ASSESSING THE IMPACTS OF BEACH SCRAPING ON THE MACROINVERTEBRATES OF NEW BRIGHTON BEACH, NORTHERN NSW

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Abstract

As part of an assessment of mitigation strategies for coastal erosion and associated recession of the back beach erosion escarpment, Byron Shire Council undertook trial beach scraping at New Brighton beach in August and September 2010. Sand was removed to a depth of up to 0.5m along a 1.31-km section of intertidal beach. Using a bulldozer and excavators, this sand was moved to the back (upper) beach to increase sand reserves in the dune system. We assessed the impact of scraping on the small invertebrates living within the beach (upper strandline to the lower tidal limit).

We established 2 sites in the impact area and 2 control sites well away from the beach scraping works, and sampled 5 beach levels before the impact, and 1 day, 1 week, 2 weeks and 4 weeks after scraping. We extracted replicated cores of sand from which macroinvertebrates were removed, identified and counted, and subsequently analysed the data to determine: i) the size of the immediate impact; and ii) the temporal scale of recovery should an impact be detected.

Remarkably, none of the variables assessed in this study (species richness, abundance, community structure) displayed unambiguous evidence of immediate effects and the primary trend was of high dynamism across the entire study area. Assessments of community structure suggested that patterns were mostly dependent on the date of sampling. Thus, macroinvertebrate assemblages were more similar within a specific sampling period at all sites than within a site over time.

This study confirms suggestions from similar research that beaches are highly dynamic and thus have the capacity to recover rapidly from some forms of physical disturbance. In this study, natural disturbances, such as periods of high swell, appear to have had more of an effect than the mechanical removal of sand from the beach face.

Additional keywords: BACI, dynamism, infauna, recovery

Introduction

Recession of unconsolidated shorelines is a global phenomenon that is likely to be exacerbated with predicted rises in sea level (Speybroeck *et al.*, 2006). The consequences of such recession can be considerable, leading to loss of property, infrastructure and amenity. Management approaches to address this issue have been many and varied, ranging from hard-engineering solutions in an attempt to stabilise shorelines (e.g. the construction of seawalls and groynes), to ‘planned retreat’ policies (i.e. a planning tool detailing limits to development in coastal areas vulnerable to erosion – Leitch, 2009).

Beach scraping, during which sand is won from the intertidal beach face and deposited on the upper beach/dunal interface, is one of a raft of soft-engineering solutions that is used to manage coastal erosion and may be defined as "*the movement of small to medium quantities of sand from the lower part of the littoral beach system to the dune, using mechanical means*" (Carley *et al.*, 2010). This process increases the dune volume (and height, if desired) to better protect against short-term coastal erosion threat, and may improve beach amenity and access. Beach scraping effectively mimics beach recovery processes (i.e. onshore transport of sand under low swell and onshore wind regimes), but over much shorter temporal scales (Carley *et al.*, 2010).

New Brighton beach, located in the Byron Shire, northern NSW, has endured a history of coastal erosion (NSW PWD, 1978; BSC, 2010a). To manage the erosion threat, beach scraping was undertaken in 1979 to rebuild the heavily eroded dune system, and continued regularly thereafter up until 1996 (WBM, 2000, 2004) when it was discontinued due to possible negative impacts on pipi (*Donax deltoides*) populations (Carley *et al.*, 2010).

The New Brighton foredune was again severely affected during the erosion event associated with a severe East Coast Low in May 2009. In response to this, and following completion of a technical investigation into the feasibility of beach scraping (Carley *et al.*, 2010), Byron Shire Council (BSC) implemented a 'trial' beach scraping project at New Brighton beach in September 2010. The objective of the trial was to increase the dune volume on New Brighton beach in order to reduce the severity of the immediate coastline hazard threat to infrastructure (roads and services) and private property adjacent to the dune (BSC, 2010b). As such, the project did not aim to fully remove the immediate hazard risk from a 'design' storm bite. Whilst this is a desirable outcome from a human and built-asset risk management perspective, the ecological, economic and social impacts of such a large scraping undertaking were unquantified and potentially unacceptable (BSC, 2010b). Thus, under the beach scraping trial, only approximately 30% of the sand volume identified as required to build the dunes to a design profile was to be scraped (BSC, 2010b; Carley *et al.*, 2010). Assessment of the impacts on biological communities could then be completed prior to consideration of future scraping works.

