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The resilience of tropical intertidal seagrass meadows, grazed by dugongs, and the impact of anthropogenic stressors

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Summary

Seagrasses are specialized marine flowering plants that have adapted to the nearshore environment. This group of plants is known to provide ecosystem services through supporting a complex trophic food web and a detritus-based food chain, as well as by performing sediment trapping and nutrient filtration, sediment stabilization, and providing breeding -and nursery areas for finfish and shellfish. Multiple stressors, including sedimentation, nutrient runoff, physical disturbance, oil pollution, commercial fishing practices, overgrazing by marine macro herbivores, algal blooms, and global warming, cause seagrass declines.

Balikpapan Bay is one of many tropical bays in Indonesia, a bay that has a central role for human development, as a major commercial port, supporting industrial developments, with mining activities near the bay, and with a major residential centre (the city of Balikpapan). Balikpapan Bay is also a shipping entry for the new capital city of Indonesia called 'Nusantara'. It is certain that in the future Balikpapan Bay will become the centre of further major developments due to the construction of the new capital inland. Balikpapan Bay is also home to many important and protected marine organisms, including the dugong (*Dugong dugon*, Muller 1776), porpoise (*Orcaela brevirostris*, Owen 1886), Pacific bottlenose dolphin (*Tursiops aduncus*, Ehrenberg, 1833), and others. This marine biodiversity is supported by the presence of mangrove, seagrass, and coral reef habitats.

Seagrass and mangrove habitats still survive in this area while coral reef habitats have declined due to high turbidity and increased sedimentation loads. Seagrasses in Balikpapan Bay generally only survive in the intertidal area. In the subtidal areas, seagrasses are absent or very scarce due to the lack of light penetration due to sedimentation. Seven seagrass meadows were included in this research which were comprised of five species; 1) *Halodule pinifolia* (Cymodoceaceae), 2) *Halophila minor* (Hydrocharitaceae), 3) *Halophila ovalis* (Hydrocharitaceae), 4) *Thalassia hemprichii* (Hydrocharitaceae), and 5) *Enhalus acoroides* (Hydrocharitaceae). Of these species, the typically colonizing and opportunist seagrasses of the genus *Halodule* and *Thalassia* dominated the intertidal seagrass meadows while the subtidal zone was dominated by *Enhalus* spp (only found in Kariangau) (Chapter 2). These seagrass meadows support the survival of the only marine herbivorous mammal, the dugong (*Dugong dugon*). Seagrass is the main food for dugongs. Rotational cultivating grazing of seagrass by dugongs is known to increase the productivity of seagrass by absorbing carbon in marine waters and enhances the presence of pioneer species such as *Halodule* spp and *Halophila* spp. This study revealed that 1-2 dugongs graze seasonally in Balikpapan Bay and they play a role as gardeners for seagrass meadows. In Balikpapan Bay, dugongs show a repetitive and rotational feeding pattern at certain locations, and they have a tendency to avoid human presence (chapter 2). In addition, we suspect that Balikpapan Bay acts as a shelter for the dugong, especially when the sea (Makassar Strait) is in bad condition due to strong winds and high waves. Finally, Balikpapan Bay is suspected to be a nursery ground for dugongs, since some fishermen reported regularly observing a dugong with a calf around seagrass meadows.

Balikpapan Bay is one of the centers of the oil industry in Indonesia, with a risk of oil pollution. In 2018, there was a severe oil spill since an undersea pipeline leak caused thousands of barrels of oil to pollute the waters of the bay. This pollution impacted the seagrass ecosystem

on a large scale. This study revealed that the oil spill caused seagrasses in the bay to lose most of the above ground biomass (Chapter 3). While shortly after the oil spill some recovery took place of seagrass biomass, probably thanks to below ground storage, we noticed that both total biomass and the ratio of above- to belowground biomass were still affected 13 months after the oil spill. Our research also showed different seagrass recovery responses at different locations after oil exposure. The oil spill also affected the grazing of dugongs in the bay. Shortly after the oil spill, freshwater dolphins were found dead, while dugongs were not found dead or stranded. During 2018, we did not find any dugong feeding tracks in any of the seagrass meadows. New tracks were found only 13 months later, in March and April 2019 (Chapter 3). It was concluded that, although the recovery capacity of pioneer seagrass species such as *H. pinifolia* is relatively high, dugongs need at least one year to return to grazing in polluted seagrass meadows.

Living in the intertidal zone, seagrasses depend on an adequate degree of water clarity to sustain productivity in their submerged environment, challenged by sedimentation due to high sediment loads and high turbidity at high tide. Intertidal seagrasses also face the challenge of adapting to extreme conditions of desiccation due to exposure to sunlight. This study reveals a possible model of physiological adaptation of seagrasses to these extreme conditions. Elongated rhizomes and roots seem to play an important role in distributing nutrients and food reserves for seagrasses especially under extreme conditions of desiccation and low light availability (due to sedimentation and turbidity). Small patches of seagrass may find it difficult to survive in water conditions with high turbidity and sediment loads (Chapters 4 & 5). This thesis illustrates the resilience of seagrass communities in intertidal areas, especially in the tropics. It is suggested that in future coastal developments the importance of intertidal seagrass meadows should get more attention as part of coastal management plans including the reduction of sediment loads and chemical pollution such as oil spills, while the presence of dugongs can be used as an indicator for good quality intertidal seagrass beds.