

Evidence of negative impacts of ecological tourism on turtlegrass (*Thalassia testudinum*) beds in a marine protected area of the Mexican Caribbean

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Abstract Many marine protected areas (MPAs) have been established in recent years. Some MPAs are open to tourists to foster environmental education and generate revenue for the MPA. This has been coined “ecological tourism”. Here, we examine the impact of ecological tourism on turtlegrass (*Thalassia testudinum*) health in one area of the “Costa Occidental de Isla Mujeres, Punta Cancún y Punta Nizuc” MPA in the Mexican Caribbean. A heavily visited location was compared with an unvisited location. Turtlegrass leaves at the visited location were sparser, shorter,

grew more slowly, and had more epiphytes than at the unvisited location. Vertical and horizontal rhizomes of turtlegrass also grew more slowly at the visited than at the unvisited location. There is reasonable evidence to suggest that the observed differences are likely due to the deleterious impacts of novice and careless snorkelers. If continuing, these impacts could cause severe degradation of the visited areas in this MPA and, thus, changes in management policies seem in order.

Keywords Ecological tourism · Marine protected areas · Turtlegrass · Ecological indicators

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Introduction

Given the fast increase in coastal human populations worldwide and the many deleterious environmental impacts that may follow (Vitousek et al. 1997; Lotze et al. 2006) ocean-bordering countries have made the management of coastal resources a priority (Turner 2000; Valiela 2006). Seagrass beds represent important structural and functional components of coastal ecosystems (Hemminga and Duarte 2000; Williams and Heck 2001), but they have been declining and continue to decline in many parts of the world due to human pressure (Hauxwell et al. 2003; Orth et al. 2006). Human activities most impacting seagrasses include those altering water quality or clarity, such as nutrient and sediment loading from runoff and

sewage disposal, dredging and filling, pollution, and development (Short and Wyllie-Echeverria 1996; Hauxwell et al. 2001).

One management practice to conserve or restore valuable marine habitat such as seagrass beds is the creation of marine protected areas (MPAs; Gubbay 1995). These are well-defined areas protected from human disturbance for the purpose of maintaining biodiversity and environmental health, enhancing fisheries, or preserving some unique feature or artifact (NRC 2001; Fabinyi 2008). Ecological tourism in these areas, such as sportfishing, snorkeling, and free- or scuba-diving, is regulated. Allowing tourists into MPAs generates revenue for MPA maintenance and contributes to the environmental education of the general public.

However, some MPAs have not been fully effective in protecting seagrass beds from human visitation. Sargent et al. (1995) documented substantial scarring by boat propellers in seagrass beds of the Florida Keys National Marine Sanctuary. Boat anchoring has caused considerable damage to seagrass beds in a number of Mediterranean MPAs (Francour et al. 1999; Milazzo et al. 2004; Lloret et al. 2008). Visitors, mainly through boating impacts such as anchoring, propeller scars, and grounding, have been long known to cause damage to seagrass beds in unprotected locations (Walker et al. 1989; Short and Wyllie-Echeverria 1996; Montefalcone et al. 2006; Orth et al. 2006), but this should not occur in MPAs. In addition, inexperienced and careless snorkelers, by resuspending sediment and kicking and ripping off the leaves, could exert damage to seagrass beds in MPAs, but this potential problem has received little attention (McCrone 2001; Milazzo et al. 2002; Lloret et al. 2008). Ascertaining the extent and causes of environmental damage inflicted by tourists is important for the management and viability of MPAs.

The Mexican government declared one MPA in Cancun (SE, Mexico), a prime destination for tourists in the Caribbean region. The MPA is named “Costa Occidental de Isla Mujeres, Punta Cancún y Punta Nizuc”; it covers 8,673 ha and is visited by 2.5 million tourists every year (Cancún 1998). Turtlegrass (*Thalassia testudinum*) beds are conspicuous in the shallow areas (<5 m) of this MPA. In this paper, we compare the morphology and growth dynamics of turtlegrass between two locations within the MPA. The two locations have similar physical and

hydrological characteristics (i.e., temperature, salinity, nutrient concentrations), but one location is heavily frequented by tourists, whereas the other is not visited. The main activity in the visited location is snorkeling; thus, this comparison allows us to suggest how snorkeling by tourists can affect the health of seagrass beds.

