Significant effect of human trampling on subtidal seagrass beds

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Abstract. Human trampling in subtidal nearshore waters is often an unavoidable consequence of routine activities carried out by local people living in small islands, especially during low tide. An experiment was conducted around Barrang Lompo Island in South Sulawesi, Indonesia to determine the effect of human trampling on the multi-species subtidal seagrass beds. Two daily trampling treatments (by an adult and by children) were applied to seagrass beds for about two weeks. Seagrass density was significantly decreased by human trampling, although the impact of trampling by an adult and by children was not significantly different. In terms of leaf loss, the seagrass most heavily impacted by trampling activities was *Cymodocea rotundata* which was also the densest species. Two species were significantly differently affected by adult and children trampling: *Syringodium isoetifolium* leaf loss was much higher when trampled by children, while *Halodule uninervis* suffered much more from uprooting and rhizome damage when trampled by an adult. The results suggest that daily human trampling activities can potentially cause significant damage to seagrass communities, with the extent of damage determined mostly by the properties and relative abundance of each species rather than differences in tramply by adults and children. This indicates a need for further research on the relationship between the specific traits of seagrasses and environmental factors that influence seagrass response to and recovery from mechanical disturbances such as trampling.

Key Words: human trampling, subtidal, *Cymodocea rotundata*, *Syringodium isoetifolium*, *Halodule uninervis*.

Introduction. Seagrass beds are highly productive marine ecosystems with a high diversity of seagrass species and supporting a diversity of marine fauna (Hemminga & Duarte 2000; Francis et al 2001). For example 27 families of Polychaetes, 10 species of gastropods, and 18 species of bivalves were found in the seagrass ecosystems of Kung Krabaen Bay, Thailand (Satumanatpan et al 2011), 82 species of macrofauna were found in seagrass beds in the Kingdom of Bahrain (Al-Wedaei et al 2011), 120 fish taxa were found in tropical Southeast Asian seagrass meadows (Pogoreutz et al 2012), while 63 fish taxa (Nadiarti et al 2015) and 149 benthic macrofaunal species (Lin et al 2018) have been reported from Indonesian seagrass beds.

Unfortunately, there is an increasing evidence of a decline in seagrass ecosystem extent and condition due to human disturbances such as direct physical damage and decreased water quality (Duarte et al 2004; Waycott et al 2009; Govers et al 2014; Evans et al 2018; Joseph et al 2018). Human trampling is considered to be one of the causes of seagrass degradation and loss (Short et al 2011) and is a part of daily activities, especially for local residents in small islands. This is a common phenomenon in Indonesia, where trampling activities mostly happen when gleaning at low tide, or when operating gill nets during fishing in the seagrass beds (Short et al 2011; Nurdin et al 2019).

There are relatively few studies on the effects of human trampling on seagrass beds. Those available have mostly addressed the effect of human trampling on temperate seagrass beds, e.g. the effects on *Thalassia testudinum* seagrass beds and on sexual reproduction in the seagrass *Zostera noltei* (Eckrich & Holmquist 2000) as well as the effect of trampling and digging on *Z. noltei* intertidal seagrass beds (Garmendia et al 2017). There is a dearth of studies in tropical the multispecific seagrass beds, although Nurdin et al (2019) carried out a preliminary study on trampling in intertidal seagrass beds, albeit with limited time-frame and a lack of replicates.

The present study investigated the direct impacts of trampling by an adult and by children on the multispecific subtidal seagrass beds around Barrang Lompo Island, Indonesia. This study compared the impacts of adult trampling and trampling by children on the seagrass meadows, including the effect on seagrass density and the relative severity of damage suffered by different seagrass species.

