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The role of dugong and turtle grazing in Torres Strait seagrass declines

Exclusions experiments show the role of green turtle and dugong grazing in structuring Torres Strait seagrass meadows

A.L. Scott, T. Whap, J. Kris, S. Joe, M. Carlisle, M. David, M.A. Rasheed, P.H. York and A.B. Carter

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Front Cover image: Seagrass exclusion cage experiments at Orman Reefs (Credit: TropWATER)
Back Cover image: Seagrass exclusion cage experiments at Mabuyag Island (Credit: TropWATER)

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Executive summary

- Seagrass declines in western Torres Strait that occurred in 2019 and 2020 have been recognised as a concern by the local community. Grazing by dugongs and green turtles was identified as a possible cause of these declines.

- Exclusion cages were used at two of the affected seagrass meadows (Orman Reefs and Mabuyag Island) to understand how herbivory by green turtles and dugongs (megaherbivores) was impacting seagrass meadows.

- Where grazing pressure was removed (inside exclusion cages) the seagrass canopy height and biomass were significantly higher than the open to grazing control plots at both locations by the end of the seven-month experiment.

- Grazing pressure is very high at both sites and herbivory is likely to be contributing to the seagrass declines in these meadows. This seems to be driven principally by green turtle grazing.

- Based on the declines recorded in the long-term monitoring program at these meadows and the results from this study, it seems likely that megaherbivore grazing may have been a key driver of the declines at the Orman Reefs site, and grazing pressure is continuing to lead to reduced seagrass abundance at both sites.

- Studying megaherbivore movements and the changing spatial status of seagrass across the broader region would increase understanding of the dynamics of these plant-animal interactions in the region. This would also help to establish whether grazing is the sole cause of declines at these sites, or part of natural cycles linked to other drivers such as wind, sediment movements or other impacts to seagrasses

- This study confirms megaherbivore grazing is a key element in shaping seagrass dynamics in Torres Strait and points to the value of further assessments of megaherbivore and seagrass dynamics in northern Australia.

1. Introduction

Torres Strait is home to some of the most extensive and diverse seagrass meadows in the world (Coles et al., 2003; Carter et al., 2014). These seagrass meadows are hugely important, both ecologically and culturally. Seagrass meadows provide valuable ecosystem services such as protecting coastlines from erosion, storing carbon and providing a home for fisheries species (Nordlund et al., 2016). Seagrasses are also a food source for a range of herbivores, from invertebrates, to fish, to dugong (Scott et al., 2018). Torres Strait seagrasses support the largest dugong (*Dugong dugon*) population in the world and large numbers of green turtles (*Chelonia mydas*) (Limpus, 2008; Marsh et al., 2011). The seagrass meadows in Torres Strait are culturally important to communities, both in terms of their intrinsic value, and as a critical food source for totemic megaherbivores - green turtles and dugong (TSRA, 2016).

Although seagrasses are well adapted to cope with grazing pressure, herbivory can cause changes in the characteristics of seagrass meadows. Grazing can structure seagrass meadows by reducing aboveground biomass and canopy height as herbivores feed, and changing seagrass species composition by causing a shift towards faster growing species that are better adapted to high levels of disturbance (Scott et al., 2018). These structuring impacts of herbivory on seagrasses can be particularly dramatic when megaherbivores such as green turtles and dugong are present (Bakker et al., 2016). Megaherbivores consume large amounts of seagrass, move between meadows, and can have more destructive feeding strategies. For example, dugongs consume both above and belowground seagrass while grazing, and green turtles may form grazed plots as they feed, consuming almost all the aboveground material in a small area and causing reductions in belowground plant material too (Marsh et al., 2011; Scott et al., 2020). These grazer-mediated changes in seagrass meadow structure can alter the ecosystem services that a meadow provides (Scott et al., 2018; Christianen et al., 2021).

Overgrazing by megaherbivores has led to seagrass meadow loss in some locations. Overgrazing often occurs where numbers of herbivores increase due to effective conservation programs, but their predators are declining (Heithaus et al., 2014). This mismatch means herbivores can reach densities greater than the seagrass meadow can support. If excessive grazing pressure is sustained over a long period, it may lead to the loss of one or many meadows in an area; such losses have been observed in Bermuda, Indonesia and the Indian Ocean (Christianen et al., 2014; Fourqurean et al., 2019; Gangal et al., 2021).

Seagrass meadows in Torres Strait are surveyed as part of the Torres Strait Seagrass Monitoring Program. This program identified dramatic declines in seagrass condition, particularly reductions in biomass and larger and more stable species, in the Western Cluster in 2019 and 2020 (Figure 1; Carter et al., 2020; Carter et al. 2021). Seagrass meadow condition around Mabuyag Island, Orman Reefs and the Dugong Sanctuary decreased dramatically from very good condition to poor and very poor condition respectively in the 2020 Torres Strait Seagrass report card (Carter et al., 2020). The 2021 report card showed Orman Reefs remained in a poor condition (Carter et al., 2021). Meadows in this region provide a critical food source for some of the highest densities of green turtles and dugong in Torres Strait (Hagihara et al 2016) and are culturally important to the local communities. The Torres Strait Regional Authority (TSRA), Rangers and Traditional Owners therefore identified the widespread declines in deep-water, intertidal island and reef-top seagrass meadows in the Torres Strait Western Cluster as a critical concern.

