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15B Seagrasses and seagrass ecosystems

Seagrass response to mariculture-induced physico-chemical gradients in Bolinao, northwestern Philippines

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Abstract. We analyzed 15-month data on seagrass species composition, % cover, shoot density, biomass and leaf growth rates from four 50 x 50 m quadrats established along a 5-km gradient in nutrients, chlorophyll-a, and siltation in Bolinao, northwestern Philippines. The gradient results from the extensive mariculture (*Chanos chanos*) activities in the area, which started in the 1980's, in addition to the upland degradation done much earlier. Results show that some definite biological responses of *E. acoroides* and *T. hemprichii* to the stressors along the low-high nutrient/siltation gradient can be summed up in the following: (1) a marked decrease in the number of seagrass species, (2) percent cover in the two species did not vary significantly with the sampling months within the 15-month period; (3) an increase in cover and shoot density in *E. acoroides*, but a decrease in the parameters in *T. hemprichii*; (3) no clear relationship between the above- and below-ground biomass ratios in *E. acoroides*, but an increase in the ratios in *T. hemprichii*; and (4) the low-to-high leaf growth rates of the two species. Based on increasing sensitivity (decreasing resistance) to a combined effect of nutrients, chlorophyll-a and siltation, we propose the following sequence of the species: *Enhalus acoroides* > *Thalassia hemprichii* >*Cymodocea rotundata* > *Halodule uninervis* > *C. serrulata* > *Halophila ovalis* > *Syringodium isoetifolium.* We likewise propose that changes in the biological parameters in the study be considered in the search for indicators useful for a better understanding of fish farm and siltation effects on the coastal environment.

Key words: nutrients, chlorophyll-a, gradient, seagrass, mariculture, biodiversity, bioshield.

Introduction

The milkfish (*Chanos chanos*) mariculture in Bolinao (Province of Pangasinan, Philippines) and vicinity has been an offshoot of the exponential development of fish farming across the world, at a rate of 8.8% yr^{-1} between 1970 and 2004 (FAO 2007). The release of fish feces and excess feed pellets in the cages enhances organic matter and nutrient loading into the water and sediments, (e.g. Holmer et al. 2003a), increasing oxygen consumption (e.g. Holmer et al. 2002) and promoting anaerobic degradation of organic matter (e.g. Danovaro et al. 2000; Holmer et al. 2002, 2003b). The resulting depletion of sediment oxygen and increase in the concentration of toxic products from anaerobic pathways (e.g. sulphides and ammonium) negatively affect local benthic communities (e.g. Terrados et al. 1999, Ruiz et al. 2001, Holmer et al. 2003b). The overall result is the increase in the residence time of the sediments and fish feeds, leading to a rapid increase in bacterial populations, to death of aerobes and benthos, and finally to fish kills. Costing the town about US$25,000 a day, the latter is at present an almost regular occurrence in Bolinao and immediate vicinity.

Bolinao has 22,500 ha of the most diverse assemblage of seagrasses in the northern part of the Philippines. Recently, however, changes in the composition and distribution of the plants have been observed. These changes are largely associated with the development of fish farming, aggravated by increasing sediment loading from rivers in the town's southeastern end. Here more nutrient inputs from more fish cages coming from a neighboring town apparently worsen water and sediment quality conditions. Terrados (1999) and Duarte (2002) demonstrated that siltation, milkfish aquaculture and physical disturbance in Bolinao resulted in the loss of seagrass. Marba et. al. (2010) found the positive effect of seagrass roots and rhizomes on sediment redox potential and, thus, the general conditions for microbial processes in the seagrass beds.

In the Mediterranean Sea, fish farm development has encroached in areas dominated by the endemic seagrass, *Posidonia oceanica*, a key species sustaining meadow communities of high diversity (Templado 1984), which provides important ecosystem functions and services (Hemminga and Duarte 2000). Such services are being jeopardized by the tendency towards a substantial decline of these ecosystems (e.g. Marbà et al. 2005), faster than the 2% yr^{-1} global rate of decline of seagrass ecosystems (Duarte et al. in press).

In the present study we analyzed 15-month data from permanent quadrats along nutrient and siltation gradients in Bolinao. An initial component of a bigger and long-term monitoring effort with experimental manipulation of 'forcing factor's, we aim to establish a general relationship linking seagrass population and community response with organic loading and nutrient inputs from fish farms (cages and pens). In the long term, this relationship could allow us to predict loading thresholds that would significantly be useful in understanding the 'bioshield' function of seagrasses, which in turn could help local and national effort to regulate fish farm culture in critical areas in the country.