Material and method

Trampling experiment design. The human trampling experiment was carried out over 13 days (from 23rd August to 4th September 2020) in the subtidal seagrass beds around the south-southeast coast of Barrang Lompo Island, South Sulawesi, Indonesia at the approximate coordinates 05°03'01''S, 119°19'52''E (Figure 1). The percentage seagrass cover in this area was about 70-80% and the multi-species seagrass community was visually dominated by *Cymodocea rotundata,* followed by *Thalassia hemprichii* and *Syringodium isoetifolium,* interspersed with other seagrass species (*Halophila ovalis*, *Halodule uninervis*, *Enhalus acoroides*), and some macroalgal species (*Dictyota ciliata*, *Padina australis*, and *Boodlea composita*). The substrate in the study area was generally dominated by sand with some (mostly biogenic) rubble.

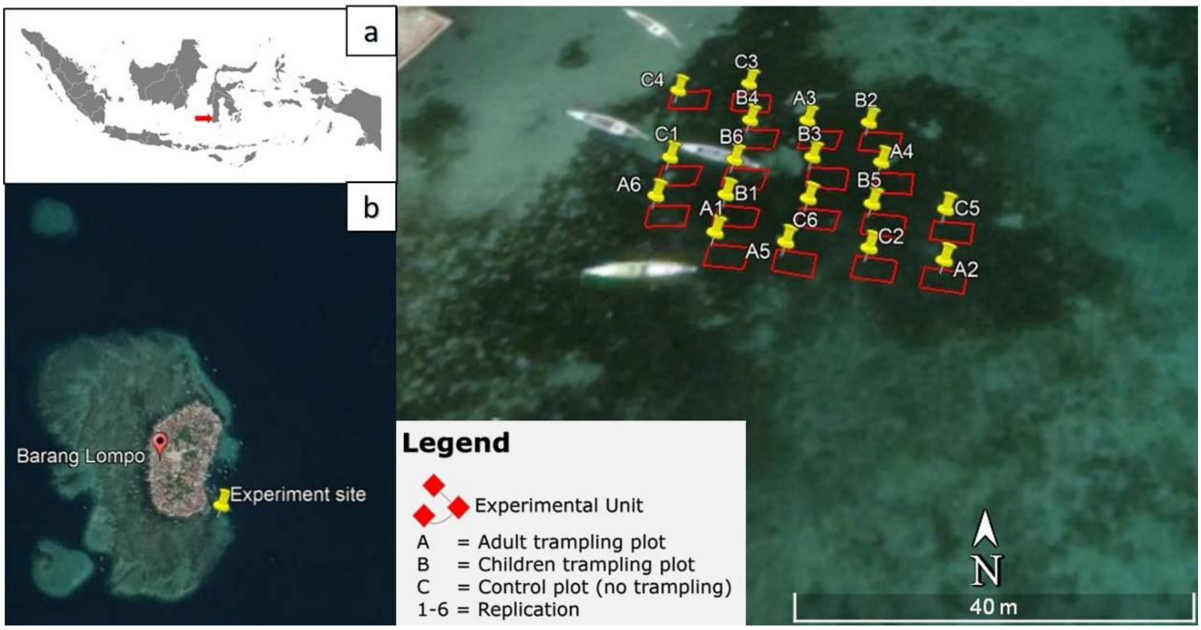

Figure 1. Satellite image (Google Earth Pro) showing the trampling experiment layout design and the location of the experimental plots in the subtidal seagrass meadows of Barrang Lompo Island (insert **b**) in South Sulawesi, Indonesia (insert **a**).

The human trampling treatment protocols were adopted from Nurdin et al (2019) and the trampling frequency was adopted from Eckrich & Holmquist (2000) and Garmendia et al (2017). The three experimental treatments were: A. adult trampling; B. children trampling; and C. no trampling (control). A completely randomized experimental design was applied with six replicates per treatment, giving a total of 18 plots which were placed randomly within the experimental area. Each plot measured 3 m x 5 m (15 m^2) and the plots were at least 3 m apart (Figure 1). The trampling treatment involved one adult or three children walking back and forth 20 times from end-to end of each plot at low tide each day, with the trampling applied as evenly as possible across each trampling plot. Both the adult (68 kg) and the three children (around 30 kg each) wore rubber flip flops as is the common practice of local people in the study area. In treatment C (control plots) there was no trampling, but the same plot demarcation technique (wooden pegs and raffia string) was used.