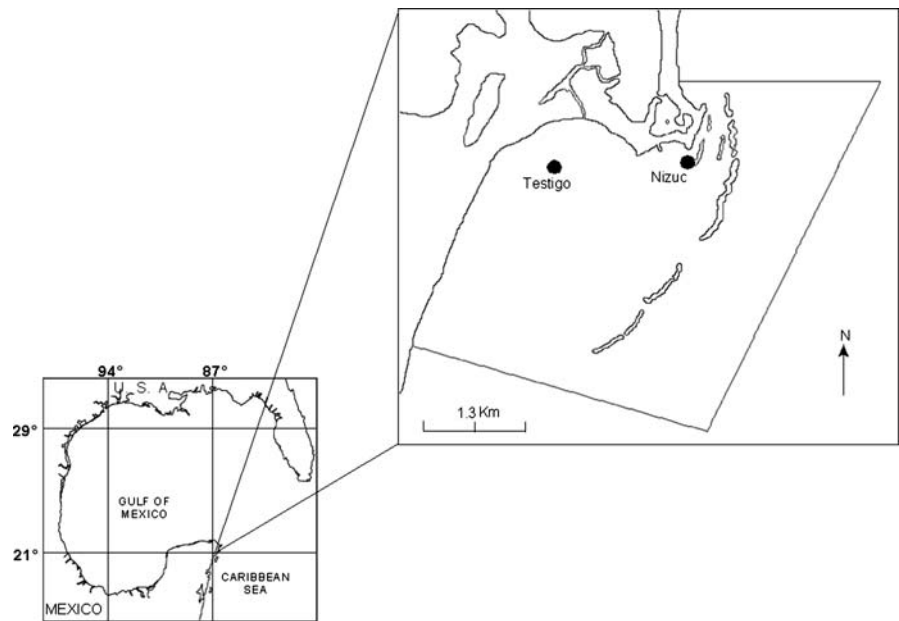
Materials and methods

Study locations

The “Costa Occidental de Isla Mujeres, Punta Cancún y Punta Nizuc” MPA includes several regions. Punta Nizuc is one of those regions where a shallow (<3 m) coral reef barrier occurs, and the main recreational activity for tourists is snorkeling. Approximately 500 tourists visit Punta Nizuc daily during the low season and 3,000 during the high season (Cancún 1998). The visitors arrive at Punta Nizuc in jet skis from 9 a.m. until 5 p.m. and, among other activities, they snorkel in the coral reef and adjacent seagrass beds dominated by turtlegrass (CONANP 2000). The visitors are normally inexperienced snorkelers, and during the 30–45 min that on average each snorkeler spends in the water, they often resuspend sediment and kick and rip seagrass leaves.

The study was conducted in August 1999 in the Punta Nizuc region of the MPA (Fig. 1). Our first sampling location was situated in a turtlegrass bed heavily visited and disturbed by tourists. The second sampling location was less than 2 km from the visited station and was unvisited by tourists (Cancún 1998). Other than visitation by tourists, the two locations have similar physical and hydrological characteristics (Herrera-Silveira et al. 2006). Salinity ranges from ca. 34 to 38 ppt, and temperature from ca. 25 to 32°C, in the two locations (*t*-tests comparing salinity and temperature between the two locations, $P > 0.05$ for both variables). Dissolved nutrient concentrations in the water-column are low (i.e., median $\text{NO}_3 < 2.5 \mu\text{M}$; median $\text{NH}_4 < 3 \mu\text{M}$; median $\text{PO}_4 < 0.25 \mu\text{M}$) in the two locations (*t*-tests comparing NO_3 , NH_4 , and PO_4 concentrations between the two locations, $P > 0.05$ for all concentrations). The two locations face open shorelines and have similar exposure to wave and storm action. Turtlegrass populates the bottom in both locations. All samples were taken at 3 m.