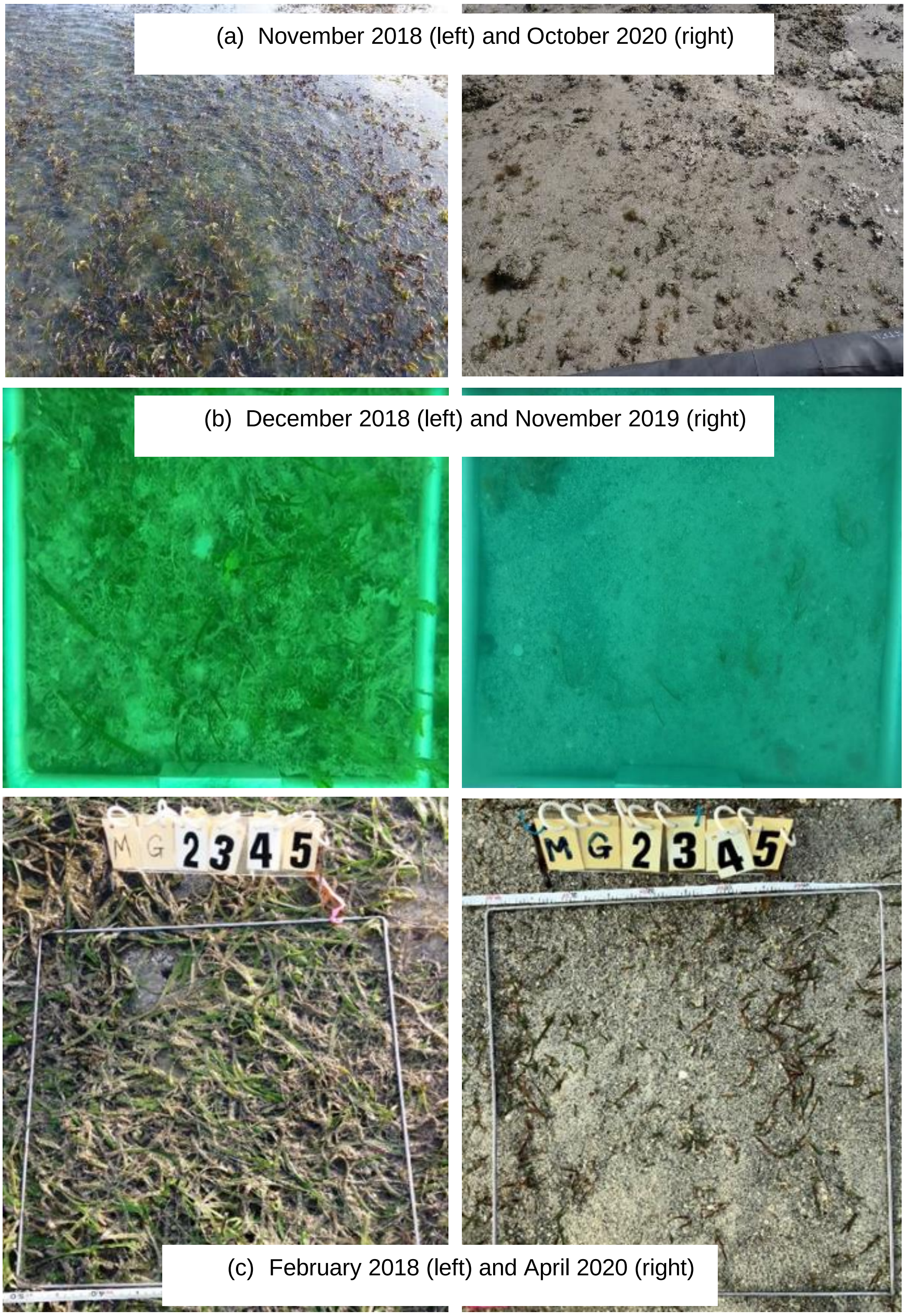

Figure 1: Seagrass abundance (biomass/ percent cover) declines were detected by all monitoring programs in the Western Cluster: (a) meadow-scale intertidal Reef-top Monitoring Program at Gariar Reef, (b) Ranger-led Subtidal Monitoring Program at Orman Reefs, and (c) Ranger-led Torres Strait Seagrass Observers Program at Mabuyag Island.

Seagrass diebacks have implications for the local communities who rely on healthy seagrass meadows and the animals they support. Any dieback events are also likely to cause long distance movements of megaherbivores, which would have implications for seagrass meadows and communities throughout the Torres Strait and northern Australia (Preen and Marsh, 1995; Marsh and Kwan, 2008). Indigenous Knowledge and scientific studies demonstrate seagrass diebacks have occurred previously in this region, but the causes of these declines are unknown (Johannes and MacFarlane, 1991; Poiner and Peterkin, 1996; Marsh et al., 2004). Potential causes for the recent seagrass declines were identified by scientists and Traditional Owners: (1) changed environmental conditions, (2) disease, and (3) increased herbivory. Testing of seagrass samples as a collaboration between Rangers, Traditional Owners and DAWE biosecurity ruled out the presence of disease in western Torres Strait (Carter et al., 2021). Changes in environmental conditions may have contributed to declines, but local data to confirm this is limited (Carter et al., 2021).

Unusually large numbers of grazing green turtles and dugong were observed by researchers, Rangers and Traditional Owners in areas where seagrass declines were most dramatic. The community, through the Goemulgaw Prescribed Body Corporate (PBC) and TSRA Land and Sea Rangers at Mabuyag Island, identified a need to understand the role of herbivory in these declines and championed the co-development of a partnership with James Cook University researchers. The aim of this study was to (1) quantify the role of grazing by megaherbivores in structuring the seagrass meadows on Orman Reefs and Mabuyag Island, and (2) understand the degree to which grazing may be contributing to seagrass declines. This information will inform management measures and any interventions that may be required.