Data collection and analysis. Seagrass density (overall and by species) in each plot was measured before and after the experiment using a quadrat (50 cm x 50 cm) (English et al 1997) with 10 replicates. Detached leaves and uprooted seagrass plants were collected separately from each plot after the trampling on every day during the experimental period. After removing all unwanted impurities such as salt particles and any organisms attached, this plant matter was oven-dried at 70°C until constant dry weight was achieved.

Seagrass densities before and after trampling experiments were compared using one-way analysis of variance (One Way ANOVA) followed by post-hoc Dunn's multiple comparison tests if significant differences were found. The dry weight of the detached seagrass leaves as well as the uprooted seagrasses and broken rhizomes collected after trampling were compared between the treatments using Two Way ANOVA followed by Bonferroni post-test if there were significant differences. All statistical analyses were performed in PRISM 5 software, with significance evaluated at the 95% confidence level ($\alpha = 0.05$).

Results. The density of each seagrass species before the experiment (Figure 2) shows that *C. rotundata* had the highest shoot density ($p < 0.0001$), followed by *S. isoetifolium* and *T. hemprichii* (not significantly different from each other). *E. acoroides*, *H. ovalis*, and *H. uninervis* were present in low shoot densities which were not significantly different from each other.

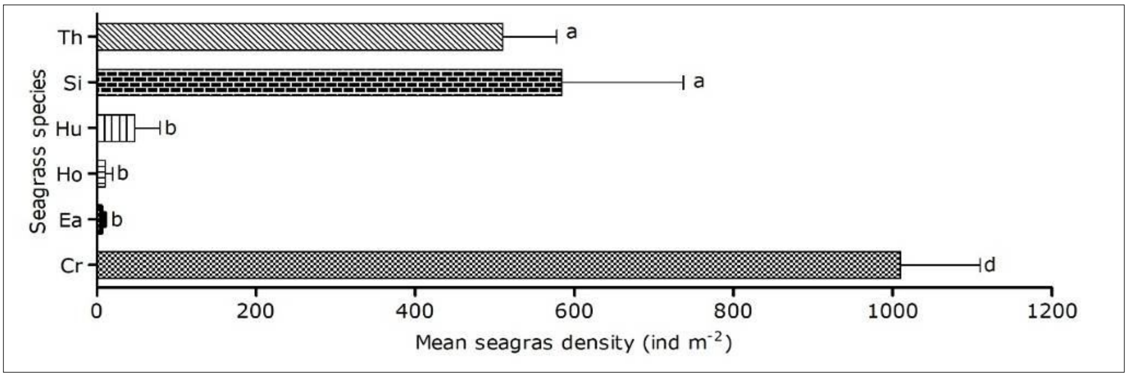

Figure 2. Density of seagrass species before experiment. *Cymodocea rotundata* (Cr), *Enhalus acoroides* (EA), *Halophila ovalis* (Ho), *Halodule uninervis* (Hu), *Syringodium isoetifolium* (Si), *Thalassia hemprichii* (Th). Error bars indicate standard error of the mean; different letters close to error bars indicate significant differences.

The combined species mean seagrass density before trampling (Figure 3A) did not differ significantly between the treatment plots ($p > 0.05$). However, the mean seagrass density after trampling (Figure 3B) was significantly lower for both the adult and children trampling plots compared to the control plots ($p < 0.05$). Furthermore, the post-trampling density was significantly different from the pre-trampling density in the plots subjected to both trampling treatments, but not in the control plots.

The biomass of detached seagrass leaves was significantly higher than the biomass of uprooted seagrasses and broken rhizomes (RtRh). However, there was no significant difference between the adult trampling treatment and children trampling treatment in terms of either detached leaves or uprooted and broken rhizomes (Figure 4).