Fig. 1 Map of the study locations. The *closed area* in the inset represents the Punta Nizuc region within the “Costa Occidental de Isla Mujeres, Punta Cancún y Punta Nizuc” MPA. *Testigo* unvisited location, *Nizuc* visited location



Variables measured

Shoot density (number of shoots per m^2) was measured within triplicate 0.25 m^2 quadrats at each location. In addition, approximately 200 vertical short shoots were collected in the visited location and 100 shoots in the unvisited location. For each short shoot, we counted the number of leaves on the shoot, measured the length and width of the leaves, and counted the number of nodes and measured the length (cm) of the vertical rhizome. If the short shoot was still attached to horizontal rhizome (i.e., it had not broken off as a result of sampling), we also measured the length of horizontal rhizome from that shoot to the nearest neighboring shoot. Furthermore, for a subsample of 10 short shoots in each location, we scraped the epiphytes off the leaves carefully with a razor blade, dried leaves and epiphytes at 85°C for 24 h, and weighed the dry leaves and epiphytes. From these measurements, leaf specific area (cm^2 of leaf surface per g dry weight) and epiphyte biomass (g epiphyte dry weight per cm^2 of leaf surface) were calculated for each of the 10 shoots. Shoot leaf weight (g leaf dry weight per shoot) was calculated for all shoots, where leaf length and width had been measured using the mean value of leaf specific area obtained for the subsample of 10 shoots.

Leaf growth (g leaf dry weight per shoot per day) was measured following the conventional leaf

marking technique (Zieman 1974). We marked fifteen shoots in each location and leaves were left to grow for 1 week before retrieval. We used techniques of seagrass growth reconstruction to estimate rates of vertical and horizontal rhizome growth (e.g., Gallegos et al. 1993; Duarte et al. 1994; Kenworthy and Schwarzschild 1998). Vertical rhizome growth rates (cm per short shoot per day) correspond to the slope of the regression between the length of the vertical rhizome (cm) and the age (days) of the short shoot adjusted for the shoots where these parameters were measured. To derive the age of the short shoots, we calculated the period of time required for the formation of the nodes and leaves (i.e., nodes correspond to the insertion point of former leaves into the vertical rhizome) counted in the shoot. This was done with a two-step process. First, using a dissecting microscope and micrometer, we measured the length of all the internodes (i.e., space between consecutive nodes) along the vertical rhizomes of three old shoots (i.e., shoots with a high number of nodes) for each location. Second, we reconstructed the seasonal cycles of nodal growth and, after applying filters for short- and long-temporal variability as described by Duarte et al. (1994) and Marba et al. (1994), we estimated that turtlegrass short shoots in the two locations produced ca. 20 nodes per year. Thus, the age of the short shoot (days) was derived as $(\text{number of nodes} + \text{leaves in the shoot}) / 20 \text{ nodes per year} \times 365 \text{ days per year}$.

The rate of horizontal rhizome growth (cm per horizontal rhizome per day) was derived as the slope of the regression between the length of a piece of horizontal rhizome and the age difference between the shoots at the beginning and end of that piece, with that difference corresponding to the time elapsed for the formation of that piece (Duarte et al. 1994). Finally, we also examined the evolution of internodal length over the years prior to sampling. We did this for the same six short shoots used to derive age estimates. To standardize for differences in internodal length among vertical rhizomes, we recalculated the length of each internode as a fraction of the maximum internodal length found in the rhizome (i.e., we divided the length of each internode by the length of the longest internode in that rhizome) and, for each location, plotted the mean fraction (i.e., average of the three rhizomes) versus the numerical position of the internode along the rhizome.

Statistical analyses

Shoot morphological variables (shoot density, shoot leaf weight, number of leaves per shoot, leaf specific area), shoot leaf growth, and epiphyte biomass were compared between the two locations with Mann–Whitney tests, a non-parametric substitute for the *t*-test, due to the non-compliance of untransformed and transformed data with the normality and homoscedasticity requirements of the *t*-test. To test for differences in rates of horizontal and vertical rhizome growth between the two locations, we first adjusted the regressions as described earlier to derive the rates (i.e., rates correspond to the slopes of the regressions), and we then tested whether the slopes were different between the locations using ANCOVA. All differences were considered statistically significant at $P < 0.05$.

