Diversity, shoot density, and growth variations of seagrasses from the coastal waters of Minahasa Peninsula, Indonesia

[1]Billy T. Wagey, [1]Carolus P. Paruntu,[2]Ridwan Lasabuda

[1] Marine Science Department, Faculty of Fisheries and Marine Science, Sam Ratulangi University, Manado, Indonesia; [2] Management of Aquatic Resources Department, Faculty of Fisheries and Marine Science, Sam Ratulangi University, Manado, Indonesia. Corresponding author: B. Wagey, billywagey@unsrat.ac.id

Abstract. Seagrasses are ecologically and economically important marine plants. The abundance, diversity, growth and morphology are influenced by the biophysical conditions of their environment. In this paper we compared these parameters in three sampling locations in the Minahasa Peninsula in Sulawesi, Indonesia in relation to the biophysical factors. Shoot density of three species of seagrass differ between sites, particularly higher shoot density for *Enhalus acoroides* in Bolmong while reduced density in the other two species (*Thalassia hemprichii* and *Syringodium isoetifolium*) in Bunaken. This study revealed that aside from nutrient levels (nitrogen and phosphorus), physico-chemical parameters did not significantly differ between sampling locations yet seagrass diversity and growth rates differ between locations. The data presented herein can be used as baseline information to pursue conservation of seagrass ecosystem in the Minahasa Peninsula and adjacent coastal waters.
Key Words: ecology, morphology, seagrass, shoot density, Sulawesi.

Introduction. Seagrasses are submerged macrophytes that play key ecological functions (Spalding et al 2003). The ecological and economic importance of seagrass meadows is well-known (McKenzie et al 2021). They have high biological productivity comparable to other ecosystems (Duffy 2006). Seagrass beds serve primarily as nursery grounds especially for commercially important fishes (Jackson et al 2001) and are home to a wide array of economically important invertebrates (Unsworth & Cullen 2010). Aside from primary production, their ecological functions include recycling nutrients, stabilizers bottom waters, sediment traps and barriers to erosion (Nadiarti et al 2012). Indonesia has a fair share of the world's seagrass ecosystems. However, Indonesia's seagrass meadows are under threat due to anthropogenic activities (Unsworth et al 2018).

Wagey (2017, 2018) provided a review of the studies done in Indonesia and nearby areas on seagrass ecology with emphasis on researches in the North Sulawesi waters. Tilaar et al (2019) underscores the importance of seagrasses in Sulawesi and elsewhere in Indonesia in terms of their role as carbon sink. In the face of the global problem of climate change, seagrass beds are known as carbon sink (Duarte et al 2010) and therefore, monitoring their productivity and related parameters such as growth, shoot density, diversity patterns, amongst others will be highly beneficial not just in terms of the ecological services that these submerged macrophytes has been providing but also in terms of their contribution in sequestering anthropogenic carbon dioxide. Such information can also be vital in monitoring the health of seagrass beds as an ecosystem to determine possible impacts of coastal developments (Cullen-Unsworth & Unsworth 2016) to subsequently better inform the general public and policy makers for the better management of seagrass habitats and adjoining marine habitats like coral reefs through citizen science approaches (Hyder et al 2015; Fortes et al 2018).

This study aimed to provide a more comprehensive assessment of the seagrass abundance (expressed as shoot density), diversity, and growth rates in relation to the biophysical conditions in the Minahasa Peninsula of the North Sulawesi, Indonesia.

Material and Method

Description of the study sites. The study was conducted in three sampling stations in the coastal waters of the Minahasa Peninsula (Figure 1). Specific locations of the sampling sites were marked with a hand-held GPS (Yucom trek 100G). Bunaken (1.573391°N; 124.805580°E) sampling station is within the Bunaken National Park (BNP) in Manado City. Bolmong (0.847726°N; 123.913579°E) is located in the southwestern segment of Minahasa Peninsula. Both Bunaken and Bolmong stations are part of the Celebes Sea and along the western side of the Minahasa peninsula. Basaan (0.938118°N; 124.792819°E), on the other hand, is located at the western side of the peninsula facing the Molucca Sea. All stations have sandy-muddy substrates.