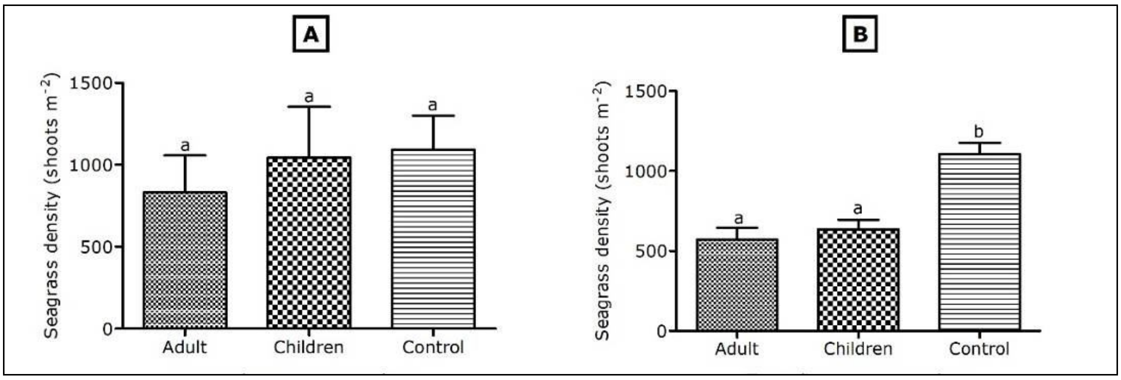

Figure 3. Mean seagrass density before (A) and after (B) the trampling experiment. Error bars show standard error; different letters above the error bars indicate significant differences ($p < 0.05$).

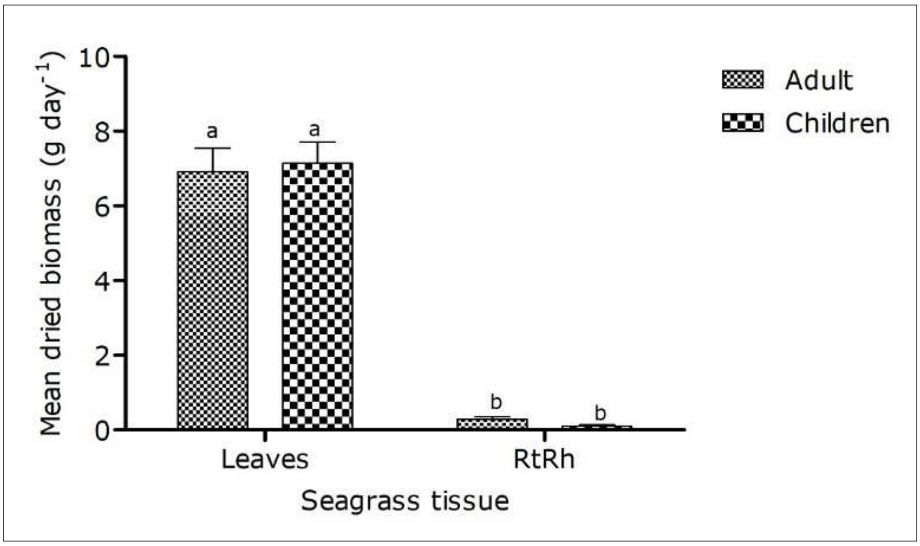

Figure 4. Dry biomass of detached seagrass leaves (Leaves) and uprooted seagrass and broken rhizome (RtRh) from adult trampling plots and children trampling plots. Error bars show the standard error; different letters above the error bars indicate significant differences ($p < 0.05$).

Detached seagrass leaves (Figure 5A) and uprooted seagrass and broken rhizome (Figure 5B) differed significantly between seagrass species. However, a significant difference between adult and children trampling treatments was only found for two species. The detached leaf biomass of *S. isoetifolium* was significantly higher in the children trampling treatment than the adult trampling treatment; conversely, the biomass of uprooted and broken *H. uninervis* rhizomes was significantly higher in the adult trampling treatment compared to the children trampling treatment.