2. Methods

2.1 Study sites

We use a short-term field study, adapting recent methods applied in the Great Barrier Reef (Scott et al., 2020, 2021a, 2021b, York et al., in prep), to investigate the role of megaherbivore grazing in two key locations where seagrass declines have been most dramatic: the Orman Reefs and Mabuyag Island (Figure 2). The experiment was set up at two locations shown in Figure 2; Mabuyag Island and Koey Maza (Kai Reef), the largest reef in the Orman Reef complex. Koey Maza is an intertidal reef-top meadow dominated by the common reef-associated seagrass species *Thalassia hemprichii.* Mabuyag Island is a diverse intertidal meadow with up to seven species present; in recent surveys this meadow has been dominated by either *Cymodocea serrulata* or *T. hemprichii* (Carter et al., 2021).

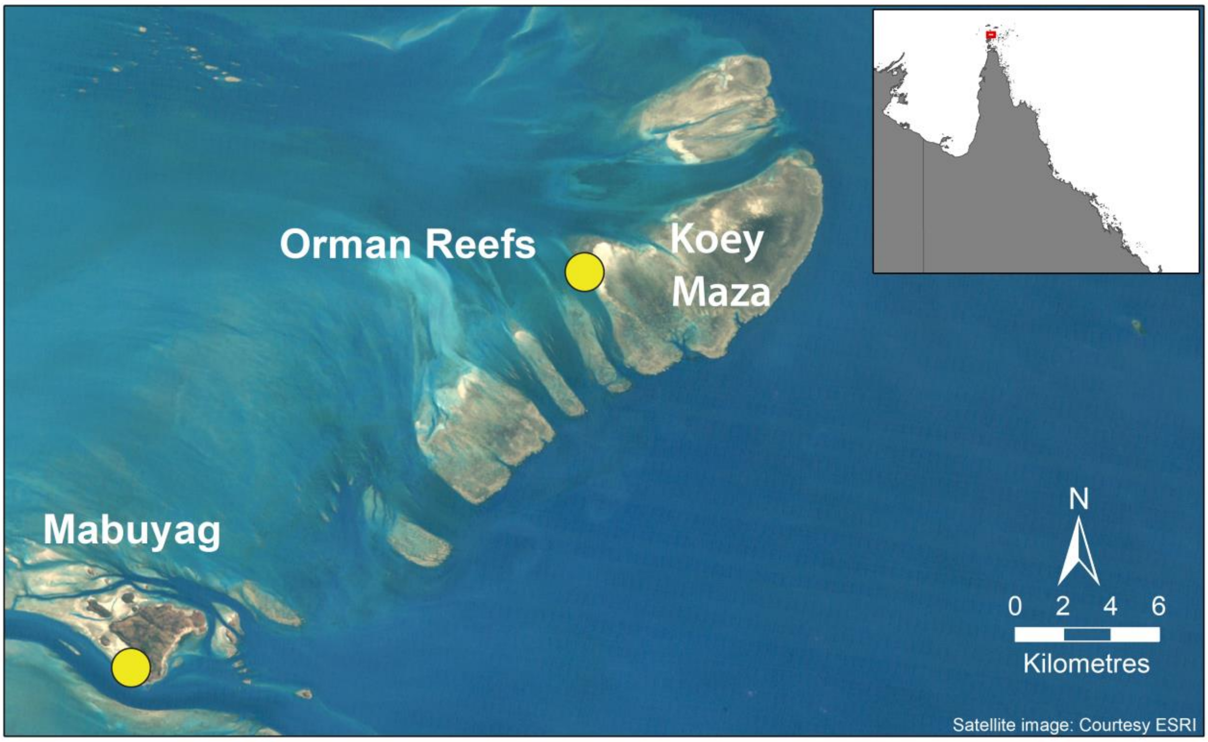

Figure 2: Map of Mabuyag and Orman Reefs with experimental sites shown as yellow dots

2.2 Field methods

Megaherbivore exclusion cages were used to prevent green turtles and dugong grazing on small areas of seagrass. Six steel megaherbivore exclusion cages 2 x 2 x 0.5 m were deployed in the seagrass at each location and secured with steel pegs, six control plots 2 x 2 m were established adjacent to exclusion cages and corners were marked with star pickets. Seagrass metrics (biomass and canopy height) inside cages and adjacent control plots were measured at the beginning (September 2021), during the experiment at two months (November 2021) and six months, (March 2022) and at the end of the experiment after seven months (April 2022) to understand the grazing pressure on seagrass meadows in both locations. Previous studies in tropical locations using the same exclusion cages have shown that experimental units do not impact the light environment (Scott et al 2020, 2021).

Within each plot, three replicate 0.5m^2 quadrats were used to collect data on the seagrass meadow. Seagrass canopy height was measured by grasping a handful of seagrass and ignoring the longest 20% (Duarte and Kirkman 2001), four canopy height measurements were taken from each of the three quadrats. Seagrass aboveground biomass was measured in each quadrat using assessments in the field and post-field calibrations following the methods described in Mellors (1991).