In order to achieve the project objectives, sand was removed from the intertidal beach along a 1.31-km section of New Brighton beach over the period from 28 August to 22 September 2010. The desired volume to be scraped from the intertidal zone was between 8-18m^3 of sand/m run of beach. Intertidal sand was won and placed against the back beach erosion escarpment using three 20-t excavators. The scrape depth was approximately 0.2–0.3m (with depths down to 0.5m in some patches – pers. obs.) and, at the time of compiling this paper, the exact quantities of sand redistributed in this way have yet to be fully quantified.

One of the critical questions in the analysis of beach scraping is its impact on the ecology of beaches and thus its overall sustainability. As an integral component of the trial scraping episode, a robust ecological monitoring program was implemented to investigate the ecological impact on the beach environment at New Brighton beach.

The primary objective of the study was to assess the impact of beach scraping on the biodiversity of the fauna inhabiting the beach matrix of the intertidal region (the infauna). This broader objective was further refined to assess the short-term effect (immediately after scraping activities ceased) and, if impact was detected, subsequent recovery (i.e. long-term impact) after the conclusion of beach scraping.

Methods

Study design

In order to assess the impacts of beach scraping, we sampled using a Before-After-Control-Impact (BACI) model incorporating a nested component (sites nested within impact and control treatments). Two sites were designated *a priori* as impact (beach scraping sites) or control (at least 500m from the area of beach scraping – Fig. 1). To reduce any confounding with respect to pre-existing differences between sampling sites, all sites were chosen for their similarity in terms of aspect, beach width, slope, and grain size (all assessed visually). The impact sites were located well within the boundaries of the proposed scraping area (Fig. 1). The GPS coordinates for each site were determined in the first sampling period to enable subsequent samples to be taken from the same location. Samples were taken immediately before beach scraping occurred and then at the following intervals following the conclusion of the works: 1 day, 1 week, 2 weeks and 4 weeks. By arrangement with the contractors and BSC, both impact sites were scraped exactly 1 day before the first post-impact sampling. As only one site could be sampled within a single tidal cycle, this meant that the final scraping event took place over 2 consecutive days.

The timing of the post-impact sampling events was based on the limited number of published accounts quantifying the temporal scale of recovery of beach infauna to extractive events. Schoeman *et al.* (2000) experimentally removed 200m^2 of sediment to a depth of 0.3m from the intertidal section of a beach in South Africa and found that any putative impacts were no longer evident after approximately 2 weeks. Given the much larger scale of the beach scraping works (a linear distance of 1.31km), we anticipated that recovery would take more than 2 weeks and thus factored in sampling intervals up to 4 weeks after the event. An option to conduct additional sampling 8 weeks after the conclusion of scraping was considered should impacts still be evident after 4 weeks.

Field methods

At each sampling time and at each site, 5 transects were randomly placed perpendicular to the shore from the upper strandline to the lower tidal level. The beach was then stratified into 5 levels and a single core sample (0.33 x 0.33m) was randomly removed from within each level (Level 1 at the strandline on the upper beach, Level 5 at the lowest tidal limit – other levels at equal spacing between these – approximately 5m apart) in each transect. Samples were taken to a depth of 0.25m using a shovel; a metal collar, inserted into the beach to a depth of 0.3m, was used to prevent slumping at the lower tidal levels. A small sample of sediment was also removed from immediately adjacent to each sample to allow assessment of granulometry.

Samples were sieved in the field through a 1-mm mesh screen and preserved in a 5% formalin and sea-water solution. Samples containing a large quantity of large particles that were retained by the sieve (gravel and pebbles) were stored in calico bags in formalin solution and later examined in the laboratory to remove the fauna. All samples were labelled using waterproof labels.