The species with the most detached leaf biomass were *C. rotundata* and *S. isoetifolium* followed by *T. hemprichii* and *E. acoroides*. Meanwhile, the species with the highest uprooted seagrass and broken rhizome biomass were *H. uninervis*, followed by *C. rotundata, T. hemprichii,* and *S. isoetifolium.* The least damaged seagrass species were *H. ovalis* and *Halodule uninervis,* with few detached leaves, uprooted shoots or broken rhizomes during the trampling experiment.

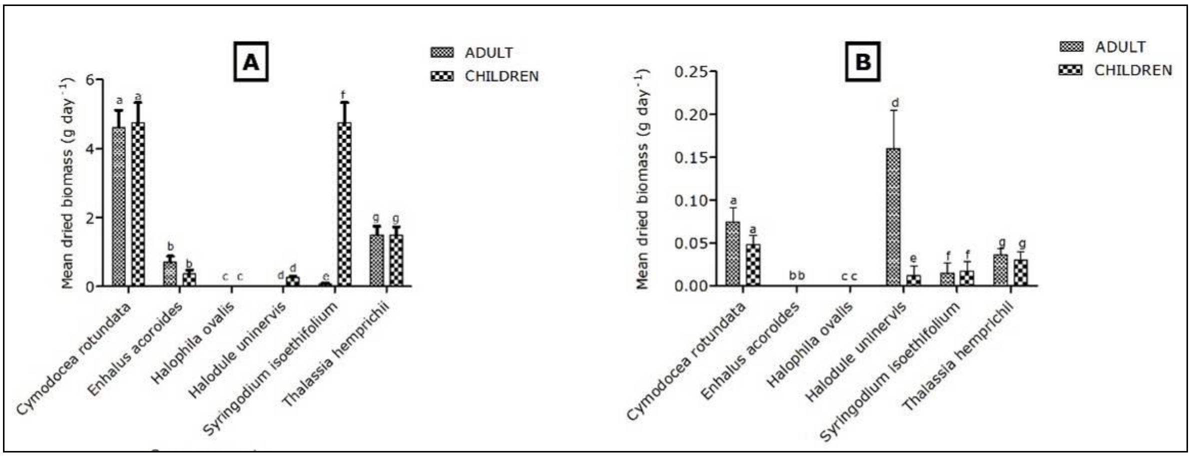

Figure 5. Dry biomass by species of detached seagrass leaves (A) and uprooted seagrass and broken rhizomes (B) in adult and children trampling plots. Error bars show standard error; different letters above the error bars indicate significant differences ($p < 0.05$).

Discussion. This study demonstrates that human trampling, whether by adults or children, can impact seagrass density and cause mechanical damage. The results differed from those of the preliminary study (Nurdin et al 2019) which indicated that trampling by children might have less impact on seagrass density compared to adult trampling. This may due to limited treatment replication and different seagrass bed conditions (e.g. intertidal compared to subtidal) as well as the different footwear (boots) worn by the adult in the previous study (Nurdin et al 2019).

The amount of seagrass damage due to trampling was comparable between the adult and children trampling treatments, with the biomass of detached seagrass leaves being higher than that of uprooted shoots and broken rhizomes. This indicates that the seagrass leaves are more vulnerable to physical damage than the root and rhizomes. The seagrass leaves as the above-ground parts of the plant are frequently exposed to direct sunlight, especially during low tides; this exposure can cause dryness and 'burning' of the leaves (Erftemeijer & Herman 1994). This vulnerability could be made more severed by trampling disturbance, and could be one factor resulting in more damage to the seagrasses above-ground (leaves) than below-ground (roots and rhizomes). Since this study was conducted in the subtidal seagrass beds, the seagrass species in this experimental site would likely be more sensitive to desiccation than those in the intertidal beds (Björk et al 1999). However, such a comparison was not included in this study due to limited human and other resources.