2.3 Data analysis

The effects of time and treatment (and their interaction) on (1) canopy height and (2) seagrass biomass was analysed using a generalised linear model (GLM) with a gamma distribution and log-link in R v3.5.2 (R core team, 2019). Each location was analysed separately. Analysis of deviance was used to determine significance levels of main effects and F statistics are presented for each model. For each model a post-hoc Tukey test was conducted to compare differences between caging treatments at each sampling time using the *emmeans* package (Lenth, 2019). Residual and q-q plots of normalised results were inspected for heteroscedasticity and non-normality. Data were plotted using the *ggplot2* package (Wickham, 2016).

2.3.1 Restrictions on analysis

During the March 2022 survey of Orman Reefs, damage to one of the cages and the seagrass inside the cage was evident, so this cage was excluded from the analysis for March and April 2022. Canopy height at Orman Reefs was not measured in April 2022 due to tide restrictions, however biomass was recorded.

We were unable to sample the site at Mabuyag Island in March 2022 due to COVID restrictions, however both canopy height and aboveground biomass were measured in April 2022.

3. Results

Excluding megaherbivores from grazing impacted seagrass structural properties at both locations, but the time taken for there to be a significant positive effect on seagrass growth varied. The differences inside and outside of exclusion cages were visible at the end of the experiment in April 2022 (Figure 3).

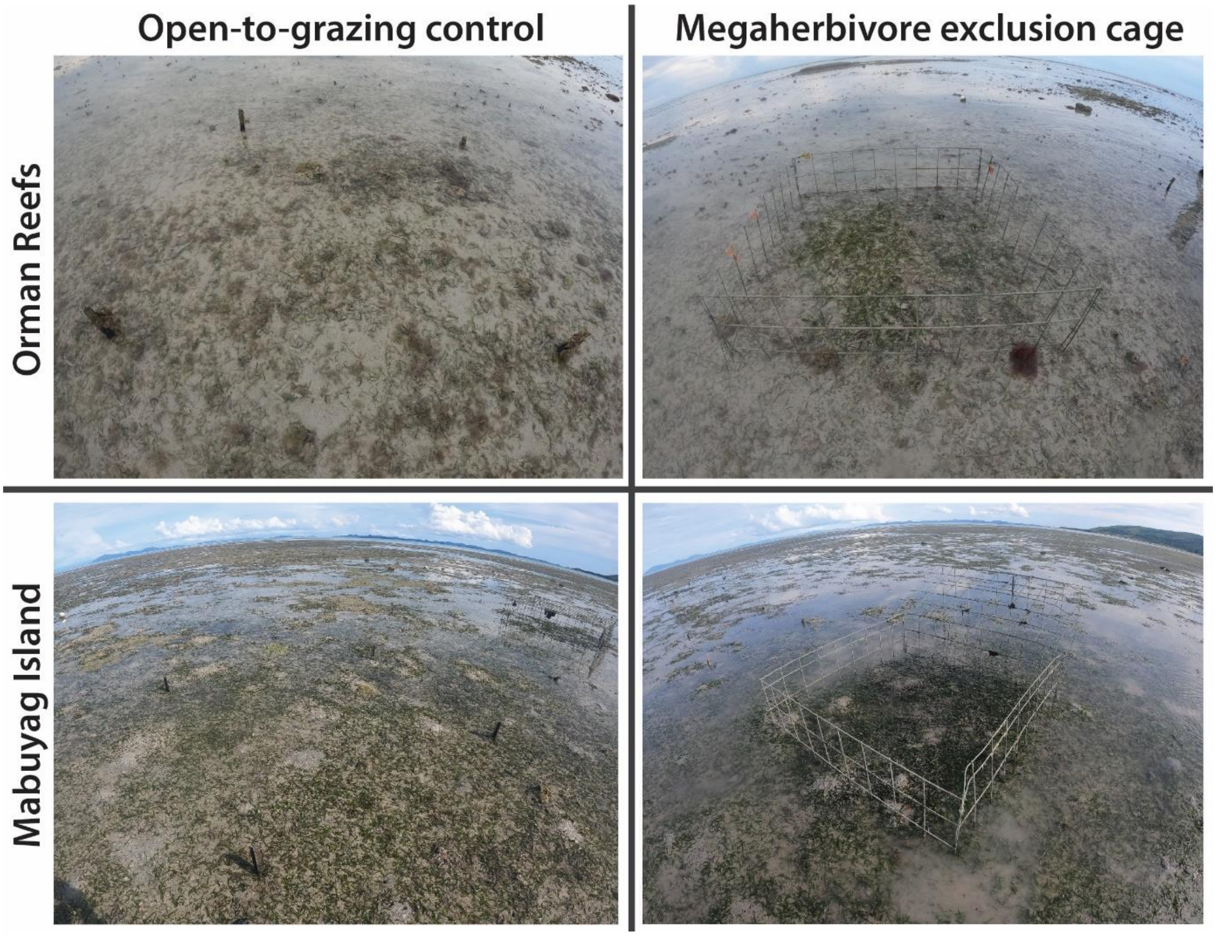

Figure 3: Field observations from final sampling in April 2022 at Orman Reefs and Mabuyag Island.

3.1 Orman Reefs

3.1.1 Canopy height

Canopy height was the same in exclusion cage and control plots at the start of the experiment on Orman Reefs (Tukey post hoc; $p>0.05$), but was significantly higher in exclusion cages after two months (November 2021; Tukey post hoc; $p<0.0001$) and six months (March 2022; Tukey post hoc; $p<0.0001$) with no grazing (time x treatment interaction; $F_2=17.1258$, $p<0.001$) (Figure 4).

