Southern Cross University
National Marine Science Centre



The Effects of Beach Scraping on the Infauna of New Brighton Beach, Northern NSW

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Report prepared for Byron Shire Council, June 2011

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Executive summary

As part of an assessment of mitigation strategies for beach erosion, Byron Shire Council undertook trial beach scraping at New Brighton beach in August and September 2010. The objectives of the works were: i) to build sand reserves for protection of beachfront development and infrastructure from short-term coastal erosion; and ii) to augment the natural buffer provided by sand dunes. Monitoring of the environmental impacts of these works was initiated across the habitats and taxa likely to be affected. This report summarises the data from a comprehensive assessment of the impacts of scraping on beach infauna (animals living within the intertidal beach).

Sand was removed to a depth of up to 0.5 m along a 1.31-km section of beach during the scraping event. Backhoes with excavators were used to move this sand to the upper beach to widen the dune.

Pre-impact sampling was conducted at two sites where beach scraping was to occur and at two control sites well away from the impact area. At each site, replicated core samples (measuring 0.33 x 0.33 x 0.25 m) were taken at five beach levels along five transects running perpendicular to the shore. Sampling was repeated 1 day, 1 week, 2 weeks and 4 weeks after scraping in order to determine: i) the size of the immediate impact; and ii) the temporal scale of recovery. Samples were sieved through a 1-mm sieve to retain the macrofauna: these animals were later identified and counted in the laboratory.

Remarkably, none of the variables assessed in this study 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, beach infaunal assemblages were more similar within a specific sampling period at all sites than within a site over time.

Beach granulometry showed some predictable changes over the pre-impact and first post-impact samples with a slight increase in grain size in the upper beach levels (Levels 1-2) and a reduction in the gradient of increasing grain size down the beach. However, these changes were small and did not represent gross modification of the physical habitat.

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

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Introduction

Background

Shoreline recession is a global problem 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, amenity and infrastructure. 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 walls 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 beach face and deposited on the upper beach/dunal interface, is one of a raft of soft engineering solutions that has been proposed to mitigate the effects of shoreline recession (e.g. Carley et al., 2010). The general principle is that sand is scraped from the intertidal section of the beach and relocated above the high-tide mark to widen the dune; this improves the dune's ability to act as a buffer to wave action. Beach scraping has been used much less frequently than the related method of beach nourishment (where sand sourced elsewhere is deposited on the beach or in the shallow subtidal adjacent to the beach). One of the critical questions in the analysis of this activity is its impact on the ecology of beaches and thus its overall sustainability. This study addressed this question for the beach environment at New Brighton, northern NSW.

Beaches and human impacts – relevant studies

Beaches are subjected to a range of anthropogenic pressures (reviewed in Defeo et al., 2009), many of which have been shown to have an impact on the invertebrate fauna living within the beach matrix (e.g. Off Road Vehicles (ORVs) – Schlacher et al., 2008). Beach nourishment has been conducted on eroding beaches worldwide for a considerable period of time. Consequently, a number of specific studies have assessed the impacts of such activities (e.g. Racocinski et al., 1996; Peterson and Bishop, 2005; Speybroeck, et al., 2006; Defeo, et al., 2009). However, by far the majority of these have evaluated the impacts of deposition of material at the receiving site rather than the impacts of removal, which is the primary issue for a scraped beach face. The most relevant study in this case is a small-scale experiment, conducted on a beach in South Africa, which removed 200 m^2 of sediment, to a depth of 0.3 m, from the intertidal zone (Schoeman et al., 2000). The study found that, while there was measurable impact for some variables (e.g. reductions in species richness), temporal variability was high at all sites. Any putative impacts were no longer evident after approximately 2 weeks (Schoeman, et al., 2000). The important points to consider here are that: beach infaunal assemblages are inherently variable both spatially and temporally; and, recovery following the removal of a relatively shallow layer of sand is rapid. The study by Schoeman et al. (2000) is important because it informs the choice of time-scale over which to conduct studies on similar beaches.