Results

Shoot morphological differences were found between the two locations (Fig. 2). Shoots were sparser and weighed less at the visited than at the unvisited location (Mann–Whitney test for both variables, $P < 0.05$). At the visited location, mean (\pm SE) shoot density and leaf weight were $545.7 (\pm 12.4)$ shoots per m^2 and $0.10 (\pm 0.01)$ g leaf dry weight per shoot,

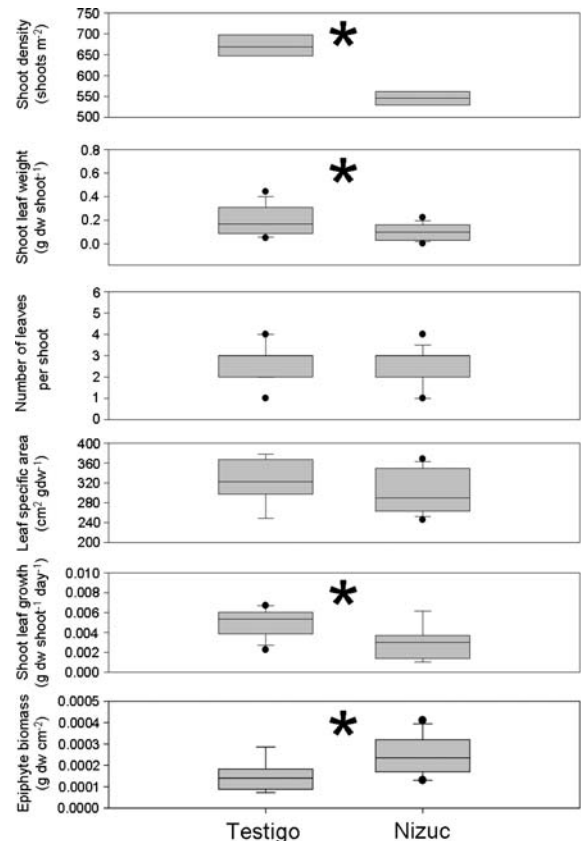


Fig. 2 Box plots of morphological and growth parameters of turtlegrass (*Thalassia testudinum*) at the unvisited (“Testigo”) and visited (“Nizuc”) locations. Boxes encompass the 25 and 75% quartiles and the central line represents the median. Bars encompass the range of values between (1) the 25% quartile minus 1.5 times the difference between the quartiles 75 and 25% and (2) the 75% quartile plus 1.5 times the difference between the quartiles 75 and 25%. Circles represent values outside these limits. Asterisks denote significant differences at $P < 0.05$ between the locations

and at the unvisited location those values were $672.0 (\pm 19.4)$ shoots per m^2 and $0.20 (\pm 0.01)$ g leaf dry weight per shoot. Number of leaves per shoot and leaf specific area, however, did not differ significantly between the two locations (Mann–Whitney test for both variables, $P \geq 0.05$). Shoot leaf growth rates were lower at the visited than at the unvisited location (Mann–Whitney test, $P < 0.05$), with the mean values (\pm SE) being $0.0030 (\pm 0.0007)$ at the visited location and $0.0049 (\pm 0.0004)$ g leaf dry weight per shoot per day at the unvisited location. Epiphyte biomass was higher at the visited (mean \pm SE: 0.00025 ± 0.00003) than at the unvisited location

(0.00015 ± 0.00003 g epiphyte dry weight per cm^2 of leaf surface; Mann–Whitney test, $P < 0.05$).

The regression equation between vertical rhizome length and shoot age for the unvisited location was (Fig. 3a)

$$\begin{aligned} \text{Length (cm)} &= 0.117 (\pm 0.082) \\ &+ 0.00575 (\pm 0.0003) \text{ age (days)} \\ (n = 88, R^2 = 0.81, P < 0.05) \end{aligned} \quad (1)$$

and for the visited location was

$$\begin{aligned} \text{Length (cm)} &= 0.549 (\pm 0.051) \\ &+ 0.00259 (\pm 0.00007) \text{ age (days)} \\ (n = 201, R^2 = 0.86, P < 0.05) \end{aligned} \quad (2)$$

The regression slope, which corresponds to the rate of vertical rhizome growth (cm per short shoot per day), is higher for the unvisited than for the visited location (ANCOVA, $P < 0.05$).

The regression equation between horizontal rhizome length and shoot age difference for the unvisited location was (Fig. 3b)

$$\begin{aligned} \text{Length (cm)} &= 10.06 (\pm 4.36) \\ &+ 0.0491 (\pm 0.0145) \text{ age (days)} \\ (n = 7, R^2 = 0.64, P < 0.05) \end{aligned} \quad (3)$$

and for the visited location was

$$\begin{aligned} \text{Length (cm)} &= 13.48 (\pm 0.83) \\ &+ 0.0068 (\pm 0.0014) \text{ age (days)} \\ (n = 9, R^2 = 0.73, P < 0.05) \end{aligned} \quad (4)$$

The regression slope, which corresponds to the rate of horizontal rhizome growth (cm per horizontal rhizome per day), is higher for the unvisited than for the visited location (ANCOVA, $P < 0.05$).

