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Indication of visitor trampling impacts on intertidal seagrass beds in a New Zealand marine reserve

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ABSTRACT

Marine Protected Areas (MPAs) are recognised as an important tool for protecting sensitive habitats and ecosystems from anthropogenic impacts. Despite this protection, many of these areas are open to non-extractive or consumptive visitor activities, which often receive little regulation. This paper examines the effects of low-impact visitor activities on *Zostera marina* seagrass beds within the Te Angiangi Marine Reserve, New Zealand. Seagrass cover (shoot count and blade length) was compared between an area that received high levels of visitor use and an analogous, relatively-unused area within the marine reserve. The high-use area had significantly lower seagrass cover than the control site, with a gradient of increasing impact observed closer to the beach and at the edge of a high-use swimming area. These impacts reflect estimated visitor use patterns in the area and highlight the need for additional management strategies that consider the potential impacts of seemingly 'low-impact' visitor activities on sensitive habitats within no-take MPAs.

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1. Introduction

Seagrasses beds are highly productive ecosystems that play an important role in coastal ecology (Hemminga and Duarte, 2000). Despite their ecological importance and wide global distribution, the health and extent of seagrass-dominated ecosystems worldwide is threatened by a number of natural and anthropogenic factors, particularly changes in sediment loading due to coastal development activities (Short et al., 2011; Waycott et al., 2009). In response to seagrass loss caused by increasing anthropogenic impacts, there has been an increase in the number of Marine Protected Areas (MPAs) around the world that include seagrass ecosystems and seagrass monitoring and restoration projects (Orth et al., 2006).

While the strictest forms of no-take MPAs restrict public access (i.e. IUCN category Ia), the scope for creating these areas is extremely limited. Thus, in practice, non-extractive uses are generally accepted within most no-take areas (Lubchenco et al., 2003; Roberts et al., 2003). In many MPAs, these activities are promoted, with visits to no-take areas an important component of many recreational, scientific and educational activities. Within the no-take restrictions, people are often encouraged to appreciate and study the marine life that develops within these areas, and often, these areas experience higher visitation levels than nearby areas that are not protected (Ballantine and Langlois, 2008). However, this increased level of visitation and the activities conducted by visitors have the potential to cause significant environmental damage unless properly managed (Thurstan et al., 2012).

Visitor impacts on seagrass beds are well documented for many common activities, such as jet-skiing, motor boating, scuba diving and snorkelling (Walker et al., 1989; Short and Wyllie-Echeverria, 1996; Montefalcone et al., 2006; McCrone, 2001; Milazzo et al., 2004a; Lloret et al., 2008; Herrera-Silveira et al., 2010), and these activities often receive a clear form of regulation in MPAs where they are permitted. Trampling by visitors can also be an important source of disturbance and stress for marine communities within coastal MPAs (Milazzo et al., 2002; Casu et al., 2006), however, many 'low-impact' activities related to trampling are often permitted with minimal regulation (Thurstan et al., 2012).

Trampling occurs with all forms of visitor access, although vulnerability to trampling depends on the nature and morphology of local habitats and communities and the intensity of human use (Keough and Quinn, 1998; Milazzo et al., 2004b; Araujo et al., 2009). In an experimental analysis of the impacts of trampling on seagrass beds, Eckrich and Holmquist (2000) reported that seagrass biomass was inversely related to trampling intensity and duration. Seagrass

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cover decreased after four months of either light or heavy trampling, with a higher decline in cover in the heavily-trampled area. In addition, neither seagrass area completely recovered to pre-experimental conditions in the seven months following the final trampling treatment. These results suggest that even relatively low trampling intensities may result in long-lasting negative effects on seagrass beds. This will have important implications for MPA management, where the impacts of visitor trampling are often overlooked.

The aim of the present study was to compare the state of two intertidal *Zostera marina* seagrass beds around Stingray Bay, a highly-visited area within the New Zealand Te Angiangi Marine Reserve, in order to assess the influence of visitor trampling in this area. Within New Zealand, no-take 'Marine Reserves' offer the highest level of protection to marine life and are established for the purpose of preserving marine life for scientific study. Although there are strict rules around the removal or disturbance of marine habitats and life within marine reserve boundaries, there are no access restrictions, and many activities such as sailing, snorkelling and diving are encouraged. Based on estimated visitor use patterns within the Te Angiangi Marine Reserve, particularly around Stingray Bay, it was hypothesised that the effects of visitor trampling would be most apparent: (1) along the beach/rock platform interface and (2) along the pool-edge of Stingray Bay, with a gradient of diminishing impact away from these areas.