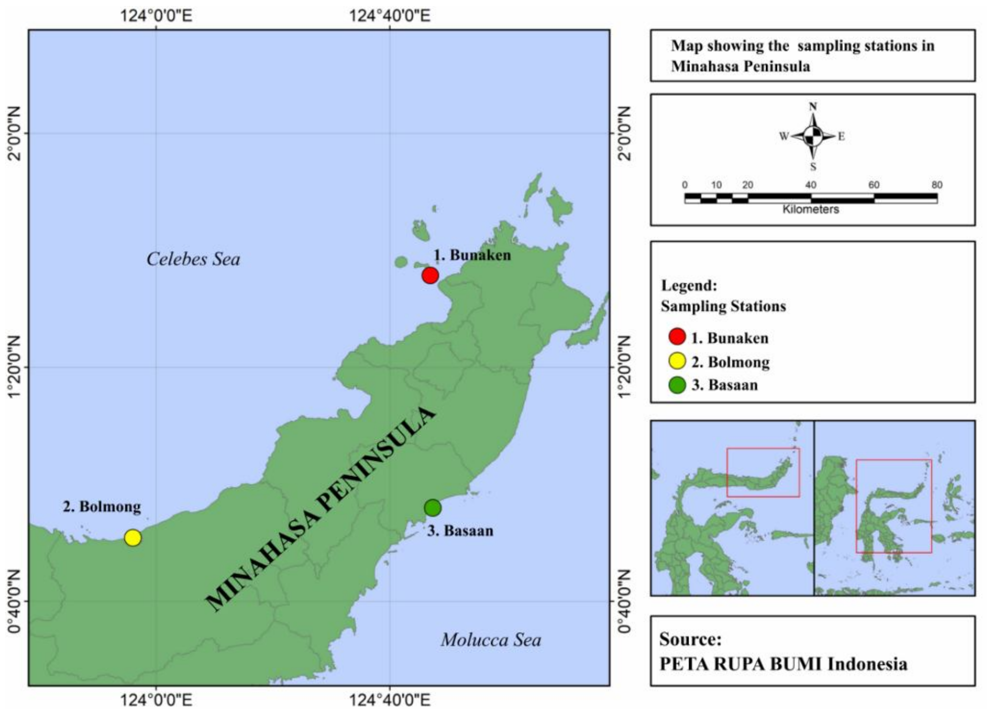

Figure 1. Location of the sampling stations in the Minahasa peninsula, North Sulawesi, Indonesia.

Procedures

Physico-chemical parameters. The following physico-chemical data were measured simultaneously in situ during the sampling between May to September 2022 using the multi-parameter water quality monitoring device (HORIBA U50 series): 1) water temperature; 2) pH; 3) pH/mV; 4) oxidation reduction potential (ORP); 5) conductivity; 6) turbidity; 7) dissolved oxygen (DO); 8) total dissolved solids (TDS); 9) seawater specific gravity; and 10) salinity. In addition, a HOBO data logger that measure light intensity and temperature was also deployed (set at 2-min interval readings) for at least three days in each site.

Sediment samples (1-liter per site) were taken from each site and brought to the testing laboratory Baristand the Industrial Hall in Mapanget sub district, Manado City for analyses of nitrogen and phosphorus content.

Seagrass sampling. In each sampling site, three transects were established perpendicular to the shoreline (~100 m each transect) and at least 25 m from each other. In each transect, replicate 1 m^2 quadrats were laid at 10 m interval (11 quadrats per transect), following the methods used by Fitrian et al (2017). Each species of seagrass were identified and the number of shoots were counted to determine shoot density. Identification followed seagrass taxonomic keys and field guides (Calumpong & Meñez 1997).

Growth rate. To monitor growth rate of the three seagrass species, a total of 10 seagrass shoots were randomly selected and tagged with white cotton threads as markers and growth increments measured each week for 5 weeks, following the methodologies modified from Erftemeijer et al (1993) and Short & Duarte (2001).

Data analysis. Physico-chemical data were plotted using ggplot2 package in R version 4.0 (R Core Team 2020). The differences in the values of physico-chemical parameters between sampling stations were tested using either One-Way Analysis of Variance (ANOVA) or using Kruskal-Wallis using aov function in R depending on the prior normality tests. In cases where there is significant difference in each of the tests, subsequent post hoc tests (Dunn's test with Bonferonni correction for Kruskal-Wallis test and Tukey's HSD test) were performed.