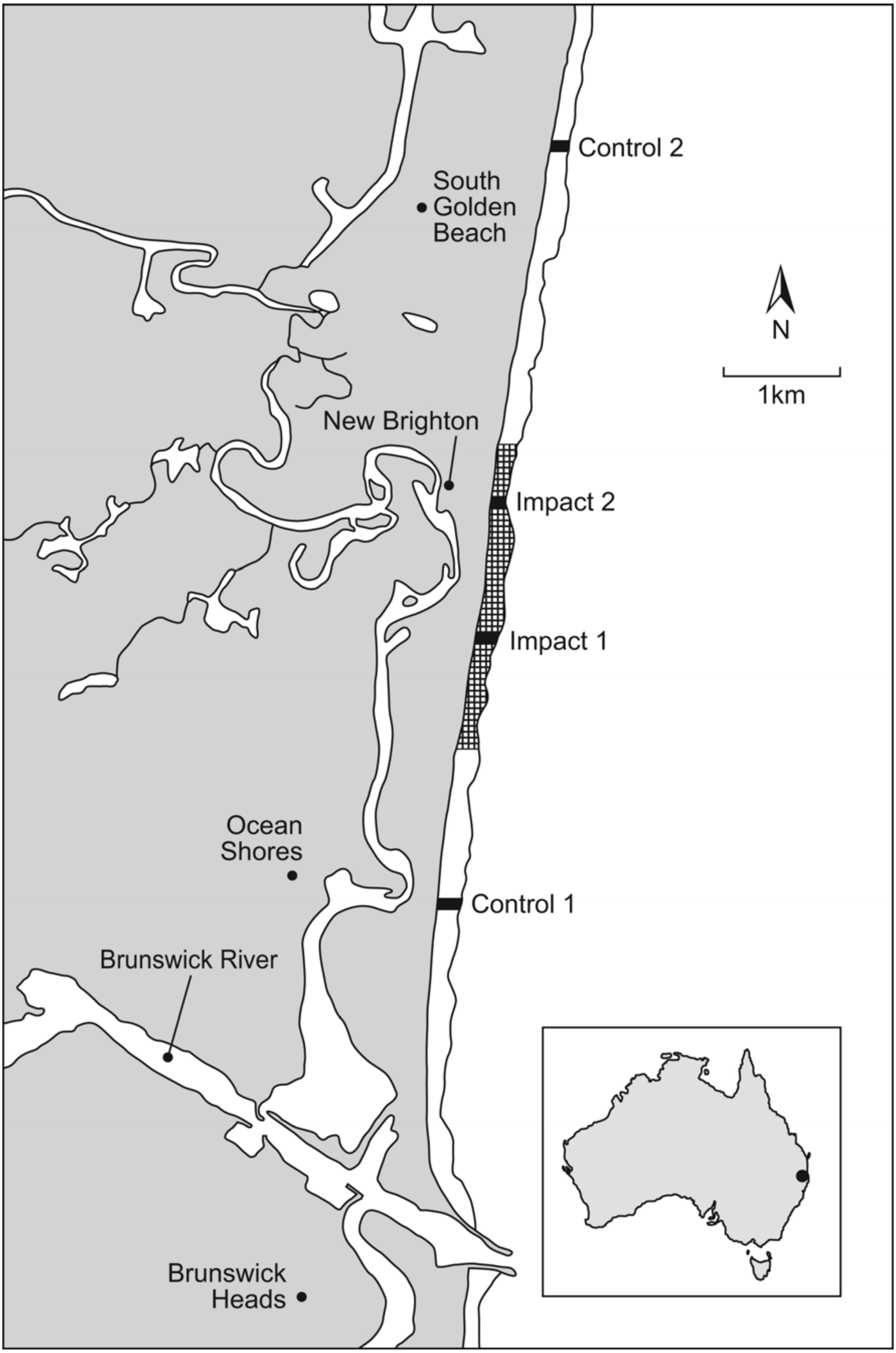

Fig. 1. Map of the study area showing the position of the sampling sites relative to the beach-scraping area (hatched).

Laboratory methods

All infaunal animals were identified to the highest level of taxonomic resolution possible (as 'recognisable taxonomic units' – species-level targeted), and transferred to 70% ethanol for long-term storage. Genus and species names were only determined for some taxa – the rest were identified to family level and given a species code. A full reference collection was retained at the NMSC, Coffs Harbour. In samples that contained large amounts of coarse particles, 25ml of a 2.5% solution of Rose Bengal was added to the sample. This stains organic material a light pink colour and makes it easier to find macrofauna against the inorganic sand matrix.

For granulometric analysis, sediment samples were dried overnight in an oven set at 60°C then sieved through a nested set of sieves for 15min. Mesh sizes used were those standardised for granulometric analysis according to the Wentworth scale. Contents were then weighed and the average grain size determined.

Statistical methods

In addition to graphical summaries of trends in the data (for species richness and total abundance), formal tests of differences were performed using both univariate and multivariate statistical methods. To allow a 'whole of beach face' approach, the core samples from each beach level were pooled for each transect (e.g. Schoeman *et al.*, 2003). This provided 5 replicate samples per site per sample period, and a total of 100 for the study. The immediate effect of scraping was assessed by comparing the pre-impact data with the immediate post-impact data. The designated protocol for further analysis was that additional comparisons would be made with each subsequent set of post-impact samples only until there was no evidence of impact.

