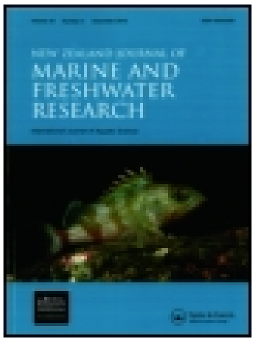

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Short communication

Influence of the small intertidal seagrass *Zostera novazelandica* on linear water flow and sediment texture

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Abstract The influence of a small intertidal seagrass, *Zostera novazelandica* (Setchell), on tidal current velocities and sediment texture was studied at Harwood, Otago Harbour, New Zealand. Tidal current velocities were substantially reduced inside the *Z. novazelandica* patch compared to velocities above the patch (3.7 times greater) and outside it (2.5 times greater), causing a low-flow environment among the 12-cm-tall seagrass. Current velocities combined over one tidal cycle occupied a much wider range outside (1.2–4.6 cm s^{-1}) and above (1.9–7.1 cm s^{-1}) the seagrass patch than inside (0.1–1.8 cm s^{-1}) indicating slower and less variable water flow. Suspended mud (<0.063 mm) settled to the bottom in this low-energy environment and was protected from resuspension by seagrass cover, indicated by significantly elevated amounts of mud inside the seagrass patch (1.1%) compared to outside (0.4%). These results indicate that *Z. novazelandica* may reduce water flow and accumulate finer sediment sizes to a lesser extent than larger subtidal seagrass species.

Keywords *Zostera novazelandica*; seagrass; eelgrass; current velocity; flow reduction; sedimentation

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INTRODUCTION

Seagrasses exert strong effects on water motion (Fonseca et al. 1982; Gambi et al. 1990; Verduin & Backhaus 2000) and sediment dynamics (Ward et al. 1984; Fonseca & Fisher 1986). Seagrass beds are complex systems whose physical structure is dominated by the leaf, root, and rhizome systems. The leaves reduce current speed by increasing resistance to water currents within the seagrass beds (Fonseca et al. 1982), which in turn creates a low-energy microenvironment inside the meadow (Ginsburg & Lowenstam 1958). The reduction of current velocity causes fine-grained suspended particles to settle out, and they are then stabilised by the root and rhizome system of the seagrasses (Ginsburg & Lowenstam 1958).

Most studies concerned with the effect of seagrasses on hydrodynamics and sediment properties have concentrated on larger and/or subtidal species (c. 30–100 cm), notably *Zostera marina* (e.g., Fonseca et al. 1982; Marshall & Lukas 1970), *Thalassia testudinum* (e.g., Almasi et al. 1987; Koch 1996), *Syringodium filiforme* (Fonseca & Fisher 1986), *Halodule wrightii* (Kenworthy et al. 1982), and *Posidonia oceanica* (Danovaro et al. 1994; Gacia et al. 1999). In contrast, *Zostera novazelandica* (Setchell), endemic to New Zealand (Kuo & McComb 1989), has a maximum blade length of 15 cm and its influence on water flow and sediment dynamics is not known. Information on the influence of *Z. novazelandica* on water motion and sediment properties will, therefore, address the impact that smaller seagrass species may have in the intertidal zone.

METHODS

Study area

Measurements of tidal current velocities and sediment properties were undertaken inside and outside a seagrass patch on the extensive intertidal sandflats at Harwood (45°48′S, 170°41′E) in Otago Harbour,