One-Way ANOVA was used to test differences in the shoot density (i.e., the average number of shoots per 1-m qudrat) between sites. Prior to the test, data were checked for normality using Shapiro-Wilk test, QQ-plot, and outliers checked using boxplot using ggplot2 in R. In variables that violated the assumptions of normality, data were log-transformed to qualify for the parametric test. Because there are 0s in the quadrat-level shot density data, the entire datasets were log(x+1) transformed to conform to the parametric assumptions of ANOVA.

The diversity of seagrass species in the three sampling sites was measured using the following: species richness (number of species and using Margalef's richness index), diversity (Shannon-Weiner index), and Simpson's index of dominance. The equations used to calculate (automated using R) the three indices of diversity are as follows:

Margalef's index (D): $D = \frac{s-1}{\ln N}$

where: s = the number of species per transect; N = the number of individuals per transect; ln = natural logarithm.

Shannon-Weiner index (H'): $H' = \sum_{i-1}^{N} pi \ln pi$

where: *pi* = the proportion of individuals of each species; N = total number of individuals; ln = natural logarithm.

With the value category (adopted from Fitrian et al (2017)): H': 0 < H < 1 = low; 1 ≤ H' ≤ 3 = medium; H' > 3 = high.

Simpson's dominance index (SDI): $D = \sum_{i-1}^{N} (pi)^2$;

where: D = Simpson's dominance index; Pi = proportion of species of the i-th of the total amount.

Values of D range from 0 (low dominance; 0-0.5) to 1 (high dominance) (Fitrian et al 2017).

Results

Physico-chemical parameters. The physico-chemical parameters that were measured *in situ* (Table 1) during sampling in the sampling sites showed that the mean values of these parameters did not differ significantly from each other based on the Kruskal-Wallis tests performed for each parameter (p > 0.05).

Table 1

Summary of the *in situ* physico-chemical data between sampling locations in the Minahasa Peninsula

Parameter	Site						Kruskal-Wallis test				
	Basaan		Bolmong		Bunaken						
	Mean	SD	Mean	SD	Mean	SD	N	F	df	p-value	*
Temperature (°C)	31.95	0.02	31.93	0.16	32.08	0.09	9	4.325	2	0.115	ns
Conductivity (μS cm^{-1})	31.95	0.02	31.93	0.16	32.08	0.09	9	0.202	2	0.904	ns
Dissolved oxygen (mg L^{-1})	7.21	0.74	6.57	0.14	7.82	1.15	9	3.289	2	0.193	ns
Water specific gravity	17.47	0.21	17.43	0.35	17.43	0.21	9	0.022	2	0.989	ns
Oxidative reduction potential (mV)	261	32.6	233.67	35.8	166.67	28.01	9	5.956	2	0.051	ns
pH	7.27	0.39	7.66	0.67	9.01	0.93	9	5.956	2	0.051	ns
pH/mV	-16.33	23.71	-39.67	40.86	-122	56.45	9	5.956	2	0.051	ns
Salinity (ppt)	29.97	0.26	29.92	0.42	29.96	0.25	9	0.089	2	0.957	ns
Total dissolved solids (g L^{-1})	28.2	0.17	28.2	0.36	28.2	0.2	9	0.07	2	0.966	ns
Turbidity (NTU)	5.33	1.94	5.5	3.78	0.67	1.15	9	5.468	2	0.065	ns

Note: *significance at 0.05 alpha level; ns - not significant; df - degrees of freedom.

Nutrient level. The level of total nitrogen and phosphorus (expressed in %) was tested only once (Figure 2). Bunaken had the highest nitrogen and phosphorus levels among the sites, followed by Bolmong and Basaan, in that order. However, the data presented here should be taken with caveats due to the limited samples tested for these parameters. Nonetheless, Bunaken is also expected to have high nitrogen and phosphorus levels due to its proximity to high human population density and extensive mangrove areas.