Material and Methods

We adopted a modified Seagrass Net method (Short et al. 2001) in delineating the four 50 x 50 m permanent quadrats established along a 5-km gradient in nutrients (N, Si, P) and chlorophyll-a in Bolinao, northwestern Philippines (Fig. 1). These gradients result from the dominant current system bringing the nutrients and chlorophyll-a outward from the extensive mariculture (*Chanos chanos*) activities in the area, which started in the 1980's, aggravated by land-based discharge of sediments from the south study stations.

While seven seagrass species present at the site were studied, we focused on only the two species common to all stations (*Enhalus acoroides* and *Thalassia hemprichii*) in monitoring quarterly changes (n = 24) in the seagrass beds i.e., species composition, % cover, shoot density ($number.m^{-2}$), leaf growth rate ($cm.d^{-1}$), and biomass ($g.DW.m^{-2}$). The two species are the first and fourth among the seven seagrasses in Bolinao with the highest tolerance to siltation (Bach et al 1998). Physical and chemical parameter monitoring was undertaken by the Physical Oceanography and Geochemistry Components of the project, Coastal Ecosystem Conservation and Adaptive Management Project (CECAM) sponsored by the Japan International Cooperation Agency-Japan Science and Technology Agency (2010-2015).

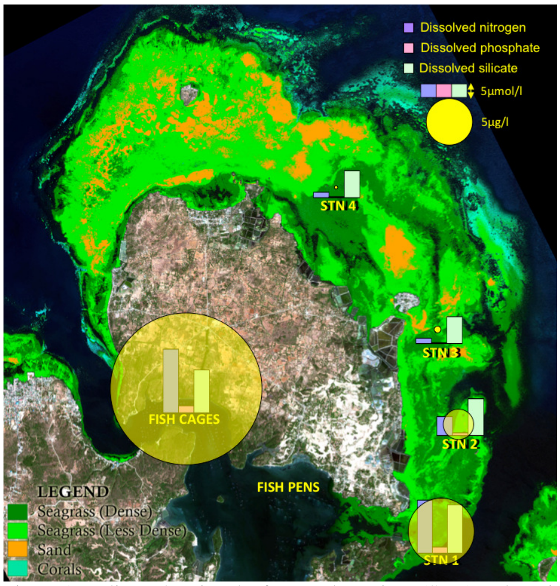

Figure 1: Bolinao showing the four study stations (STN) and spatial distribution of 6-day-temporal averaged concentration from water sampling analysis of (a) dissolved nutrients (ammonia, nitrate, nitrite, phosphate, silicate) and (b) chlorophyll-a relative to the fish cages (Modified from Tsuchiya et al. unpublished)

An initial 15-month data set was used in the analysis of the responses and relationships among the parameters. Since 2007, measurements of the gradient parameters are being continuously monitored by the CECAM Project, a joint Philippines-Japan research initiative aimed at filling the gaps in science needed in the adaptive management of the coastal environment. Data here provided are extracts from the project's database and are used simply and solely to justify the fact that gradients exist along the areas of concern in this study.

Results

Seagrass species composition increased markedly from 2 (*Enhalus acoroides, Thalassia hemprichii*) at Station 1 (closest to the fish cage area) to 7 (*E. acoroides, Thalassia hemprichii, Halophila ovalis, Cymodocea rotundata, C. serrulata, Halodule uninervis,* and *Syringodium isoetifolium),* at Station 4 (the Bolinao Seagrass Reserve, farthest from the cages). Seagrass species composition in Stations 2 and 3 was variously intermediate, i.e., 4 species in Station 2 and 6 in Station 3. Only *E. acoroides* was recorded at the farthest end of the channel (south, not shown in Fig. 1) and, with the species, only *C. rotundata* was found a few meters south of the cages.

In terms of cover (%) and density ($g.DW.m^{-2}$), *T. hemprichii* and *E. acoroides* exhibited opposite responses to the gradients (Fig. 2), with *T. hemprichii*, showing marked increases in both parameters from Station 1 to Station 4, while *E. acoroides* showed decreases. This trend was also generally true within all succeeding quarterly periods, the slight deviation from the trend observed only between Stations 3 and 4. The latter station had much greater cover than the former. Station 4 being inside the Bolinao Seagrass Reserve, has the most diverse assemblage of the ecosystem components.