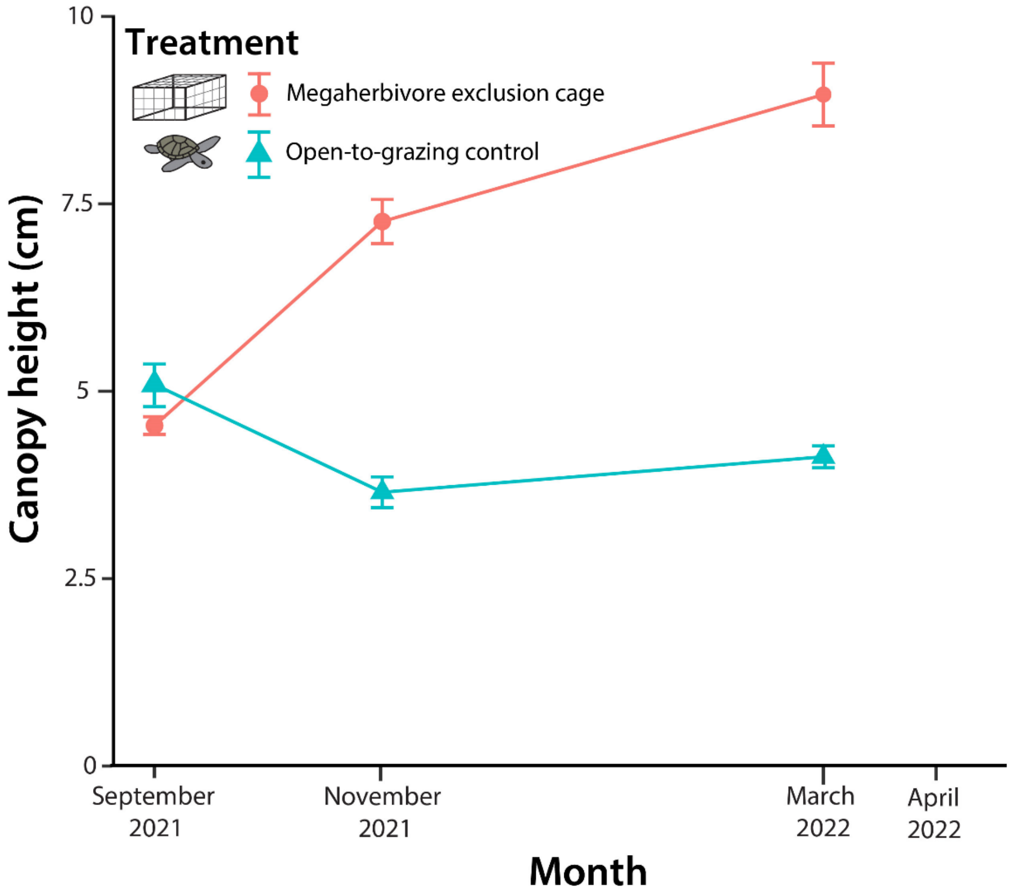

Figure 4: Mean canopy height with standard error for cage and control plots at Orman Reefs.

3.1.2 Aboveground biomass

There was no difference in aboveground biomass between exclusion cage and control plots at the start of the experiment on Orman Reefs (Tukey post hoc; $p>0.05$). Within two months of caging, seagrass biomass inside the exclusion cages was significantly greater (Tukey post hoc; $p<0.001$), and continued to increase over the life of the experiment (time x treatment interaction; $F_3=50.383$; $p<0.001$). By the end of the experiment, aboveground biomass inside the exclusion cages was over five times greater than in the control plots where grazing had continued (Figure 5).