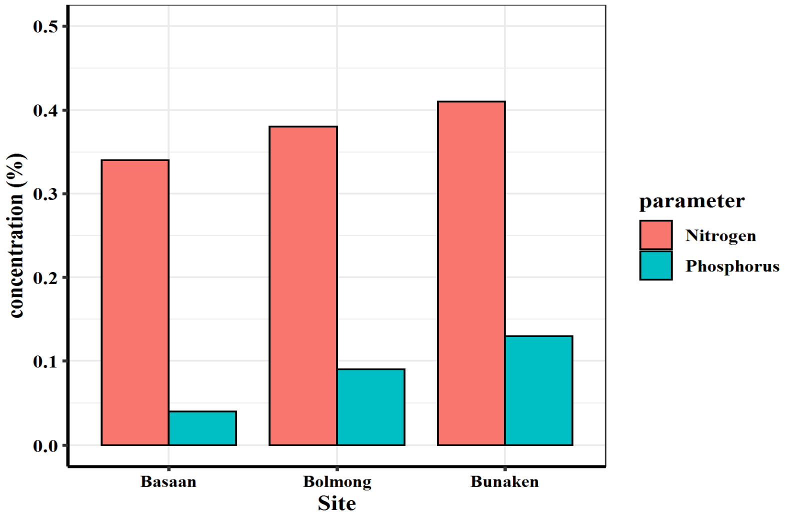

Figure 2. Nutrient levels (total nitrogen and phosphorus in %) in the seawater samples from each sampling site.

Diversity. Of the 8 species of seagrass documented by this study, 7 species were recorded in Bolmong, 6 in Basaan, and only 4 species recorded in Bunaken. A similar was also observed in terms of the diversity indices used such taxa (species) richness (Figure 3A), Margalef's richness index (Figure 3B), Shannon-Weiner's H' index (Figure 3C), and Simpson's index (Figure 3D). Based on these indices, it can be assumed that the three sites had low to medium species diversity and in terms of dominance, Bolmong and Basaan both had moderate dominance as compared to Bunaken.

