased residence time of seawater within the sponge holobiont. HMA is adapted to feed on DOC and LMA for filtering of particle. DOC uptake by LMA not mediated symbiotic microbes.

Nitrogen Cycling and the Vicious-Circle Hypothesis

Sponges play a key role in nitrogen cycling within coral reef ecosystems, processing dissolved inorganic nitrogen (DIN) through the metabolic breakdown of their food sources. They also obtain particulate organic nitrogen (PON) by consuming picoplankton, with detritus serving as a significant carbon source for some species. However, due to the high carbon-to-nitrogen (C:N) ratio in detritus, its contribution of nitrogen is limited, though it may help balance the nitrogen budget for certain sponges (Morganti et al. 2017). High microbial abundance (HMA) sponge species acquire most of their organic nitrogen as dissolved organic nitrogen (DON), while low microbial abundance (LMA) species produce DON and rely primarily on picoplankton for nitrogen intake (Morganti et al. 2017; Ribes et al. 2012). This diversity in nitrogen sources underscores the varied metabolic strategies sponges use to fulfil their nutritional needs, supporting reef productivity and stability. Stable isotope signatures and biomarker genes provide evidence of nitrogen (N_2) fixation by sponge-associated cyanobacteria and heterotrophic bacterial symbionts in both high microbial abundance (HMA) and low microbial abundance (LMA) sponges. However, the rates of N_2 fixation are relatively low and do not contribute significantly to the nitrogen requirements of sponges (Ribes et al. 2015; Rix et al. 2015). Additionally, functional genes for denitrification and anammox have been identified within sponge microbial communities (Fan et al. 2012; Mohamed et al. 2010). Sponges create the necessary anaerobic conditions for these processes by reducing or temporarily halting their pumping activity (Hoffmann et al. 2005). Despite these findings, the full extent and magnitude of nitrogen transformations within the sponge holobiont remain largely unresolved (Hoffmann et al. 2009). This highlights the need for further investigation into the nitrogen-cycling pathways facilitated by sponge-microbe symbioses in reef ecosystems.

Phosphorus Cycling:

Sponge-mediated fluxes of dissolved inorganic phosphate (as PO_4^{3-}) is more compared to phosphorus in dissolved or particulate organic forms. The majority of sponges minor source of PO_4^{3-} - HMA species may also consume PO_4^{3-} and other nutrients, variation in PO_4^{3-} fluxes may be explained by differences in ambient PO_4^{3-} concentrations (Archer et al. 2017). Microbial symbionts of sponges may also sequester significant amounts of phosphorus in the form of polyphosphate (Zhang et al. 2015), with up to 40% of total phosphorus in sponge tissue present as polyphosphate granules, potentially representing a large proportion of total phosphorus in coral reef ecosystems. Polyphosphate granules may serve to store phosphorus for the sponge holobiont but may also lead to the sequestration of phosphorus in sediments if polyphosphate is released by sponges (Zhang et al. 2015)

Nutrition, Nutrients and Pollution

Sponge abundance relative to levels of pollution multiple variables associated with anthropogenic effects on reefs that may enhance sponge abundances, loss of living coral cover. sponge colonization sponges eat DOC and detritus, and both of these food sources increase in proximity to sewage outfalls or organic pollution. Enriched nutrients from anthropogenic sources enhance picoplankton abundances, providing highest-quality food source that sponges are known to eat (McMurray et al. 2016). Indirectly link enhanced abundance of sponges to eutrophication but more direct tests of the abilities of sponges to use the components of organic pollution for food.

Silicon Enigma

Silicon is an essential nutrient for the skeletons of many marine organisms, including sponges, and plays a role in the global cycles of carbon, nitrogen, and phosphate in marine ecosystems. As a limiting nutrient for diatoms, silicon is biologically available as dissolved silicic acid (DSi), which is found in higher concentrations at greater depths and higher latitudes. However, on shallow coral reefs, the availability of silicon is often limited, potentially restricting sponge growth. This scarcity of DSi in shallow waters may impact sponge populations and, consequently, the biogeochemical processes they support within reef ecosystems. On Caribbean reefs, 3 of the 10 most abundant sponges lack siliceous skeletons, including the single most abundant species, Aplysina cauliformis. While the tissues of many of the dominant genera of emergent reef sponges are perfused with glass spicules (Xestospongia, Agelas, Niphates and Callyspongia) other common genera lack spicules (Aplysina, Verongula, Aiolochroia, andIrcinia) no apparent differences in sponge morphology between the two categories

CONCLUSION

Sponges are integral to the biogeochemical functioning of coral reef ecosystems, serving as nutrient recyclers and energy conduits through processes like the sponge loop. By converting dissolved organic carbon into particulate organic carbon and facilitating nitrogen cycling through complex microbial interactions, sponges help retain biomass and enhance the productivity of nutrient-poor reef waters. Their ability to influence carbon, nitrogen, and silicon dynamics underscores their role as foundational organisms supporting coral reef resilience and health. Understanding these processes is essential for reef conservation, as it highlights how sponges maintain ecosystem balance and aid in adapting to environmental changes. As coral reefs face increasing pressures, recognizing and preserving the contributions of sponges will be crucial for sustaining these diverse and vital habitats.

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