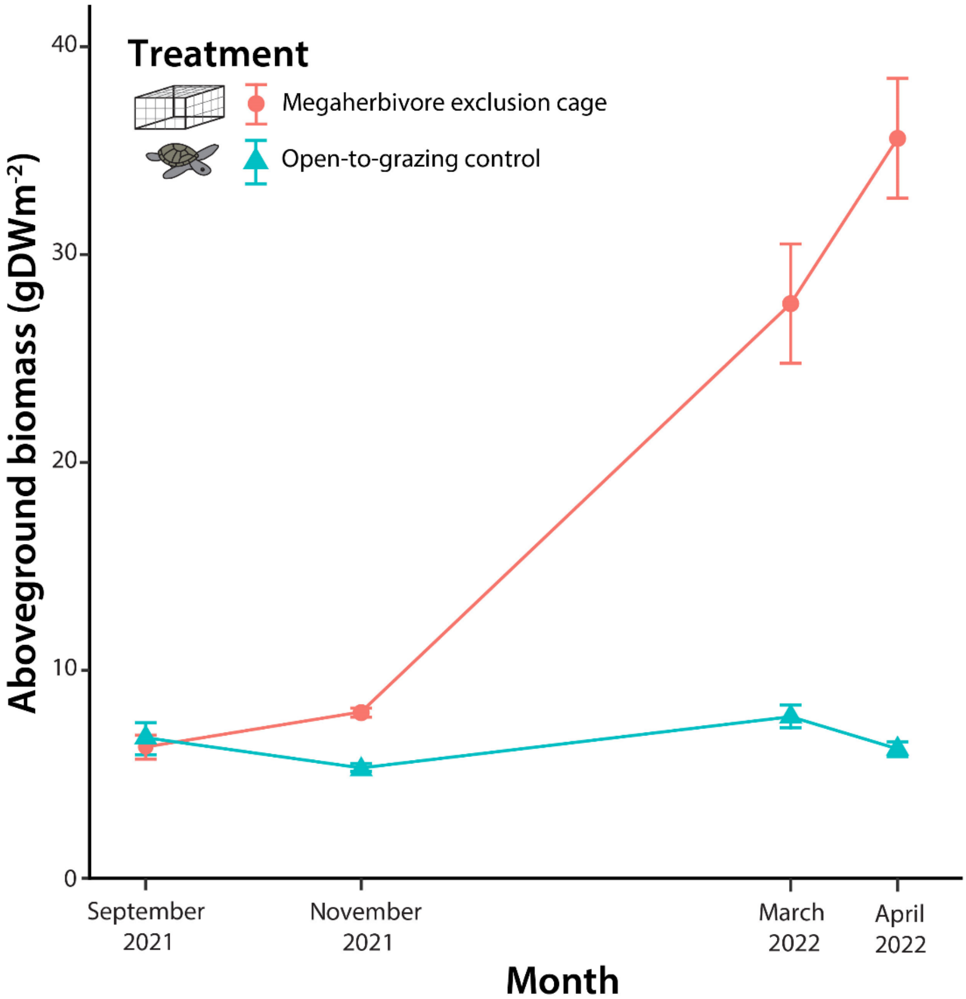

Figure 5: Mean aboveground biomass with standard error for cage and control plots at Orman Reefs.

3.2 Mabuyag Island

3.2.1 Canopy height

Canopy heights were the same in exclusion cage and control plots for the first two months of the experiment at Mabuyag Island (Tukey post hocs; $p>0.05$) (time x treatment interaction; $F_3=43.043$ $p<0.001$). By April 2022, mean canopy height was significantly longer (6.74 +/- SE cm) compared with control plots (4.22cm +/- SE) (time x treatment interaction; $F_3=43.043$ $p<0.001$); Figure 6).

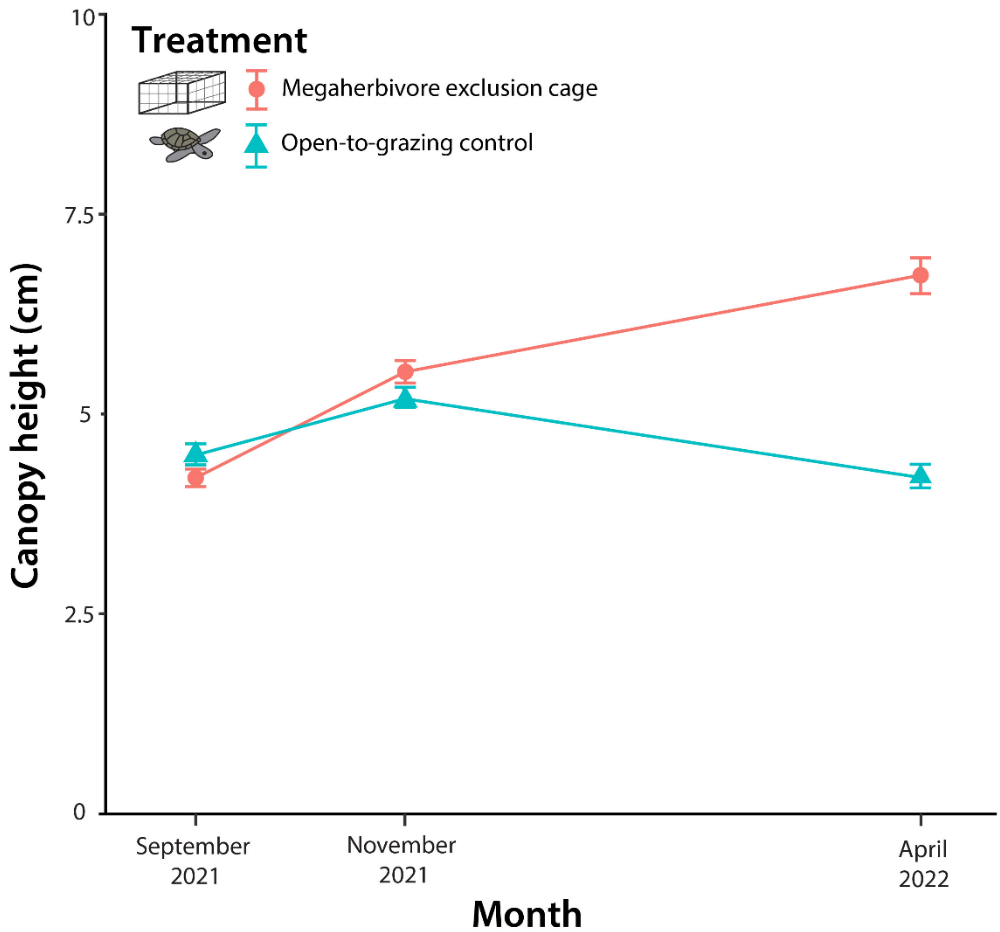

Figure 6: Mean canopy height with standard error for cage and control plots at Mabuyag Island.

3.2.2 Aboveground biomass

The effect of caging on aboveground biomass over time was similar to the effect on canopy height at Mabuyag Island (time x treatment interaction; F_3=118.118, p<0.001). Aboveground biomass was similar in exclusion cages and control plots for the first two months of the experiment (Tukey post-hocs; p>0.05), before increasing significantly in April 2022 (Tukey post-hoc; p<0.0001), where canopy height in the exclusion cages was almost double that of control plots (Figure 7).