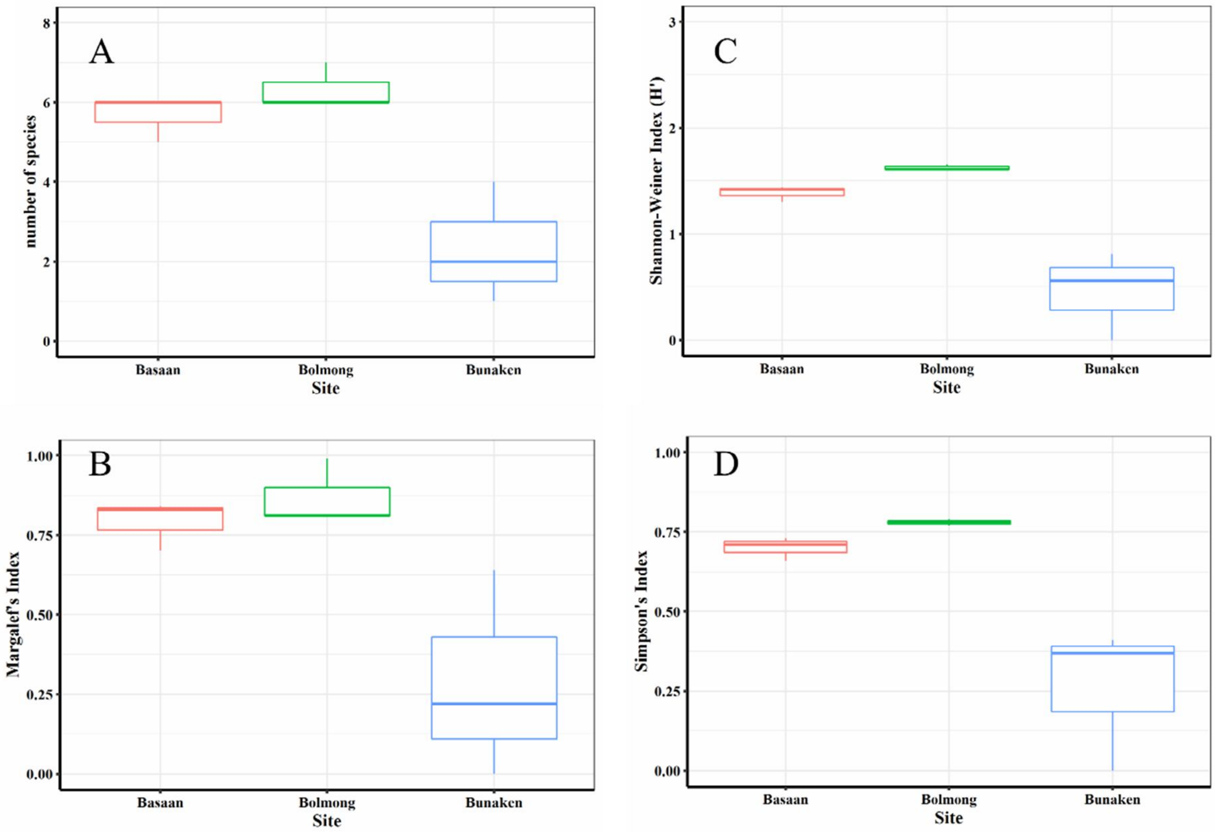

Figure 3. Species richness indeces (A - number of species; B - Margalef's Index; C - Shannon-Weiner Index; and D - Simpson's Index) used to describe seagrass diversity in the sampling sites of Minahasa Peninsula.

Shoot density. Between the three species, *E. acoroides* had the lowest range of shoot density (< 10 shoots m^{-2}) compared to *T. hemprichii* and *S. isoetifolium* (Figure 4 A-C). Shoot density of *E. acoroides* between sites differ significantly from each other based on One-Way ANOVA ($p = 0.011$), except with the pairwise comparison between Bolmong and Bunaken. For *T. hemprichii*, the significant difference observed in ANOVA was mainly due to the reduced shoot density in Bunaken for these two species ($p < 0.001$). Shoot density of *S. isoetifolium*, on the other hand, did not differ significantly between locations ($p > 0.05$).