The statistical model was the same for both univariate and multivariate tests of significance (Table 1): the terms of interest in this three-way design were the interaction between time and treatment (Ti X Tr in Table 1), and time and site nested in treatment (Ti X Site(Tr) in Table 1). A significant result for the Ti X Tr effect signifies that the variable being analysed changes differently over time in the 2 treatments. For example, if species richness was to decline, as predicted, at the impact sites following scraping, this should be evident as a significant difference ($P \leq 0.05$) for the Ti X Tr effect if species richness at control sites remained unaffected. It is also conceivable that the impact may have been greater at one of the impact sites than the other but that there was still a general impact across the 2 sites. In this case, the Ti X Site(Tr) would be expected to be significant if the trends at the control sites remained similar to the pre-impact condition. This design was used to assess impacts on the total number of animals (abundance), total number of species (species richness) and also the general change in community structure.

Table 1. Statistical design for the analysis of effects of beach scraping on beach infauna.

Source	Type	Comment
Time [Ti]	Fixed	
Treatment [Tr]	Fixed	
Site(Treatment)	Nested and Random	
Ti X Tr	Interaction	Expected to be significant if beach scraping has an impact
Ti x Site(Tr)	Interaction	Expected to be significant if beach scraping has an impact but the scale of this differs amongst sites

For the community-level data, raw abundances were transformed (square-root) prior to the construction of a Bray-Curtis similarity matrix. This matrix uses the abundance of each species to calculate the similarity between each sample and all other samples. The output is a triangular matrix which shows the ‘distance’, in terms of the differences in species and their abundance, between each pair of samples. For example, samples with the same abundance of the same species (i.e. are identical) have a similarity of 100%. On the other hand, samples that differ completely in terms of species complement will have a similarity value of 0%. These relationships were visualised using non-metric multidimensional scaling (nMDS) ordination. The output of this process is a graph in which samples with similar community structure are placed close together, with dissimilar samples further apart. This provides a simple visual overview of differences in the composition of all samples. Where Kruskal’s stress exceeded 0.2 for two-dimensional plots, three-dimensional plots were generated which, in all cases reduced the stress to <0.2. Tests of significance in community structure were assessed using Permutational Multivariate Analysis of Variance (PERMANOVA). All multivariate analyses were performed using Primer 6 (+PERMANOVA).

Changes in beach granulometry

Separate analyses were undertaken for the granulometric data to assess changes in mean grain size. These data were taken in order to help interpret any potential shifts in the biotic data as changes in mean grain size have been found to be a key driver of biotic patterns in sedimentary habitats (e.g. McLachlan, 1996). Given that sediment grain size is known to vary across the beach face (e.g. Short, 2006) each beach level was assessed separately for any immediate impact of beach scraping (using the same design as in Table 1).

Results

Sampling was carried out as planned throughout the program. While heavy seas occurred on a few occasions over the study period, sampling was possible at all pre-planned sampling periods. One swell event was particularly notable with wave heights exceeding 3m in the week prior to sampling (12-16 October 2010). This changed the beach face considerably and eroded the beach across the full study area.

The beach infauna was dominated by small crustaceans (84% of the total abundance) and worms (12%) with insects (mostly larvae) and molluscs (mostly bivalves) comprising the balance of the faunal complement. Cirolanid isopods dominated the crustaceans and contributed 69% of total infaunal abundance.

Immediate effects of beach scraping across the beach face

There was no consistent immediate effect of beach scraping (TixTr not significant – Table 2) on the community structure of beach infauna but there was a difference in the way that the sites changed over the 2 samples times (TiXSi(Tr)). However, this result could eventuate from differences in trends within either the control or impact treatments. Examination of the nMDS plot (Fig. 2), which summarises changes in community structure over the 2 sample times, indicates a general difference between each site at each time (leading to the low *P(perm)* value for Ti in Table 2), with community structure shifting upwards and to the right of the plot for all. (In this plot, each symbol represents a single transect, with time and site designated using symbol style and colour) However, each site changed in a slightly different way over time (i.e. shifting to different sections of the plot) and this explains the significant TixSi(Tr) term in Table 2. At all sites, the main differences between pre-impact and post-impact samples were primarily related to substantial (up to 50%) reductions in the abundance of cirolanid isopods, the most common group of animals comprising the beach infauna. The control sites also showed an increased abundance of insect larvae in the post-impact period, a trend which was not evident for either impact site. One impact site (Impact 1) showed a slight increase in the abundance of capitellid polychaete worms post-impact. While these patterns suggest that the relative change in community structure is different across the 2 treatments (impact sites shifting upwards while control sites shift to the right), this was not found to be significant (Table 2).

Table 2. Summary results for the 3-way PERMANOVA to assess immediate (1 day after scraping) impacts on community structure across the beach face. Ti = time, Tr = treatment, Si = site. Significant values are shown in **bold**.