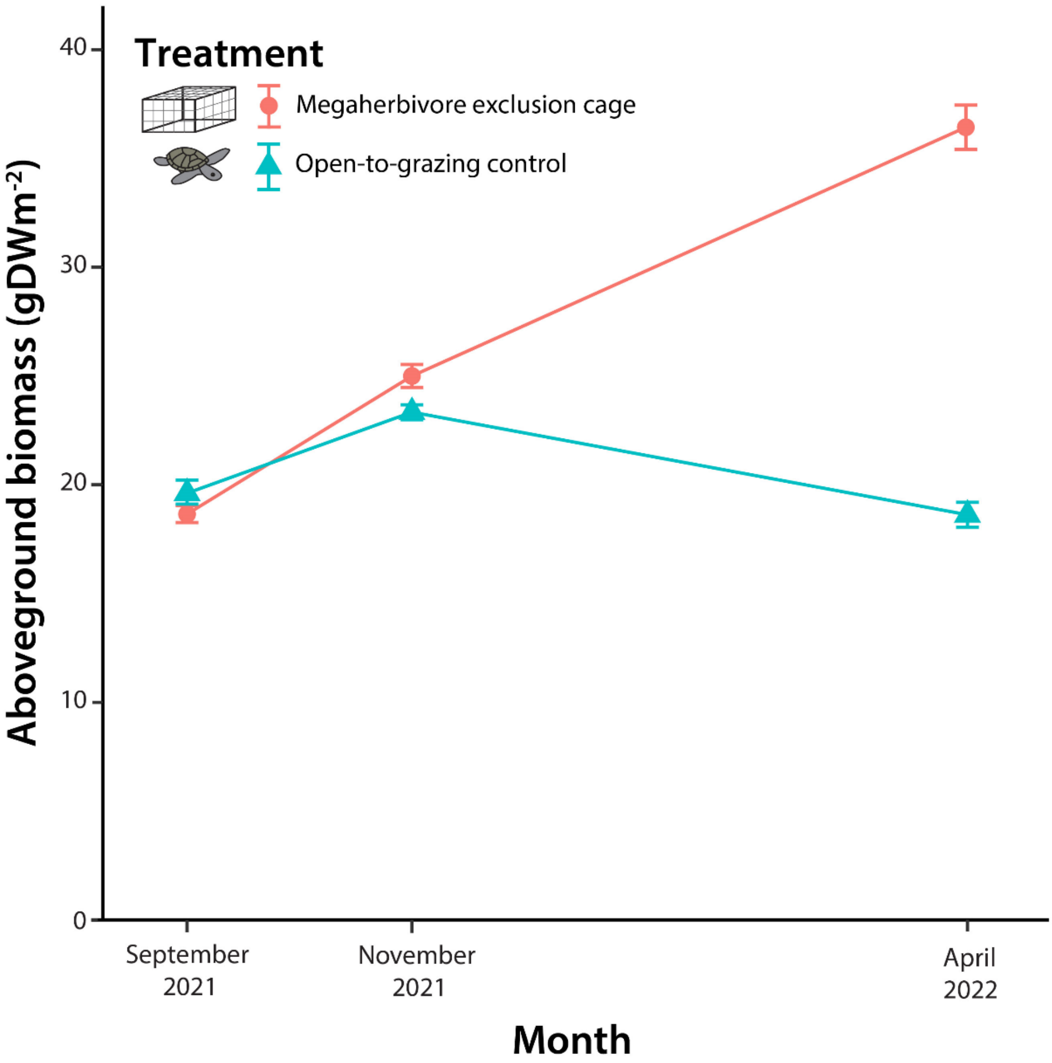

Figure 7: Mean aboveground biomass with standard error for cage and control plots at Mabuyag Island.

4. Discussion

4.1 Impact of herbivory

Megaherbivore grazing is suppressing aboveground biomass and canopy height at Orman Reefs and Mabuyag Island. The time frame for the effect of excluding megaherbivores from seagrass grazing to become measurable differed between locations – two months at Orman Reefs and seven months at Mabuyag Island - but was significant at both locations by the end of the experiment. Seagrass in the grazed control plots had shorter canopy height and lower aboveground biomass compared to seagrass within exclusion cages. These differences were particularly dramatic considering the relatively short seven-month time frame of this experiment.

Exclusion studies have shown that grazing by megaherbivores causes similar reductions in seagrass structural characteristics in meadows on the Great Barrier Reef and across the world (York et al. in prep; Heithaus et al., 2014; Scott et al., 2018). The outcomes in terms of seagrass structure will depend on the numbers of megaherbivores and the grazing strategy they use, as well as seagrass productivity (Scott et al., 2020, 2021a; Christianen et al., 2021). Megaherbivores may graze across the seagrass meadow as a whole in a 'random constant' pattern, or can focus their grazing in a 'random occasional' or 'patch rotation' pattern (Christianen et al., 2021). The sites in this study did not appear to be within a grazed patch, and helicopter surveys within this meadow and around the experimental site showed that control plots were representative of the meadow more broadly for the duration of the experiment (Carter et al 2022). Therefore, the megaherbivores in this study appear to be using a random constant strategy and browsing across the meadow as a whole. This strategy is similar to other locations in the Great Barrier Reef (York et al., in prep; Scott et al., 2021a).

Significantly greater seagrass aboveground biomass and canopy height in caged plots indicates a high grazing pressure across both meadows. Traditional Owner, Ranger and scientist observations over the period of this experiment indicate green turtles were present at both locations. The seagrass at both locations were cropped, suggesting green turtle grazing was the major contributor to our findings. Dugongs generally feed by consuming both above and belowground seagrass material, leaving distinctive feeding trails through a meadow (Tol et al., 2016). No dugong feeding trails were observed at either site in this study, indicating dugong grazing pressure is likely to be lower than green turtles at these sites.