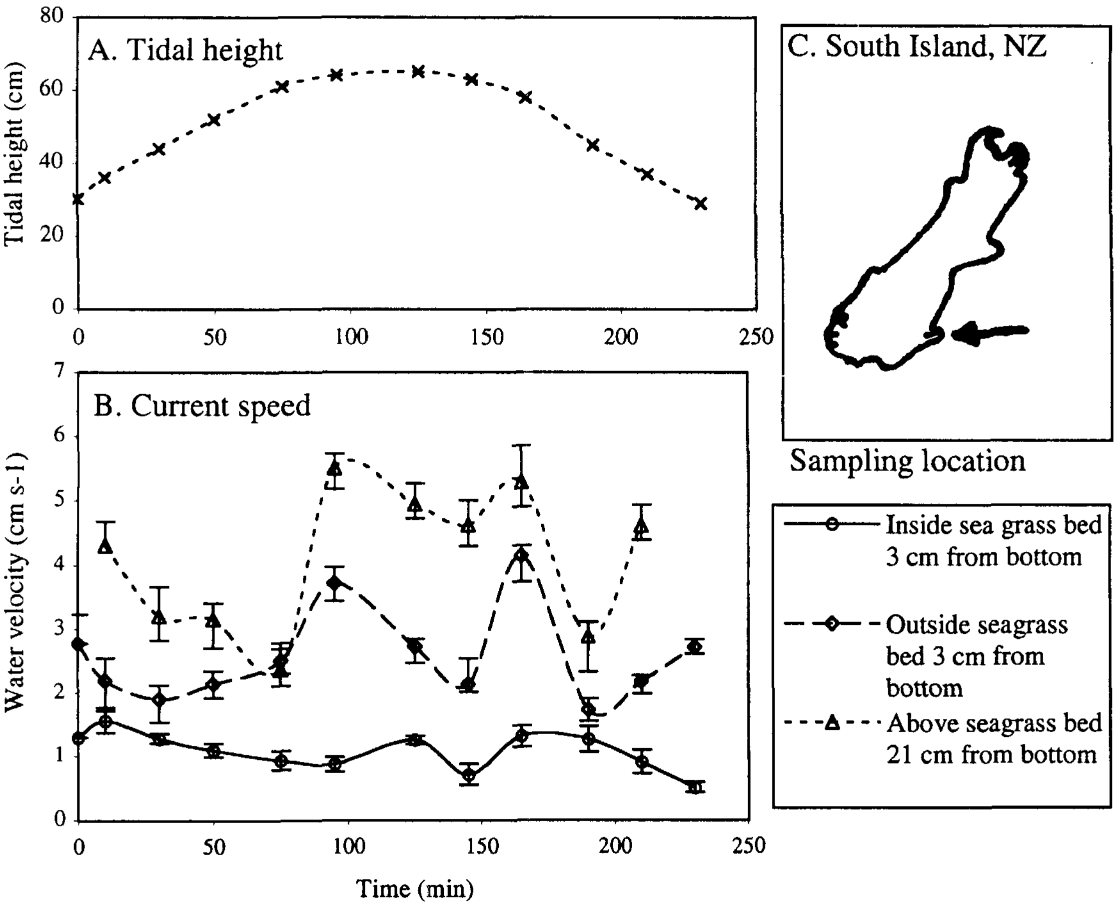

Fig. 1 A, Mean tidal current velocities over one tidal cycle; and **B**, comparison of velocities inside a seagrass (*Zostera novazelandica*) patch with those outside and above it. Error bars show one standard error. **C**, Location of the seagrass patch (Harwood, Otago Harbour, South Island, New Zealand).

South Island, New Zealand. The sandy beach slopes gently and is exposed for several hundred metres at low tide. *Z. novazelandica* is the dominant species on the Harwood intertidal sandflats with beds (5–10 m in diameter) mainly occurring as a mosaic of discrete patches in a matrix of unvegetated sediment, rather than continuous expanses of vegetation.

The study site (covering an area of 40 m^2) contained a *Z. novazelandica* patch (22 m^2) and parts of a surrounding sandflat. The site was in the upper intertidal zone, 10 m from the top of the shore, in a slight depression which was generally poorly drained at low tide. Water covered the study area for 4–6 h each tidal cycle depending on neap (mean range of 1.3 m) or spring (mean range 1.7 m) tides.

Mean tidal current velocity measurements

Mean tidal current velocities were measured by releasing dye at fixed points into the water column to track water movement. Current velocity measurements were made over one spring tidal cycle on a calm day without any significant wind (15 July 1997). Two syringes (60 ml), each connected to two injection points at 3 and 21 cm above the sediment surface, were set up, one inside the seagrass patch in a location of 100% seagrass cover, the other as a control on the adjacent sandflat. Two underwater cameras were supported by frames in a vertical position to film the injection points from above. Different coloured neutrally-buoyant dyes were used inside the seagrass patch (fluorescent calcein) and outside the patch (potassium permanganate) to improve visibility of the dye on video film.

Tidal current velocities were measured inside the seagrass cover (at 3 cm above the sediment surface), above the seagrass canopy (at 21 cm), and above the sandflat (at 3 cm) by injecting dye (c. 8 ml) into the water column c. 6 times every 20–30 min over a 12-h tidal cycle. A 2.5 m stake was used as a stationary sample point adjacent to the seagrass patch to measure the change of water height above the study site over the course of the dye measurements.