To our knowledge, the impact of trampling on different species has not been evaluated in previous human trampling studies. Each seagrass species in this study showed a different response to human trampling, which suggests the impacts might affect seagrass community balance, biodiversity and eventually sustainability. *C. rotundata* has thinner leaves and lower fibre content compared to some other seagrasses with similar morphology, such as *T. hemprichii* and *E. acoroides* (De los Santos et al 2016). This is likely the main reason why the leaves of *C. rotundata* experienced more damage and loss than those of the other seagrass species; another likely contributing factor is that this species was more abundant and hence more plants were damaged (Figure 2). However, the relative vulnerability of *C. rotundata* is supported by the findings of Martínez-Crego et al (2016) that, while nutrient content may play a role, the vulnerability of seagrasses is largely determined by the tenderness and thickness of leaves.

With the exception of above-ground *S. isoetifolium*, slightly more leaves were detached as a result of being trampled by children than by adults (Figure 5A). This might be due to slight differences in the seagrass community, with a slightly higher mean abundance of vulnerable species in the children trampling plots, even though the differences were not statistically significant. With respect to *S. isoetifolium*, the density of this species was (on average) slightly higher in the children trampling plots than in the adult trampling plots; also, despite their lower individual weight the aggregate trampling by children included a higher number of foot-falls per plot. The leaves of *S. isoetifolium* have a low fibre content (30.7±6.8%) compared to *C. rotundata* (44.1±4.4%) and *T. hemprichii* (46.8±7.2%), while *E. acoroides* has the highest leaf mass and area per shoot and highest fibre content (De los Santos et al 2016). These differences could make *S. isoetifolium* particularly vulnerable to even light-weight trampling. Meanwhile *E. acoroides* is likely more resistant to disturbance including human trampling pressure since the leaves can resist high breaking forces so that they are not easily broken or detached, in addition to this large species being less abundant in the experimental site.

H. ovalis and *H. uninervis* were the least damaged seagrass species during this experiment, possibly because these two species were the least abundant. In addition, their relatively short life-span (De los Santos et al 2016) and ability to quickly generate new leaves and shoots (Marbà et al 2004) could make them less vulnerable than species which are slower growing and have longer life-spans in the absence of disturbance.

The different responsiveness of each seagrass species to mechanical disturbance could be a factor in the different levels of damage done to the above and below ground parts of the seagrasses. In general, the below-ground parts of the seagrasses (roots and rhizomes) is more resistant to mechanical disturbance than the above-ground part, principally leaves (Marbà et al 2004). This is consonant with the finding that there were fewer broken rhizomes and uprooted seagrasses compared to broken leaves in this study.

Physical and chemical environmental factors may also have contributed to seagrass vulnerability to trampling, such as water turbidity that may affect stability of seagrass beds (Carr et al 2012) and nutrient content in the sediment which may affect the nutrient content in the seagrass that in turn will affect its vulnerability to mechanical disturbance (De Los Santos et al 2012).

Only *E. acoroides* and *H. ovalis* were not found uprooted in any of the plots under either treatment in this study. The largest seagrass species in Indonesia, *E. acoroides* has very thick, tough, hairless branching roots, which can embed firmly and stably in the sediment (Mckenzie 2003). Meanwhile, *H. ovalis* is a very small species with fine single shoots; although intuitively this species should be more vulnerable to disturbance such as trampling, it suffered the least damage of all species at the study site. The species with the most uprooted shoots in this study was *H. uninervis*, especially as a result of being trampled by children. Characterised by fine fibre roots attached to fine rhizomes, this species was (by random chance) somewhat more abundant in the children trampling plots. All seagrass species have short life-span compared to many land plants, and in general they have ability to recover from disturbance (Marbà et al 2004; De los Santos et al 2016). However, the scope of this study did not include the ability of seagrasses to recover from damage due to trampling.

Conclusions. This study suggests that the impact of daily human trampling activities has the potential to cause significant damage to seagrass communities, and could be a serious threat to seagrass ecosystems in the absence of proper management. The extent of damage to seagrasses due to human trampling is determined by the mechanical properties and abundance of each species more than by differences between adult humans and children. Species with leaves which are more tender and thinner appear to be more vulnerable. The results indicating a need for further studies on the relationship between the specific traits of seagrasses and environmental factors that influence the response and ability of seagrass to recover from mechanical disturbances, such as trampling.

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