Source	**df**	**SS**	**MS**	**Pseudo-*F***	***P(perm)***
Ti	1	10060	10060.0	4.085	0.083
Tr	1	4865	4864.5	1.556	0.309
Si(Tr)	2	6254	3127.1	3.772	**0.001**
TixTr	1	5360	5359.9	2.177	0.149
TixSi(Tr)	2	4925	2462.3	2.970	**0.001**
Res	32	26526	828.9		
Total	39	57989			

The results for the assessment of species richness and total abundance were clearer and indicated no effect of beach scraping on either measure. Indeed, none of the terms in the analysis was significant (Table 3). The variation across sites, treatments and times is evident from Fig. 3 which shows the full data set (over all sampling periods).

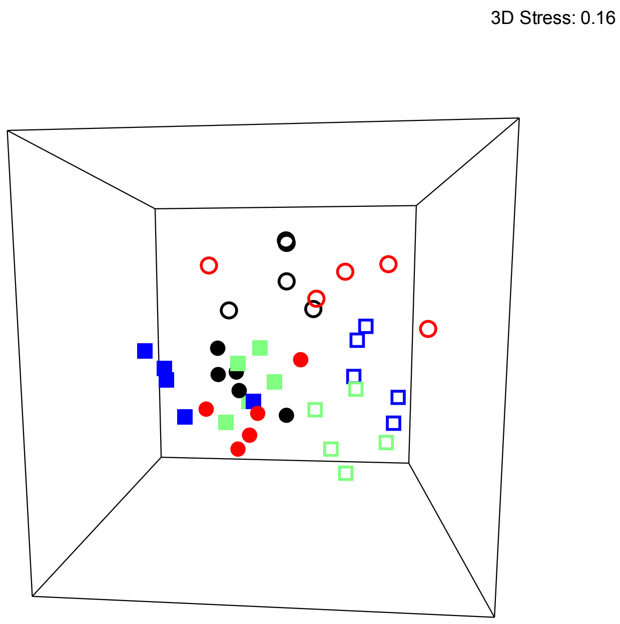

Fig. 2. Three-dimensional nMDS plot showing changes in community structure at each site before (filled symbols) and immediately after (unfilled symbols) beach scraping. Each point represents a single transect and symbols are colour-coded by site – red circles = Impact 1; black circles = Impact 2; green squares = Control 1; blue squares = Control 2. Transects that have similar community structure are placed close together and those that are dissimilar are spaced further apart.

Table 3. *P*-values for each source of variation in the 3-way ANOVA to assess the immediate effects of beach scraping on species richness (S) and total abundance (N) across the beach face. By convention, tests are considered significant if $P \leq 0.05$.

Source	S	N
Ti	0.283	0.058
Tr	0.182	0.673
Si(Tr)	0.459	0.249
TixTr	0.283	0.450
TixSi(Tr)	0.498	0.163

