Abstract

Human development over the past centuries has massively affected and altered marine habitats and coastlines. Coastal reconstruction, bottom trawling, enlargement of navigation chancels and particularly eutrophication, followed by hypoxic events and reduction in light climate, resulted in a massive decline of the benthic community and seagrass loss world-wide. For example, the coverage of eelgrass (*Zostera marina*), the most common seagrass in the Northern hemisphere, declined by 80-90% around the Danish coastline. Several water action plans have been implemented and nutrient loadings reduced, leading to improved water quality. However, eelgrass recovery is still lacking, while fauna communities are experiencing a regime shift. It appears that the consequences of the eutrophication history are still present today. Marine sediments were during decades of eutrophication enriched and polluted with organic matter. For example, in Odense Fjord the organic content is above 2% in about 40% of the estuary, whereby in estuaries with little or no anthropogenic influence the organic sediment pool is in general below 1%. The fauna community is strongly associated with sediment characteristics and unlikely to return to former high biodiversity communities if the conditions do not improve. Furthermore, anchoring capacity for seagrasses in such sediments is highly reduced and the low grain size fraction prone to resuspension, keeping the fjord in a turbid state even at low at already low wave regimes and current velocities. Unfortunately, the organic sediment pool will take several decades to degrade, suggesting that conditions may need to be changed artificially, which lead to **MS 1 and MS 2:** Both focus on restoring marine benthic habitats by capping and burying organic rich sediment with a sand cover and thereby preserving organic matter below. The mainly focus of MS 1 were laboratory experiments for validation of the theory behind this idea, such as testing if a sand-cap stays on mud without mixing at the sand and mud interface and measuring of erosion rate and light improvement in relation to sediment characteristics. Whereby in MS 2, a large scale sand-cap was performed at two locations in Odense Fjord. Both MS show, that the sand-cap will stay on top of the mud without mixing of the sand-mud-interface. By increasing grain size, resuspension frequency and rates are reduced, leading to an improvement of the benthic light condition. Besides that, the sand-cap in MS 2 supported infauna colonization and an increase of biodiversity and specie abundance. Furthermore, anchoring capacity for eelgrass is improved, supporting the potential for seagrass recovery. In order to cope with the loss of seagrasses, worldwide restoration projects have been initiated. Restoration of eelgrass in Denmark is described in **MS 3**: A large-scale restoration was performed with two different transplantation methods for apical shoots. No difference between treatments was observed and transplantations have successfully been growing and expanding since 2017. In summer of 2019 transplanted patches reached densities of over 900 shoots m^2, equal to densities of natural eelgrass meadows within the vicinity. Carbon, nitrogen and phosphate storage of the newly established patches were measured. Results indicate, that already after 2

years, these beneficial ecosystem services are provided and C, N and P (33 ± 7.5, 6.6 ± 0.9 and 3.0 ± 0.5 g m^{-2} y^{-1}) are stored. With the loss of eelgrass, a living nutrient filter was lost and even though external nutrient loadings were reduced, the reduction did not compensate for the lacking nutrient uptake by eelgrass. As shown in **MS 4**: Survival or growth of transplanted eelgrass shoots from several small-scale test stations around the Danish coastline were correlated against nutrient concentrations and loadings. The correlation clearly shows a threshold for survival of transplanted eelgrass and indicates that environmental conditions are not suitable for eelgrass restoration if nutrient loadings are above 2.5 µM dissolved inorganic nitrogen (DIN). Anyway, restoration approaches are always cost and labor expensive, wherefore stressors impacting natural eelgrass recovery via meadow expansion was examined in **MS 5**: It is shown that seagrasses provide an essential self-support within meadows that support further growth. Without this self-support, shoots and developing seedings are vulnerable and threshold for survival becomes reduced. Lugworms (*Arenicola marina*) may negatively impact eelgrass by burial of developing shoots. The effect of lugworm abundance was correlated against eelgrass density. Furthermore, this relationship was examined in combination with other common stressors: physical pressure, eutrophication and sulfide content in sediments. The findings indicate, that when the impact of lugworms is augmented by additional stressors, higher densities are required for eelgrass patched to remain stable. Last but not least, seagrass transplantation was put into perspective in a more global context as seagrass transplants were implemented in Australia, leading to **MS 6**: Small-scale test transplants were performed at different locations with different transplantation techniques of the seagrass *Zostera muelleri*. One station was too impacted by physical pressure for shoots to survive and at two locations intense fish grazing was observed, where the transplanted shoots were completely eaten. Positive shoot development was achieved with the grazing protected treatments and up to 9-fold higher where the fish was not present. Treatments including exclusion of bioturbation significantly improved development.