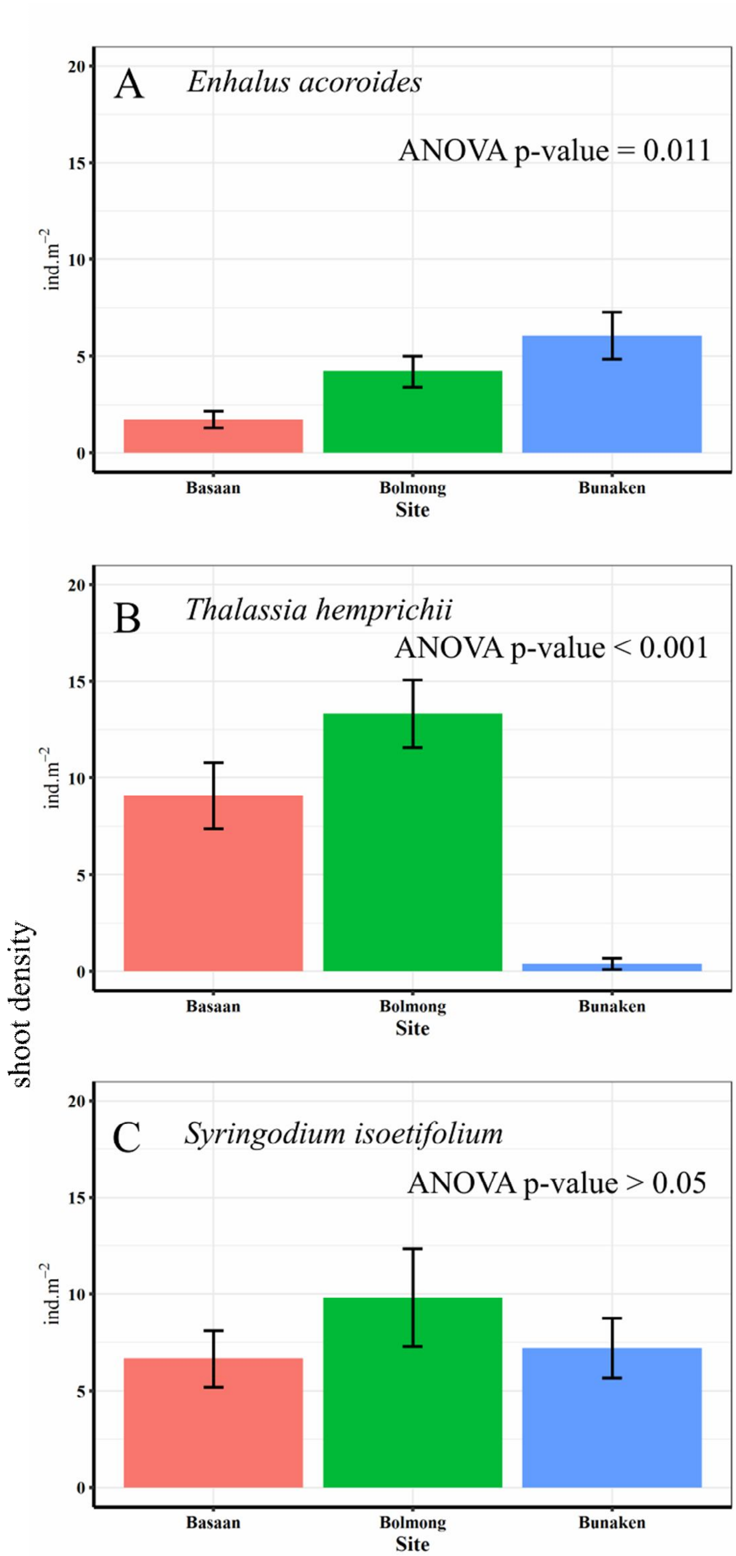

Figure 4. Differences in the shoot density of three species between sampling locations. Error bars = standard error of the means (n = 33 quadrats per site).

Growth rates. Growth patterns differ between the three species (*E. acoroides*, *T. hemprichii*, and *S. isoetifolium*) within the 5 week period (Figure 5A-C). *E. acoroides* had the highest growth rate (peaked at 8.4 mm day^{-1} in Bolmong) followed by *S. isoetifolium* at 4.9 mm day^{-1} (Bolmong) while *T. hemprichii* had the slowest growth recorded (peaked at 3.4 mm day^{-1} in Bolmong).