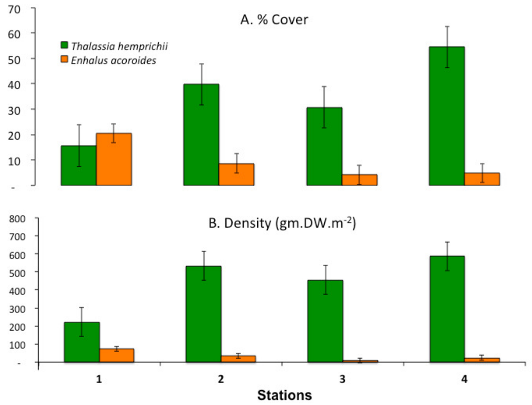

Figure 2: Cover, % (A) and shoot density, g.DW.m^{-2}, (B) of *T. hemprichii* and *E. acoroides* at the four stations along the nutrient, siltation and chlorophyll-a gradients in Bolinao (Sept 2010 – Dec 2011)

Cover in *T. hemprichii* varied significantly among stations with highest values in Station 4 (52.94%) followed in succeeding orders: Station 3 (39.8%), Station 2 (30.78%), Station 1 (15.6%) (Tests of between-subjects effect: MANOVA at 5% level of significance). Density varied significantly between sampling periods with average values ranging from 222 to 586 individuals.m^{-2}. The values were lowest at Station 1 (222 individuals.m^{-2}), while Station 2 (536 individuals.m^{-2}) is intermediate between Station 3 (455 individuals.m^{-2}) and Station 4 (586 individuals.m^{-2}). Shoot density in *T. hemprichii* was significantly highest in December 2011, while all the rest did not vary (Tukeys HSD at 5% level of significance).

In *E. acoroides*, cover did not vary between sampling periods, but significantly varied among stations. Values were highest in Station 1 (20.5%), while the rest of the stations (2, 3, 4) did not vary significantly with seagrass cover, ranging from 4.1 – 8.7% (Tukeys HSD at 5% level of significance). On the other hand, its shoot density significantly varied between sampling periods and between stations. Station 1 had the highest shoot density (72.9 individuals.m^{-2}), while Station 4 (23.7 individuals.m^{-2}) is intermediate between Station 2 (34.1 individuals.m^{-2}) and Station 3 (9.9 individuals.m^{-2}; Tukeys HSD at 5% level of significance).

In terms of leaf growth rate (cm.day^{-1}), the parameter was monitored only at Stations 1 and 4. In both stations and in all sampling months, *T. hemprichii* consistently had much slower rate of growth than *E. acoroides* (Fig. 3). Noticeably, however, growth of both species was faster in Station 1 than in Station 4, the response less clear in *T. hemprichii* (Station 1 = 0.61 cm.day^{-1}, Station 4 = 0.46 cm.day^{-1}) when compared to *E. acoroides* (Station 1 = 1.16 cm.day^{-1}, Station 4 = 0.78 cm.day^{-1}). In relation to the season, both species exhibited similar bimodal peaks, which were generally higher in December (cold, wetter season) than in March (hot, drier season).

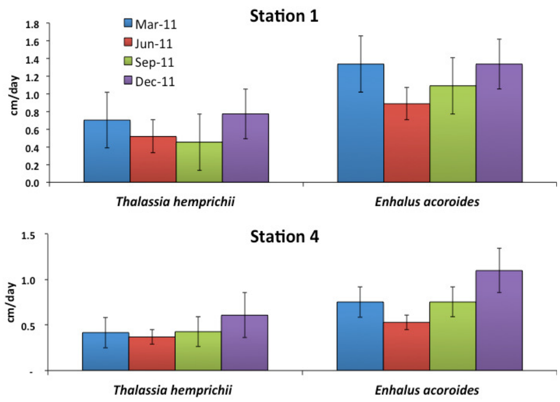

Figure 3: Leaf growth rates (cm.day^{-1}) of *T. hemprichii* and *Enhalus acoroides* at Stations 1 and 4 in Bolinao (March 2011 – Dec 2011).