At the visited location, internodal length showed a precipitous decrease over the 2½ years prior to our collection date, but this was not the case at the unvisited location (Fig. 4). Namely, at the time of collection (August 1999) the vertical internodes at the visited location had reduced their length by almost 50% in comparison with early 1997.

Discussion

We show large differences in turtlegrass morphology and growth between the visited and unvisited locations. Other than the dramatic contrast in visitation by tourists, the two locations had similar physical and hydrological characteristics. The average values of water temperature, salinity, and nutrient concentrations did not differ significantly between the two locations (Herrera-Silveira et al. 2006). Both locations were similarly exposed to wave and storm action, and the sediment in both locations was mainly composed of sand. Hence, our comparison suggests that the reduced turtlegrass health found at the visited location

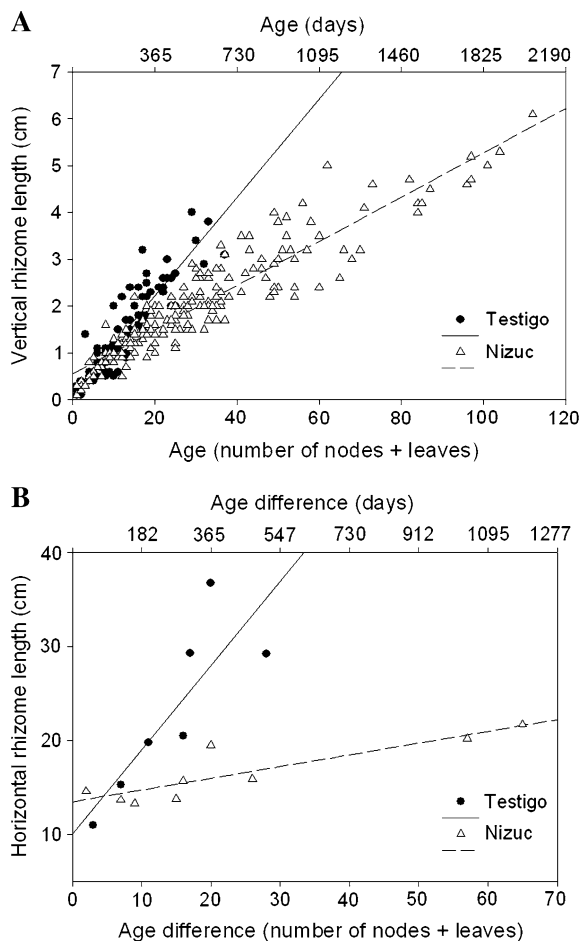


Fig. 3 **a** The relationship between the length of the vertical rhizome of a short shoot and the age of the shoot at the unvisited (“Testigo”, closed circles) and visited (“Nizuc”, open triangles) locations. **b** The relationship between the length of horizontal rhizome and the age difference between the short shoots at the beginning and end of that rhizome at the unvisited (“Testigo”, closed circles) and visited (“Nizuc”, open triangles) locations. Lines depict the regression equations (“Testigo”, continuous line; “Nizuc”, dashed line)

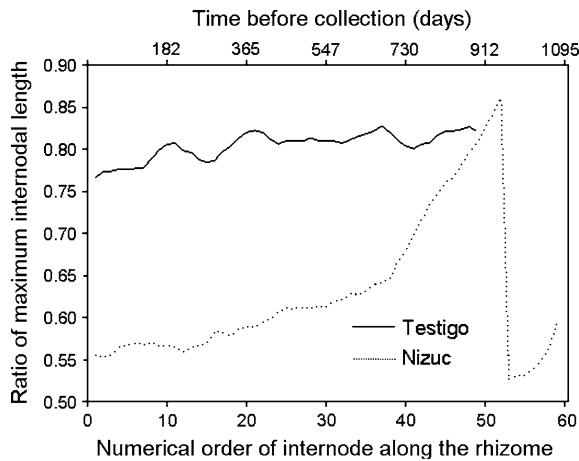


Fig. 4 The evolution of internodal length in the vertical rhizomes of short shoots. To calculate the ratio (fraction) of maximum internodal length represented by each internode, the length of the internode was divided by the length of the longest internode in the rhizome. Lines depict the mean fraction for three short shoots versus the position of the internode along the vertical rhizome (unvisited location: “Testigo”, continuous line; visited location: “Nizuc”, dotted line)

is a consequence of, through direct or indirect mechanisms, the activities of the tourists visiting the location. Nevertheless, we recognize this is only a possibility that, albeit seemingly strong, requires further experimentation for final confirmation.

