Microbe-host associations as drivers of benthic carbon and nitrogen cycling in a changing Mediterranean Sea

Doctoral Thesis by

Johanna Berlinghof

for the attainment of the academic degree of

Doktor der Naturwissenschaften

- Dr. rer. nat. –

submitted to the Faculty of Biology and Chemistry

at the University of Bremen

in December 2024

Universität Bremen

Stazione Zoologica Anton Dohrn Napoli

SUMMARY

Seagrasses, such as the endemic Mediterranean species *Posidonia oceanica*, are critical components of coastal marine ecosystems, providing essential ecosystem services, including carbon sequestration, nutrient cycling, and habitat formation. *P. oceanica* forms extensive meadows that serve as biodiversity hotspots and play a crucial role in mitigating climate change through long-term carbon storage. Despite their ecological significance, the interactions between *P. oceanica* and associated organisms, as well as their combined contributions to biogeochemical cycling, remain poorly understood, particularly under changing environmental conditions. This thesis explores the carbon and nitrogen cycling processes within the *P. oceanica* holobiont, focusing on the epiphytic and microbial communities, microbial driven metabolic processes, and the interaction between *P. oceanica* and larger associated invertebrates, such as the sponge *Chondrilla nucula*. Through field and laboratory experiments, this work demonstrates the significant role of epiphytic algae in the primary production of the seagrass holobiont, contributing a substantial portion of net primary production. Nitrogen cycling processes such as N_2 fixation, nitrification, and denitrification in the seagrass phyllosphere were quantified, revealing their importance in meeting the N demands of the seagrass holobiont, especially under natural ocean acidification conditions. Experiments near marine CO_2 vents indicated that ocean acidification accelerates net primary production and nitrogen cycling, while the structure of the microbial community associated with *P. oceanica* leaves remains largely stable. The facultative mutualism between *P. oceanica* and the sponge *C. nucula* further highlights the complexity of the seagrass holobiont. *P. oceanica* releases dissolved organic carbon, which meets a portion of the sponge's respiratory carbon demand. Conversely, *C. nucula* releases dissolved inorganic nitrogen, including ammonium and nitrate generated by microbial nitrification, which supports seagrass growth. Stable isotope analysis suggests that the association facilitates nutrient exchange, with *P. oceanica* preferentially absorbing sponge-derived ammonium, while epiphytes may benefit from sponge-produced nitrate. This dynamic reduces seasonal fluctuations in productivity, stabilizing the seagrass ecosystem during periods of senescence. Sponge-associated nitrification contributes to the nitrogen budget of the seagrass holobiont, potentially reducing nutrient limitations in oligotrophic Mediterranean waters. The microbiome of *C. nucula* plays a key role in these processes, harboring nitrifiers that mediate the production of nitrate. High-throughput sequencing revealed taxonomic diversity among microbes associated with both the sponge and seagrass, including microorganisms involved in carbon and nitrogen cycling processes. These microbial communities not only mediate nutrient exchange within the seagrass-sponge association but also contribute to the overall resilience and productivity of the ecosystem. This thesis highlights the intricate interactions within the *P. oceanica* holobiont and its nested ecosystem with *C. nucula*. These findings underscore the importance of microbial and epiphytic communities in maintaining the resilience and productivity of seagrass meadows, particularly in nutrient-poor environments like the Mediterranean Sea. This research enhances our understanding of the biogeochemical processes that support seagrass ecosystem stability and provides valuable insights to guide conservation efforts in the face of climate change and anthropogenic pressures.