In terms of biomass, ratios between the above- and belowground biomass in each of the two species showed general *(E. acoroides,* Fig. 4*)* but a marked (*T. hemprichii,* Fig. 5) decrease from Station 1 to Station 4. Belowground biomass in *T. hemprichii* was remarkably greater than its aboveground biomass (means: 13.05 and 3.40 g.DW.m^{-2}, respectively). When total biomass of the species in Stations 1 to 4 are compared, the above-ground (shoot) biomass was on the average only 31.1% of their belowground counterparts. This finding is consistent in all 4 stations and through the sampling periods. A pattern of decrease in the aboveground biomass is likewise consistently discernable when the stations are compared, with peaks in Station 2, and lowest points generally in Station 4. On the other hand, belowground biomass showed an opposite trend, where a pattern of increase was consistent from Station 1 to Station 4, with Stations 2 and 3 showing less clear responses, especially in Dec 2010 and March 2011. As in aboveground biomass, its belowground counterpart showed no significant difference when the sampling seasons are compared.

In *E. acoroides* the root-rhizome biomass was remarkably greater than its shoot biomass (means: 13.3 and 3.2 g.DW.m^{-2}, respectively). On the average, shoot biomass of the species was only 21.3% of its root-rhizome biomass. This finding is consistent in all the 4 stations (except Station 3) and through the sampling periods. No pattern was observed in the changes in the aboveground biomass among the stations and the sampling periods. However, belowground biomass showed a general decrease from Station 1 to Station 4. Comparing the biomass of *E. acoroides* in Stations 1 and 4, however, the shoots in Station 1 had almost 5 times the biomass of the same parts in Station 4. In addition, the root-rhizome biomass in Station 1 was more than twice that in Station 4.

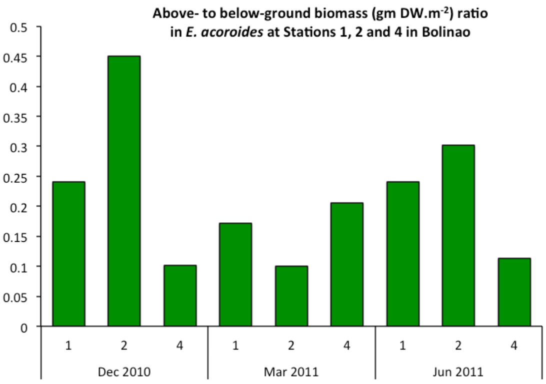

Figure 4: Above- and below-ground biomass (g.DW.m^{-2}) ratio in *E. acoroides* at Stations 1, 2 and 4 in Bolinao (Dec 2000 – June 2011).

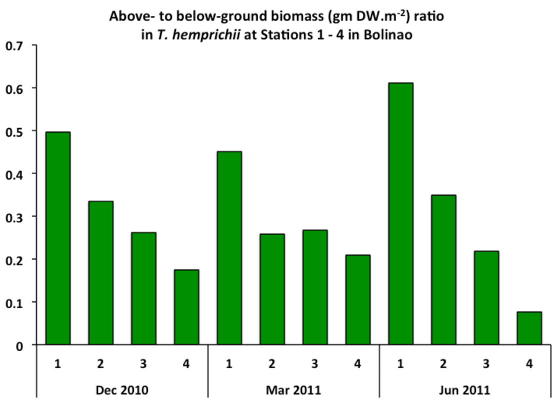

Figure 5: Above- and below-ground biomass (g.DW.m^{-2}) ratio in *T. hemprichii* at Stations 1 - 4 in Bolinao (Dec 2000 – June 2011).

Belowground biomass in *T. hemprichii* was remarkably greater than its aboveground (shoot) biomass (means: 13.05 and 3.40 g.DW.m^{-2}, respectively). When total biomass of the species in Stations 1 to 4 are compared, the above-ground (shoot) biomass was on the average only 31.1% of their below-ground counterparts. This finding is consistent all throughout the 4 stations and through the sampling periods. A pattern of decrease in the aboveground biomass is likewise consistently discernable when the stations are compared, with peaks in Station 2, and lowest points generally in Station 4. On the other hand, belowground biomass showed an opposite trend, where a pattern of increase was consistent from Station 1 to Station 4, with Stations 2 and 3 showing less clear responses, especially in Dec 2010 and March 2011. As in aboveground biomass, its belowground counterpart showed no significant difference when the sampling seasons are compared. Comparing the biomass of *T. hemprichii* in Stations 1 and 4, however, there was no significant difference between the values for the aboveground parts. On the other hand, shoot biomass in Station 1 was only 37% of that in Station 4.