Snorkeling appears to be one of the most important mechanisms by which tourists may cause damage on turtlegrass at the visited location. Many of the tourists visiting the location snorkel in the turtlegrass bed. Most of them are inexperienced and careless, and they often kick the turtlegrass and open bottom with their fins, severing the leaves and resuspending much sediment. Sediment resuspension may in turn expose the rhizome to grazers and borers, which may cause seagrass decline (Marba and Duarte 1995; Vidondo et al. 1997). Resuspended sediment can also shade seagrass leaves. We did not quantify sediment resuspension and resulting shading in the location, but other studies have documented its detrimental impacts on seagrasses and other benthic organisms (Erftemeijer and Lewis 2006; Ralph et al. 2006; Hasler and Ott 2008). We have also witnessed how some snorkelers, after diving down and reaching the turtlegrass bed, hold themselves to the leaves to observe the surrounding scenery, which often results in the divers ripping off the leaves they hold on to.

The damage exerted by snorkeling could explain why the turtlegrass bed at the visited location had sparser and shorter shoots than at the unvisited location (i.e., shoot leaf weight was lower at the visited than unvisited location, but the number of leaves per shoot and leaf specific area did not differ significantly between the locations, indicating that shoots had shorter leaves in the former location), and why turtlegrass leaves grew more slowly at the visited than at the unvisited location. Interestingly, turtlegrass leaves had more epiphytes at the visited than at the unvisited location. The two locations are oligotrophic and higher epiphyte biomass in the visited location could result from enhanced nutrient availability at the seagrass canopy level due to sediment resuspension. Additionally, the intense disturbance caused by snorkeling could reduce the abundance of epiphyte consumers in the turtlegrass bed at the visited location, thereby allowing for higher epiphyte biomass (Heck et al. 2000, 2006). In turn, higher epiphyte biomass could contribute to reducing shoot leaf growth rates (Cebrian et al. 1999; Hauxwell et al. 2001).

We also detected lower rates of turtlegrass horizontal and vertical rhizome growth in the visited than in the unvisited location. We further found that reduced vertical rhizome growth rates were due to shorter internodes, and not due to lower annual internode production. Seagrass growth reconstruction techniques allowed us to reveal these differences between the two locations with just one sampling event. Many other researchers have used seagrass growth reconstruction techniques to study several aspects of seagrass productivity and life history when only limited sampling effort is possible (e.g., Gallegos et al. 1993; Duarte et al. 1994; Kenworthy and Schwarzschild 1998; Cebrian and Duarte 2001), but fewer have used these techniques to derive rates of rhizome growth (Duarte et al. 1996; Marba et al. 1996). Our results exemplify how rates of horizontal and vertical rhizome growth can be easily derived with just one sampling event, and they suggest these measurements may be good indicators of seagrass health.

Shorter and sparser turtlegrass shoots may result in reduced structural complexity in the bed, which in turn may lead to reduced abundances of the numerous species of crustaceans, molluscs, and fishes that seek shelter in turtlegrass beds (Hughes et al. 2002; Heck et al. 2003; Cebrian et al. 2009). Moreover, sparse leaf

canopies may not attenuate wave action as much as thick canopies do, thereby allowing for higher sediment resuspension and less clear water (Terrados and Duarte 2000; Gacia and Duarte 2001; Granata et al. 2001). Therefore, it appears that continuing snorkeling “as is” by visiting tourists could lead to substantial environmental degradation with murkier waters and reduced finfish and shellfish presence, which would undoubtedly defeat the purpose as to why MPAs are created and open to tourists. Fortunately, several species of seagrasses, including turtlegrass, are resilient and can regain a healthy status after the perturbation ceases. For instance, turtlegrass recolonized large areas in Tampa Bay after water quality improved (Tomasko et al. 2005). Turtlegrass can also recover from physical damage caused by storms, propellor scars, and boat groundings (Dawes et al. 1997; Byron and Heck 2006). This offers a hopeful message for the managers of the “Costa Occidental de Isla Mujeres, Punta Cancún y Punta Nizuc” MPA, because it strongly suggests that, if new measures and regulations are implemented, the turtlegrass beds at this and other highly visited locations could spring back to a healthier status and provide a more pleasant and educational experience (e.g., clearer water, more finfish, and shellfish) for the visiting tourists.