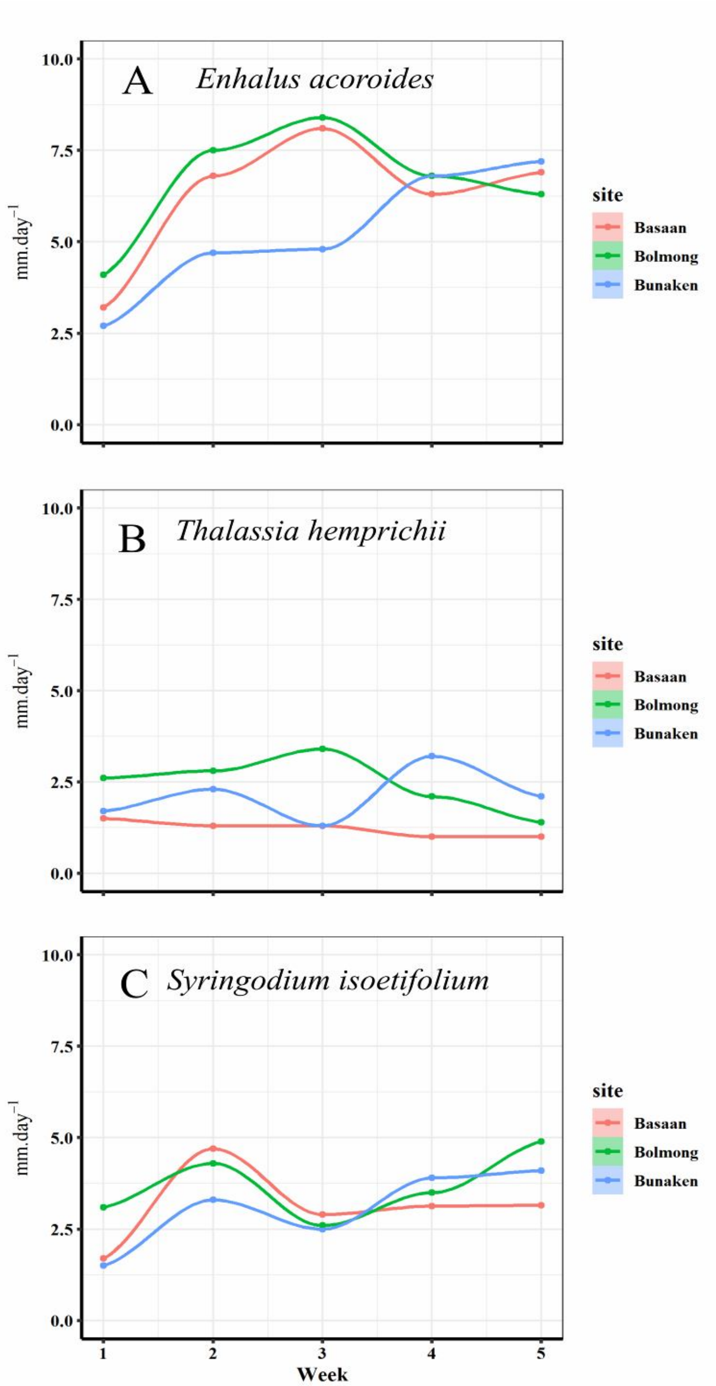

Figure 5. Growth rate patterns of the three seagrass species from the sampling stations.

Discussion. The physico-chemical parameters did not differ significantly between the sampling stations suggesting that the observed variations in the seagrass diversity and growth rate patterns were not driven by these factors. Since seagrasses are known to be phosphorus-limited (Short et al 1990), growth rate is expected to be higher in areas (e.g., Bunaken) where there is elevated amount of this element and any excess of this element in the environment should be able to promote growth of the seagrass species. However, this trend was not observed by this study. Among the sampling sites, Bolmong seemed spared from human-induced disturbances (e.g., boat traffic) and may have been a reason why the three seagrass species (*E. acoroides*, *S. isoetifolium*, and *T. hemprichii*) recorded high growth rates. Slow growth rates of seagrass observed in Bunaken might be due to physical disturbance owing to the human activities in the area such as boat traffic (for domestic and tourist use).

There are 13 known species of seagrass in Indonesia, of which 8 species were identified by this study, comparable to other areas in Indonesia (Fitrian et al 2017; Wagey 2018). Bolmong sampling station had 7 out of the 8 species. Differences in species encountered between this study and those of other surveys done in Celebes Sea and North Sulawesi areas could also be attributable to sampling methodologies and coverage of sampling.

Wagey (2013) showed that in the seagrasses in Negros Oriental, central Philippines, there were no noticeable morphological variations observed between locations. Shoot density appeared comparable to the data in other locations in Indonesia and the Philippines (Fitrian et al 2017). Differences in seagrass shoot density and even with growth may also be attributed to other factors not fully monitored by this study such as grazing (Ramili et al 2018), turbidity (Amri et al 2021), and overall sediment loading and burial due to erosion (Marba & Duarte 1994).

Conclusions. This study showed that in the coastal waters around Minahasa Peninsula, diversity and species richness were higher in the two stations (Bolmong and Basaan) as compared to Bunaken which is located within the Bunaken National Park, despite its protection status, probably due to certain physical disturbance such as boat traffic and other human activities. Future studies should investigate other potential drivers of seagrass diversity and growth rate that are not covered by the present study such as grazing. It is of interest as well to determine the potential impact of increased grazing, especially by sea urchins, in areas where invertebrate grazers increase in abundance as a result of reduced fish predators due to heavy fishing and habitat degradation.

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Conflict of interest. The authors declare that there is no conflict of interest.

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Authors:
Billy Theodorus Wagey, Marine Science Department, Faculty of Fisheries and Marine Science, Sam Ratulangi University, Kampus Bahu UNSRAT, 95115 Manado, North Sulawesi, Indonesia e-mail: billywagey@unsrat.ac.id
Carolus Paruntu, Marine Science Department, Faculty of Fisheries and Marine Science, Sam Ratulangi University, Kampus Bahu UNSRAT, 95115 Manado, North Sulawesi, Indonesia, e-mail: carolusparuntu@yahoo.com
Ridwan Lasabuda, Management Aquatic Resources Department, Faculty of Fisheries and Marine Science, Sam Ratulangi University, Kampus Bahu UNSRAT, 95115 Manado, North Sulawesi, Indonesia, e-mail: ridwanlasabuda@gmail.com

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