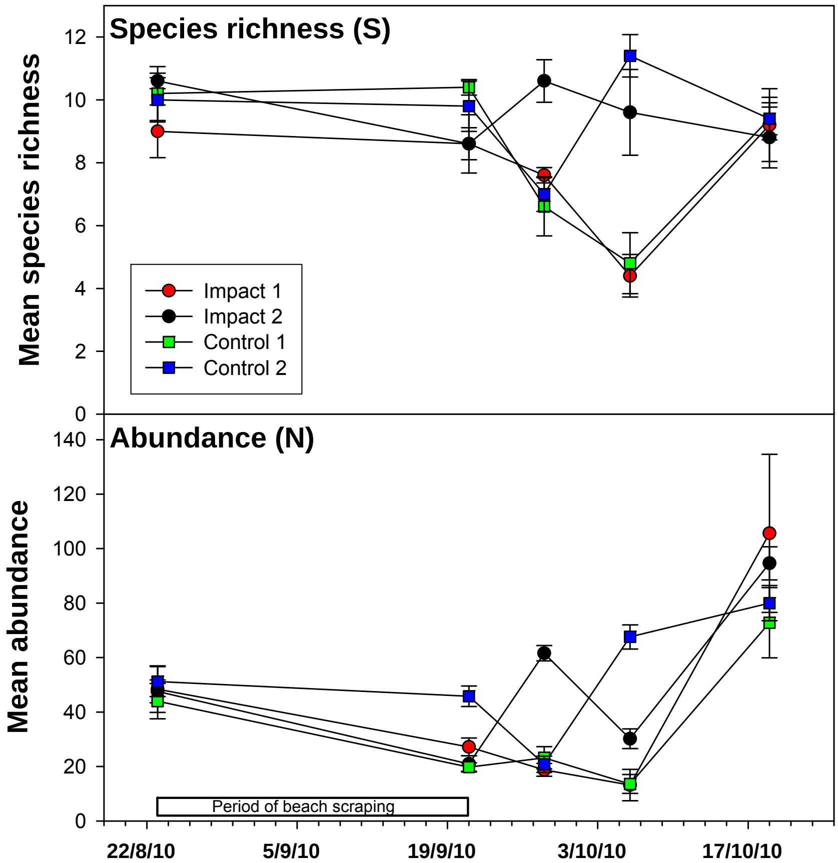

Fig. 3. Trends in mean species richness (top) and mean total abundance (bottom) for beach infauna across the full beach face at New Brighton beach. Error bars = standard errors. **Note**: beach scraping occurred from 28/8/2010–22/9/2010.

Immediate effects of beach scraping on sediment granulometry

In the pre-impact samples, there was a general trend of increasing mean grain size from Level 1 down the beach to Level 5 (Fig. 4). This is consistent with habitats on the lower shore being more continuously exposed to wave action (higher mean wave velocity) which effectively removes finer grains resulting in greater particle sizes at lower levels. Given this natural gradient, it could be predicted that sand sourced from lower on the beach and deposited in the upper beach would cause a shift upwards in mean grain size at higher shore levels. This would also lead to a loss of gradient in grain size, at least temporarily (i.e. until hydrodynamic forces re-established the natural gradient).

Both of these patterns were evident at the impact sites with mean grain size increasing at Levels 1 and 2, and differences in grain size between levels becoming less clear (Fig. 4). In the formal tests for changes in grain size attributable to beach scraping, the Ti x Tr term was significant for Level 1 (*P* = 0.003) but not for Level 2 (*P* = 0.346). The only other level to show a significant term for this effect was Level 5 (*P* = 0.002) but, in this case, all of the effects were highly significant indicating large dynamism across all levels of the 3 factors.