What measures could be implemented to enhance turtlegrass health at this and other visited locations in this MPA? Zoning has been embraced as a management practice in many MPAs (e.g., Suman et al. 1999; Francis et al. 2002; Davos et al. 2007; Portman 2007). Zoning frequently divides MPAs that are important destinations for tourists into “no visitation”, “low/moderate-visitiation”, and “high-visitiation” areas. Often times “no visitation” areas are preferred recruitment grounds for species that may subsequently disperse to visited areas such that the environmental impact in those visited areas can be somewhat palliated. Reasons for such division often include (1) catering to tourists with different demands and expectations (e.g., tourists looking for crowds or tourists rather interested in quieter places) and enhance their overall satisfaction; (2) allowing for research activities so the impacts on visited areas can be fully evaluated and measures of “adaptive management” (i.e., readjust number, location and size of the zones, and/or implement actions to reduce environmental damage in visited areas) adopted if

necessary; and (3) combining effective protection of natural resources with financial sustainability. Zoning as this ultimately aims at preserving good environmental health while educating and satisfying visitors to secure revenue.

Zoning at the “Costa Occidental de Isla Mujeres, Punta Cancún y Punta Nizuc” MPA follows a similar design and divides the MPA into three types of areas (Cancún 1998). Nucleus areas are off-limits for tourists and include well-conserved coral reefs and seagrass beds. Buffer areas only allow for low visitation and are also well conserved. Finally, a number of areas, which are often the closest to neighboring holiday resorts, are open to intense tourist visitation. The unvisited location studied here is situated within the nucleus area, and the heavily visited location within the area open to intense tourist visitation, of the Punta Nizuc region of the MPA. Managers intend to minimize environmental damage in the heavily visited location by maintaining specific routes for jet-ski traffic and mooring, and capping the number of visits and time spent in the water by the visitors. However, our results strongly suggest snorkelers inflict considerable damage on turtlegrass health at that location. The current MPA zoning design seems adequate for satisfying different tourist interests while preserving good environmental health in many areas of the MPA, but it does not appear to be preventing turtlegrass degradation in the heavily visited location studied here. Changes in the current MPA zoning design are unlikely to improve turtlegrass health in this and other locations where turtlegrass is being damaged by visitors because most turtlegrass growth occurs vegetatively from shoots in the same population (Van Tussenbroek et al. 2006). Thus, new regulatory procedures should be adopted in this and other locations where visitors are damaging turtlegrass.

Educating tourists prior to arriving and snorkeling in this and other locations may prove efficient. Tourist educational activities have been implemented or suggested as effective management practices in other heavily visited locations (e.g., Davis and Tisdell 1995; Milazzo et al. 2002; Hasler and Ott 2008; Leujak and Ormond 2008). For instance, park rangers could show the tourists an instructional video featuring the value of seagrass beds and how to minimize damage during their snorkeling experience. In addition, explanatory brochures could be available at hotels, information centers, and travel offices. Most importantly, the

tourists should be instructed to stay at least 1 m above the bottom, regardless of whether it is seagrass or sediment, and never hit or grab the leaves. Buoys and/or steaks could mark the minimum distance from the bottom not to be trespassed. This could be enforced with policing by the rangers and, if necessary, with fining and other penalties (e.g., Barker and Roberts 2004). With the instructional video and other educational materials, most tourists will certainly come to appreciate the environmental benefits of seagrass beds and, thus, likely welcome this and other protective measures. Indeed, actions as the ones suggested here can efficiently contribute toward sensitizing tourists to the need of conserving precious coastal resources, thereby increasing learning and satisfaction with their visit, which undoubtedly is one of the missions of MPAs. These educational activities, in combination with the zoning design currently in place, can help this and other MPAs achieve their goals fully.

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