Analysis of video film

Two frames were analysed per dye injection—one of the dye just after entering the water column and the second frame after the dye had travelled a measurable distance (usually in 1–3 s). The distance travelled by the dye in the time between the two frames was calculated to give current velocities in cm s^{-1}.

Sediment texture

Four replicate surface sediment samples were collected (using a core measuring 11 cm in diameter and 2 cm high) at each of two sites: one inside and one outside the seagrass patch for analysis of sediment texture. Each sediment sample was homogenised and c. 100 g of sediment was wet sieved through 5, 2, and 0.063 mm sieves. The 5 mm sieve removed most of the larger organic material, the 2 mm sieve the smaller organic material, and the 0.063 mm sieve separated the sand and mud fractions. The sand fraction retained on the 0.063 mm sieve was collected and dried at 100°C before dry sieving and weighing at 1 phi intervals (McManus 1988). The mud fraction was determined from a pipetted aliquot of the residual rinse water (McManus 1988). Standard particle size analysis was carried out using the graphical method (Lewis & McConchie 1994).

RESULTS

Mean tidal current velocities over one tidal cycle

Tidal submersion at the study site during spring tide was sufficient to allow current measurements for 4 h. After the start of the measurements, flood and ebb tide each lasted 2 h. No data were obtained for the first and last measurements at 21 cm above the bottom because the water was too shallow to allow dye to travel without being disturbed by surface turbulence. In total, 50 measurements were taken at 3 cm height inside the patch, 52 at 3 cm outside the patch, and 49 at 21 cm above the patch.

Mean tidal current velocities measured inside and outside the seagrass cover ranged from 0.5 to 5.5 cm s^{-1} over a tidal cycle (Fig. 1). Current velocities above the seagrass patch (mean = 4.1, SD = 1.3 cm s^{-1}) were 3.7 times greater than those inside (mean = 1.1, SD = 0.4 cm s^{-1}). Similarly, currents above the sandflat (mean = 2.7, SD = 0.8 cm s^{-1}) were 2.5 times greater than those inside. Mean current velocities measured inside the seagrass cover were always significantly reduced compared to those above the canopy and, in general, compared to ambient velocities 3 cm above the sandflat. Current flow outside and above the seagrass patch fluctuated over a wider range over a tidal cycle (e.g., 1.9–7.1 cm s^{-1} above the seagrass) than velocities underneath the seagrass canopy (0.1–1.8 cm s^{-1}).

Sediment parameters inside and outside a seagrass patch

Surface sediment textures inside and outside the seagrass were very similar; mean grain size in both cases was 2.4 phi, and sorting coefficient 0.4 phi. All sediments were dominated by fine sand and were well sorted. Fine sand made up more than 85% of all samples with lesser amounts of medium sand and very small fractions of mud and gravel. Nevertheless, the mud content of sediments inside the seagrass patch (mean 1.1%) was significantly higher than that outside (mean 0.4%) (pooled 2-sample t-test: T = –4.04, P = 0.007).

DISCUSSION

Mean tidal current velocities

Most studies concerned with the effect of seagrasses on water have investigated moderate to fast water flows (>5–50 cm s^{-1}) and larger seagrass species, e.g., Peterson et al. (1984), Almasi et al. (1987), and Losee & Wetzel (1993) and flume studies by Fonseca et al. (1982) and Gambi et al. (1990). In this study, the small (<15 cm) seagrass species *Z. novazelandica* was influenced by slow water flows (2–7 cm s^{-1} over a spring tidal cycle). *Z. novazelandica* clearly created a low-flow environment underneath its canopy under these conditions. These results correlate well with studies by Ackerman (1986) and Gambi et al. (1990) who reported that *Z. marina* caused a substantial reduction in slow water flows (c. 5 cm s^{-1}).

In contrast, Worcester (1995) did not find significant differences in current velocity between vegetated and unvegetated areas of *Z. marina* in the field subjected to sluggish currents (<5 cm s^{-1}). Such low velocities may have been so slow that they were not reduced significantly by *Z. marina*. In this study, the magnitude of current velocities varied over the course of a tidal cycle. Ambient current velocities at 3 cm above the bottom below c. 2.2 cm s^{-1} were generally not significantly reduced by *Z. novazelandica*, indicating that there may be a threshold velocity, depending on seagrass species, below which no further reduction in flow velocity occurs.