Green turtles and dugongs in Torres Strait are known to move throughout the region to forage (Cleguer et al., 2016, Gredzens et al., 2014). The high numbers of green turtles in the area could be due to increases in the population, or larger-scale movements driven by seagrass declines in deep water seagrass meadows in the Central and Western Clusters (Carter et al., 2021). A better picture of green turtle populations and movements over space and time in Torres Strait would help to understand links with changes in seagrass meadows.

Seagrass structure at Orman Reefs and Mabuyag Island meadows was reduced by grazing, however there were differences in the scale of the impact and the time taken to detect it. At Mabuyag Island there was no difference between exclusion cages and open-to-grazing control plots until after seven months, at the end of the experiment. At Orman Reefs the impacts of grazing could be seen after two months, and were much more dramatic. This indicates that grazing pressure in the reef-top seagrass meadow is much higher.

4.2 Management implications

Grazing pressure was high in this study, but this does not necessarily mean these meadows are in a state of decline. Seagrasses evolved under intense herbivory and are well adapted to grazing by large numbers of diverse megaherbivores (Domning, 2001; Jackson et al., 2001). In fact, a mosaic of meadows subjected to a range of grazing pressure could be more representative of the pre-Anthropocene conditions under which seagrasses evolved (Christianen et al., 2021). If the plant-herbivore system is in balance, and seagrass productivity is being consumed by megaherbivores, the meadow may appear in a poor state in terms of seagrass structure, however the meadow itself could still be productive (Scott et al., 2018). If grazing pressure does exceed a threshold level and seagrass productivity is unable to keep up, then overgrazing can occur.

Managing plant-herbivore interactions in heavily grazed meadows requires understanding when the threshold grazing limit has been reached. Overgrazing in seagrass meadows by megaherbivores in other parts of the world have been characterised by a gradual degradation in seagrass condition before meadow collapse (Fourqurean et al., 2019; Gangal et al., 2021). The time taken for green turtle grazing to deplete a meadow can depend on both meadow size and numbers of turtles (Gangal et al., 2021). Meadow decline may start with a species shift in the meadow, or with shoots that are shorter and narrower (Fourqurean et al., 2019). Both of these changes were observed at our study locations. Understanding where the threshold is in terms of overgrazing is essential, but can be challenging to identify. Regular monitoring of seagrass meadow condition and herbivore numbers and how these interact, along with research into carrying capacity of meadows, will help to identify grazing impacts and build our understanding of grazing thresholds.

We do not know if the current condition of seagrasses and level of grazing pressure is part of a normal cycle at Orman Reefs and Mabuyag Island. Seagrass monitoring at both locations indicates seagrasses are at historically low levels (Carter et al. 2021); however, monitoring has occurred for just four years at Orman Reefs, and ten years at Mabuyag Island, and cycles of seagrass decline and recovery can occur over much larger timescales (Carter et al. 2022, Dunic et al., 2021). At the Koey Maza meadow on Orman Reefs this has resulted in the near absence (less than 0.3% of biomass) of one of the key larger growing species *Enhalus accoroides* (Carter et al. 2021). We did not directly analyse species change in this study, but observed that *E. acaroides* was able to grow in caged plots, indicating the potential for recovery with a reduction in grazing pressure. Continued monitoring of the seagrass and herbivore dynamics will be important to understand if grazing pressure does push the meadow towards a tipping point.

4.3 Recommendations for future research

This study, along with other research, shows that megaherbivores are playing a large role in structuring both tropical and sub-tropical meadows across the Great Barrier Reef and Torres

Strait (York et al. in prep; Scott et al., 2020, 2021a). The grazing strategy used varies across this region with both 'random constant' and 'patch rotation' observed (York et al., in prep; Scott et al., 2020, 2021a). Despite recent research efforts, there is still a limited understanding of patterns of megaherbivory over space and time in Australian seagrasses, this information is key to ensure the conservation of both seagrass meadows and the herbivores that depend on them. Given the importance of seagrass ecosystems to people and wildlife, understanding the top-down drivers of meadow structure is also critical for effective management.

Future research should focus on:

- Carrying capacity estimates of seagrass meadows in terms of megaherbivore grazing.
- Studies across Torres Strait and Northern Australia, where very little is known about megaherbivory in seagrass meadows, to understand regional patterns in herbivory.
- Large-scale combined seagrass-herbivore surveys to understand how herbivore movements interact with changes in seagrass meadow structure.
- Incorporating seagrass productivity measurements to understand more about seagrass responses to grazing.
- Understanding more about numbers of megaherbivore predators.

4.4 Conclusions

Recent declines in seagrass meadow condition in Torres Strait are of concern to local communities and could have far reaching implications for the herbivores that rely on these meadows, and the ecosystem services that they provide.

This study showed that grazing by megaherbivores is structuring seagrass meadows in Torres Strait and is potentially contributing to the observed declines. Although declines have been previously documented (Johannes and MacFarlane, 1991; Poiner and Peterkin, 1996; Marsh et al., 2004), we do not have a good understanding of drivers of decline and pathways to recovery. Current grazing pressure may be a result of herbivore movements due to declines in other areas of Torres Strait, if this grazing pressure is continued it may cause meadows to exist in an altered state and could lead to loss of slower growing seagrass species.

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