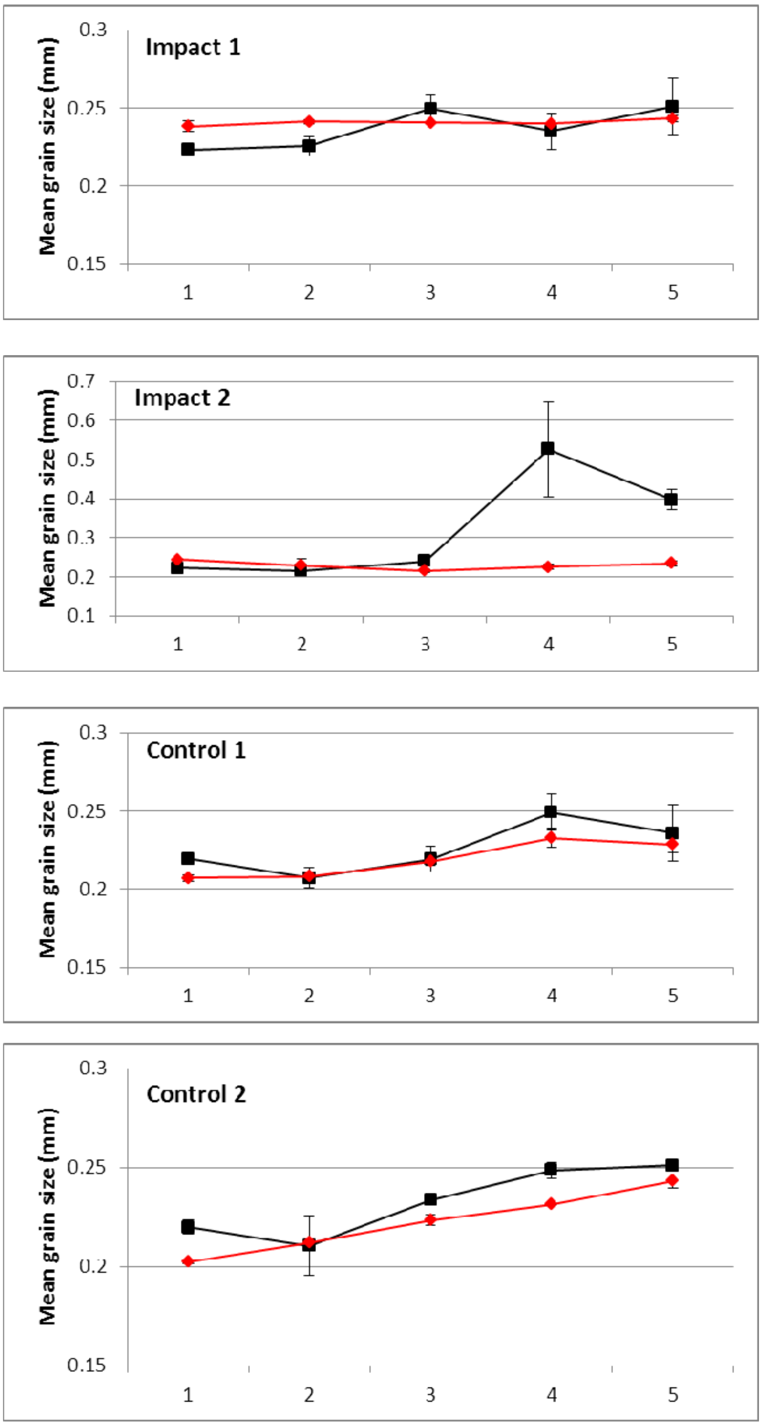

Fig. 4. Mean sediment grain size (±SE) by beach level (x-axis) for each site in the pre-impact and immediate post-impact sampling periods. Pre-impact = black squares; post-impact = red diamonds. **Note** different scale on the vertical axis for Impact 2.

Community trends over the entire study

Despite the fact that no impact was detected, even 1 day after beach scraping, it was nevertheless instructive to examine trends in community structure across the beach face (i.e. for samples pooled within each transect) over the entire study period. Given the very large number of data points, data were averaged across the 5 transects from each site at each time and the nMDS (Fig. 5) consequently displays a single point for each sample time for each site. The most obvious trend is that community structure shifts in a similar way at each site at each sample time suggesting that processes operating at the scale of the entire study area (>3km – Fig. 1) are driving patterns. Thus, pre-impact samples are clustered in the mid-bottom of the plot (labelled 1), all then move to the centre of the plot at time 2, to the right at time 3, back to the left at time 4, and to the bottom left of the plot at time 5. The convergence of community structure at all sites at time 5 (4 weeks post impact – 19 Oct.) reflects a similar trend in the values of the summary community measures (S, N – Fig. 3); this occurred immediately after the largest storm event recorded during the study (12-16 Oct.).

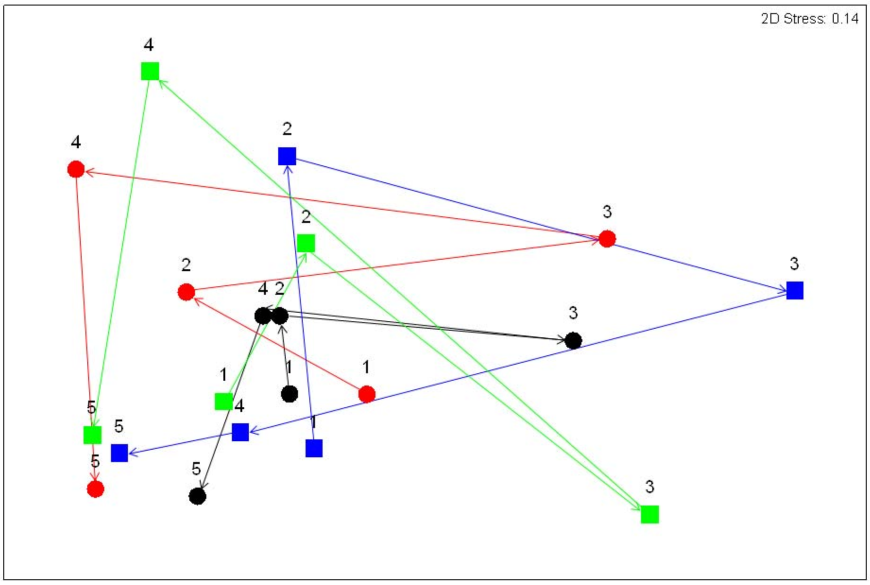

Fig. 5. Two-dimensional nMDS plot showing temporal trends for each site. Note that data points represent the average across 5 transects at each site at each sample time. Numerals represent sample times and colours, specific sites (red circles = Impact 1; black circles = Impact 2; green squares = Control 1; blue squares = Control 2).