Discussion

Along the physical gradients created by effluents from fish cages, fish pens, and river discharges from upland, the seagrass ecosystem of Bolinao is subjected to varying degrees of impacts from nutrients, organic loads, and silt. Seagrass responses to these stressors were likewise varied. Our study shows, however, that some definite biological reactions to the 'stressors' along the gradient (low-high levels) can be summed up in the following: (1) a marked decrease in the number of seagrass species, (2) percent cover in the two species did not vary significantly with the sampling months within the 15-month period; (3) an increase in cover and shoot density in *E. acoroides*, but a decrease in the parameters in *T. hemprichii*; (3) no clear relationship between the above- and below-ground biomass ratios in *E. acoroides*, but an increase in the ratios in *T. hemprichii*; and (4) the low-to-high leaf growth rates of the two species. The results indicate a collective response of the species to a combined effect of the forcing factors. They support the findings of previous studies on the impact of fish farming on the plants (Holmer et al. 2002, Marbà et al. 2005, 2006, Pergent-Martini et al. 2006, Rountos et al. 2012) or of siltation from the rapid changes in land use patterns in the coastal zone (Fortes, 1988, 2001, Short & Burdick 1996, Short & Wyllie-Echeverria 1996, Terrados et al. 1999), or its induction of changes in the sediments by increasing the concentration of nutrients, organic matter and water content (Kamp-Nielsen et al. 2001, Halun et al. 2002), changing the redox condition of sediments favorable for benthos (Marba et al. 2010), or affecting indirectly the trophic structure of the community by enhancing an increase in grazer population density (Rountos et al. 2012). These observations likewise support the classical 'high-biodiversity-low dominance' theory in ecology whereby in time, the relatively more stressed conditions close to the sources of disturbances become lowly diverse, high dominance areas, while far from them, diversity becomes significantly higher and dominance becomes lower.

Reduction of light by fast-growing algal epiphytes and macroalgae on seagrass in shallow coastal areas is the most common mechanism invoked for seagrass decline under nutrient over-enrichment (Burkholder et al. 2007). This event, however, was not obvious in the present study. While epiphytes and macroalgae were observed, these were not significant and consistent in their abundance and distribution along both temporal and spatial gradients in the study site to cause the postulated effects. The dramatic decline in the number of seagrass species as well as the varying degrees of response in cover, density, biomass and growth rates along the gradient in Bolinao may be differently controlled. Interestingly, in Station 1, there was a tendency for a reduction of belowground biomass in favor of the aboveground parts in both *E. acoroides* and *T. hemprichii*. This is a strategy of the plants to invest on shoots to compensate for the reduced light conditions. This will be a subject of the manipulative experiments soon to be undertaken as a part of the project. Hence, while only the two species common to all four stations were the focus of this paper, five other seagrass species were included in the study. Based on increasing sensitivity (decreasing resistance) to a combined effect of nutrients, chlorophyll-a and siltation, we propose the following sequence of the species: *Enhalus acoroides* > *Thalassia hemprichii* >*Cymodocea rotundata* > *Halodule uninervis* > *C. serrulata* > *Halophila ovalis* > *Syringodium isoetifolium.* Bach et al. (1998) developed a dose-response relationship among Bolinao seagrasses wherein they ranked them according to decreasing tolerance to siltation as *Enhalus* acoroides > *Cymodocea* serrulata > *Halodule uninervis* > *Thalassia hemprichii* > *Halophila ovalis* > *Cymodocea rotundata* > *Syringodium isoetifolium.* Hence, it would be interesting, to do manipulative dose-response experiments to test these results and to focus on the 'erratic' species thriving at the intermediate range of tolerance to the factors, e.g. *C. serrulata, C. rotundata* and *H. ovalis.*

The results of the study highlight the importance of seagrass as 'bioshields', reducing or mitigating impacts of unsustainable fish farms and land use practices on the coastal environment. This ecosystem service is currently under threat by a multitude of factors, both natural and human-influenced. This study has initiated a different approach towards an effective conservation and management of natural coastal resources by first addressing the scientific gaps and, as being currently implemented in the Philippines, inputting them into a community-based conservation and management framework, implementing multi-sectoral actions, and translating the outcome into a form understandable and acceptable by the people. Considering that seagrasses can be considered as "long-term" integrators (days to weeks) of nutrient availability (Burkholder et al 2007), we suggest that changes in the biological parameters in the study be considered in the search for indicators useful for a better understanding of fish farm and siltation effects on the coastal environment.

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