2. Methods

2.1. Study area

The Te Angiangi Marine Reserve is located on the eastern coast of New Zealand's North Island (Fig. 1). The reserve was established in 1997 to protect a 'typical piece of the Central Hawke's Bay coast' and covers approximately 446 ha (Department of Conservation 2008). Within Te Angiangi Marine Reserve, seagrass (*Zostera marina*) is found in a mosaic of small (<1 m^2) patches in sediment-filled crevices and pools on the open-coast rocky intertidal platform interspersed with bare rock or beds of brown algae (*Hormosira* spp.). Extensive seagrass meadows have formed, however, around the perimeter of Stingray Bay, a subtidal rock pool, bounded by the sandy beach to the west and intertidal rock platforms to the north and south (Fig. 1).

Stingray Bay is a popular area for visitors and is often used for educational activities due to its protection from the open coast. Visitors undertake a variety of activities in the Stingray Bay area, including rock-pooling, snorkelling and swimming. From discussions with the local marine reserve staff that regularly patrol the area and are responsible for delivering the majority of education activities within the reserve, we identified a 'high-use' area along the northern perimeter of the Bay. This area is easily accessible to park visitors, has a close proximity to public facilities (i.e. toilet blocks), and is the main area used by groups when visiting the marine reserve. In contrast, staff indicated that very few visitors use the southern perimeter of the Bay, with this area selected as our control site (Fig. 1). Due to the relatively small size of the bay (approx. 200 m wide at beach), the physical characteristics of the sites, e.g. the platform substrate (rocky mudstone) and tidal inundation (full exposure at low tide and full submersion at high tide), are consistent between the two sites, allowing for a comparative assessment of likely visitor trampling impacts between these two areas.

2.2. Estimation of trampling effects

Sampling was conducted in a single-period survey in February 2011, at the end of a high-use period over of the summer school holidays (mid-December to early-February). In order to measure trampling impacts, ten 20-m line transects were established within the high-use area starting at the beach/rocky platform interface (i.e. 0 m) running parallel to the shoreline at 5 m intervals out to 45 m from the beach.

Along each transect, 0.25 m^2 quadrats were placed at distances of 0 (i.e. the edge of pool), 1, 2, 3, 5, 10 and 20 m from the pool. These quadrats were further divided into 10 cm × 10 cm segments. Seagrass cover was estimated by counting the number of live shoots within two haphazardly-selected segments in each quadrat and by measuring one indicative leaf-blade length in each segment. There was one instance where the platform substrate changed to hard rock (at 20 m from the pool and 40 m from the beach), and this interval was excluded from the subsequent analyses as this substrate does not support seagrass development. Transects were not established within the control area, rather 20 quadrats were identified by haphazardly throwing markers onto the seagrass bed. Thus, samples were distributed throughout the entire area, from the edges of the meadow to ~50 m from the beach and ~20 m from the pool. Within these quadrats, seagrass cover was again measured by counting the number of live shoots within two haphazardly-selected 10 cm × 10 cm segments, along with measuring one indicative leaf-blade length in each quadrat.

2.3. Statistical analyses

All data analyses were conducted in RStudio using the computing language R (R Development Core Team, 2008). Diagnostic plots of data were checked visually for homogeneity of variance and normality, and in order to meet these assumptions, shoot count data were square-root transformed. Mean overall shoot count and blade length between the high-use and control areas were compared using independent (Welch) t-tests to test for significant ($p \leq 0.05$) differences between the sites. Within the high-use area, separate two-way analysis of variances (ANOVA) were conducted to examine the effects of distance from the beach and distance from the pool on (1) shoot count and (2) blade length. Where no significant interaction effects were observed but significant main effects ($p \leq 0.05$) were present, pairwise t-tests were used to compare means between each treatment group within the high-use area to the mean of the control area. Where a significant interaction effect ($p \leq 0.05$) was observed, simple main effects were investigated by comparing cell means for each distance from the pool at each distance from the beach. Tukey's post-hoc procedures were used to further investigate any significant effects identified.

3. Results

3.1. Overall differences between high-use and control areas

An independent sample t-test indicated a significant difference in both blade length ($t = -4.83$, $p < 0.001$) and shoot count ($t = -4.94$, $p < 0.001$) between the high-use area and the control area (Fig. 2). Within the high-use area, the distance from the pool and the distance from the beach each had a significant effect on both blade length and shoot count (Table 1). No significant interaction effect for the distance from the pool and distance from the beach was not found for blade length ($F = 1.922$, $p = 0.059$; Table 1), although there was a significant interaction effect for shoot count ($F = 3.795$, $p < 0.001$). This indicates that within the high-use area, the number of shoots was dependent on both the distance from the beach and the distance from the pool.

3.2. Description of spatial patterns

3.2.1. Blade length

Within the high-use area, blade length increased significantly

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