Discussion

This comprehensive investigation of the effects of beach scraping at New Brighton beach failed to detect clear impacts on the beach infauna even 1 day after the final works. This is an unexpected finding as previous work, assessing impacts of smaller disturbances, has indicated that recovery does not occur before a minimum of 2 weeks post impact (Schoeman *et al.*, 2000). There are a number of possible reasons for this: i) the highly dynamic nature of New Brighton beach is such that organisms are highly adapted to major changes in beach conditions (e.g. loss of sand from storms); ii) the type of impact was relatively benign in terms of factors that are known to affect beach infauna; or iii) the study was not sufficiently robust to detect changes.

Beach dynamism

Beaches are highly dynamic habitats at temporal scales ranging from diurnal (migration with tidal height - Hacking, 1996) through to seasonal, and inter-annual (McLachlan, 1990). At the same time, they are patchy in a spatial context in that animals are not distributed evenly within the beach (Schoeman *et al.*, 2003). With the backdrop of a constantly changing physico-chemical environment, organisms may become adapted to these conditions and recover quickly from disturbances. This is the case not only for beach habitats (Schoeman *et al.*, 2000) but also for shallow subtidal sedimentary habitats in high wave-energy environments (Roberts and Forrest, 1999; Smith and Rule, 2001).

The beach scraping undertaken at New Brighton beach led to the loss of the top ~0.3m of sediment across the beach face from Level 4-5 upwards. As most beach animals inhabit the upper layer of the beach (i.e. the top 0.1m or so), this would have resulted in the complete defaunation of the impacted areas. However, the lower beach/shallow subtidal region, which generally has a higher diversity (Hacking, 1998) and was undisturbed by scraping, may act as a source of highly mobile recruits that are capable of rapidly colonising disturbed areas. Many of the mobile crustaceans, which were by far the most numerous animals encountered during the study, are scavengers and have the ability to move to food sources washed in by the tide. These taxa also show the greatest levels of natural migration with tidal movement (Hacking, 1996), especially the cirolanid isopods which were the most abundant in this study (69% of the total abundance).

The nature of the impact

The factors most likely to lead to substantial change in beach infaunal communities following beach nourishment activities are: changes in granulometry; the introduction of pollutants from source areas; and changes in the slope of the beach. Each of these has been shown to be correlated with shifts in assemblage patterns in a range of previous studies (Racocinski *et al.*, 1996; Peterson and Bishop, 2005; Speybroeck *et al.*, 2006). In this context, while there were some changes in the grain size of the beach at impacted sites (increased mean grain size at higher levels, homogenisation of the natural gradient of grain size), these were small and the sand remained within the same broad size range. As the sand was sourced from the same site (i.e. within tens of metres of where it was deposited) and later became redistributed by tidal and aeolian processes, most of the characteristics were similar, and no pollutants were introduced. Observations suggest that there was a change to the slope of the upper beach but this has yet to be quantified. Nevertheless, from observations during each sample period, the change in beach slope did not appear to be great.

Limitations related to sampling intensity

Given their notorious variation over a range of spatial and temporal scales, it is very difficult to plan for optimal sampling outcomes on beaches. Indeed, a number of studies have focused on the issues of how many samples to take and where to place them, and have drawn different conclusions (Jaramillo *et al.*, 1995; Schoeman *et al.*, 2003, 2008; Peterson and Bishop, 2005). At a minimum, studies should take as many samples as possible and, preferably, use large unit sizes, especially in high-energy environments. This was the approach that was taken here. Our whole of beach-face approach generated samples that comprised a single 0.33 x 0.33m sample, dug to a depth of 0.25m, from each of the 5 beach levels. While this is suboptimal in comparison to the recommendations of the most critical authors (who recommended sampling at fixed intervals of 3m down the beach - Schoeman *et al.*, 2003), it resulted in the absence of zero counts and provided a clear indication of trends (and these trends did not support our initial expectation of a general and consistent change at the impact sites relative to the controls). The multivariate analyses, in particular, are both robust and powerful and did not reveal results consistent with an unambiguous impact.

Conclusions

The results of this study clearly indicate that the trial beach scraping event at New Brighton beach had no detectable effect on the biodiversity and assemblage patterns of beach infauna. This is a remarkable finding given the predictions of other studies conducted elsewhere. The primary reasons for the lack of impact are likely related to the high energy wave environment and high natural levels of dynamism at New Brighton beach, and the fact that deposition of scraped sand did not cause major changes to beach granulometry. It is likely that the composition and structure of beach communities is primarily driven by wave climate as demonstrated by the convergence of all community measures following the storm event that occurred immediately prior to our last sample period. In this sense, such storm events effectively 'reset' community structure over spatial scales much greater than those affected by localised physical disturbance (e.g. Hobbs *et al*., 2008).

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