Within-patch current flow combined over a tidal cycle was much less variable and more regular in magnitude than tidal current flows outside the bed. All flow velocities measured inside the patch occupied a much smaller range (0.1–1.8 cm s^{-1}) than did those at the same height outside the bed (1.2–4.6 cm s^{-1}) and above the seagrass bed (1.9–7.1 cm s^{-1}). These results agree with findings from Ackerman & Okubo (1993) and Losee & Wetzel (1993) who observed flow measured within seagrass beds to be very regular and less fluctuating than outside the bed. The seagrass canopy of *Z. novazelandica* created a microenvironment of slow and steady water flow inside the bed by reducing current flow and redirecting it around and above the patch.

Sediment texture

The similarity of sediment texture inside and around the *Z. novazelandica* seagrass patch may reflect the source of sediments available. Well-sorted fine sand is by far the most common sediment in Otago Harbour. Visual observations of the seagrass patch showed that sediment accumulated at the exposed edge of the patch as small elevations. Water currents are reduced most efficiently at the edges of meadows (Fonseca et al. 1982; Ward et al. 1984; Gambi et al. 1990), enhancing sedimentation at the margin of beds. Therefore, *Z. novazelandica* may have caught significant amounts of finer sand-sized sediment given more size classes as a source.

Peterson et al. (1984) found significantly finer sediments inside a *Z. marina* bed than outside, as did Marshall & Lukas (1970). The sediment available to their study site was moderately well sorted, and comprised more size classes than sediments at Harwood, enabling *Z. marina* to selectively filter out finer sediments. In addition, *Z. marina* is a larger seagrass species, possibly more efficient at trapping fine sediments than *Z. novazelandica*.

The *Z. novazelandica* patch accumulated significantly more mud underneath its canopy compared to the outside. This, together with reduced current flow inside the seagrass patch, indicated that *Z. novazelandica* acted as a baffle, dampening current flow and allowing mud particles to settle from the water column. Mud content inside the *Z. novazelandica* patch was 2.8 times higher than outside. Larger seagrass species generally cause higher proportions of mud to accumulate underneath their canopy compared to outside (see, e.g., Wood et al. 1969; Kenworthy et al. 1982). This indicates that *Z. novazelandica* may be less efficient in trapping mud than other seagrasses because of its small size.

The lesser proportion of mud associated with the *Z. novazelandica* patch compared to mud content in meadows of larger seagrass species may also be caused by patch size. Mud is protected from water currents more efficiently in mid-bed regions than at edges as a result of increasing reduction of currents with distance into the meadow (Fonseca et al. 1982). The *Z. novazelandica* patch may not have been large enough to slow currents to an extent to accumulate higher proportions of mud and protect these from resuspension. For example, Kenworthy et al. (1982) found mud content of sediments associated with *Z. marina* and *Halodule wrightii* to be highest in mid portions of beds (24%), intermediate in small patches and at the edges of beds (12%) and lowest outside seagrass areas (4%). These findings clearly stress the importance of considering size of seagrass beds in future studies.

Zostera novazelandica, however, occurs intertidally and in the intertidal zone the sedimentary environment is influenced differently than in the subtidal zone because of periodic exposure to air and to fluctuating water depth. The description of sediment texture inside and outside intertidal seagrass beds has received less attention (Grady 1981) compared to studies in the subtidal zone. Therefore, more consideration has to be given to sediment textures found inside and around seagrasses in the intertidal zone and the results have to be compared to sediment textures in subtidal seagrass beds. Conclusions drawn from observations of subtidal seagrasses and associated sediment may not ultimately be true for seagrasses in the intertidal zone where a somewhat different physical environment prevails.

This study considered only a single tidal cycle, under calm conditions during a spring tide (mainly for logistical reasons). More rapid currents probably occur in windy or stormy weather; this variability would be a fruitful area of study. In addition, spatial variation within the seagrass meadow is hinted at here, and is probably important. Here we present a "snapshot" of the seagrass bed under particular conditions—future work should extend these data over both time and space.

In sum, our results suggest that the small seagrass species *Z. novazelandica* substantially reduces ambient tidal current velocities. This causes higher amounts of mud to settle out inside the seagrass cover resulting in significantly higher amounts of mud underneath the seagrass canopy than outside. However, the proportion of accumulated mud associated with the *Z. novazelandica* patch is less when compared to the proportion of mud found associated with larger subtidal seagrass species. This could be the result of the relatively small size of *Z. novazelandica* and/or its intertidal occurrence. More studies are needed comparing large and small, intertidal and subtidal seagrass species to gain a better understanding of the influence of seagrass species on physical attributes in their environment.

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