Beach sampling methods

Beaches are highly dynamic habitats. As a result, sampling to detect impacts is more difficult than in less variable ecosystems and necessitates careful designs that address a range of ecological and sampling issues. The key issues are that: species richness and abundance can be low necessitating relatively large sample units (to avoid zero counts) (Hacking, 1998; Schoeman et al., 2003); there is often very large natural variation in community measures which makes the detection of impacts difficult (Schoeman, et al., 2000, 2003); there is no clear zonation on beaches, with the position of the highly motile infauna dependent on the most recent tidal cycle (Hacking, 1996; Schoeman, et al., 2003).

As a result of this dynamism, the common summary measures of community structure (species richness and abundance) are likely to have been underestimated by most sampling designs used to date (Schoeman, et al., 2003, 2008). Recent recommendations about optimal sampling strategies are sometimes conflicting. For example, Jaramillo et al. (1995), through examining extensive empirical data, recommended that a minimum sampling area of 4 m^2 was required to adequately sample beach infauna. However, using simulation techniques on transect data from 3 beaches, Schoeman et al. (2003) indicated that: i) estimates based on a total sampling area of 4 m^2 are likely to miss 30% of species; and ii) it is practically impossible to sample this volume of sand in a single tidal cycle without a large sampling team and/or some kind of mechanised sampling method. Schoeman et al. (2003) concluded that the optimal method appeared to be fixed sampling using 0.1 m^2 quadrats (dimensions: length = 0.33 m, width = 0.33 m, depth = 0.25 m) at intervals of 3 m down the beach; however, this recommendation was based on data from only 3 beaches. This size of quadrat has been widely advocated as the most appropriate for exposed beaches where faunal densities may be relatively low and aggregations of fauna patchy (e.g. McLachlan, 1990; Hacking, 1998). Where smaller unit sizes have been used, these have generally been replicated a large number of times and pooled across transects running across the beach face from the upper to lower tidal limits (e.g. Schoeman, et al., 2000).

Description of the beach scraping works

The objectives of the beach scraping works were: i) to build sand reserves for protection of beachfront development and infrastructure from short-term coastal erosion; and ii) to augment the natural buffer provided by sand dunes. In order to achieve these objectives, sand was scraped from the beach along a 1.31-km section of New Brighton beach over the period from 28 August to 22 September 2010. The sand was moved, using backhoes with excavators, to the upper section of the beach to increase the volume of sand in the dune system (Figs. 1-3). At the time of compiling this report, the exact quantities of sand redistributed in this way have yet to be fully quantified.

Study approach and objectives

As is often the case in applied studies of ecological impact funded by project proponents, the extent of the study is constrained by financial and temporal considerations. While this was also the case for this study, information from previous studies was used to ensure that sampling was as comprehensive as possible and followed recommendations with respect to sample size, replication and spatial and temporal scale.

The primary objective of the study was to assess the impact of beach scraping on the biodiversity and abundance of the fauna inhabiting the beach matrix of the intertidal region. Note that, while impacts might be expected on ghost crab populations (F. Ocypodidae) in the upper beach and dune, an assessment of this impact was outside the scope of the study. The broad 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. The design and analytical considerations inherent in this approach are detailed below.

Fig. 1. A backhoe removed the top 0.2-0.5 m of sand from the beach at New Brighton (Photo: S. Smith).

Fig. 2. Sand was pushed to the top of the beach to widen the dune (Photo: S. Smith).

Fig. 3. Beach scraping works showing its extent and impact on New Brighton beach (Photo: S. Smith).

Methods

Study design

The study used a nested design to assess the impacts of beach scraping. After consultation with the Byron Shore Council (BSC) management team, two sites were designated *a priori* as impact (beach scraping sites) or control (at least 500 m from the area of beach scraping – Fig. 4, Table 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. 4). The coordinates for each site were determined in the first sampling period using GPS to enable subsequent samples to be taken from the same site (each of which measured 40 m along the beach). The initial intention was to use a Multiple Before-After Control Impact design (MBACI) to assess 2 impact sites and 2 controls at multiple times before and after the impact. This provides a powerful design which minimises confounding in the interpretation of results. However, given the narrow window of opportunity to complete the works, it was only possible to sample once before the commencement of beach scraping. No sampling was conducted during the beach scraping activities (28 August to 22 September, 2010).

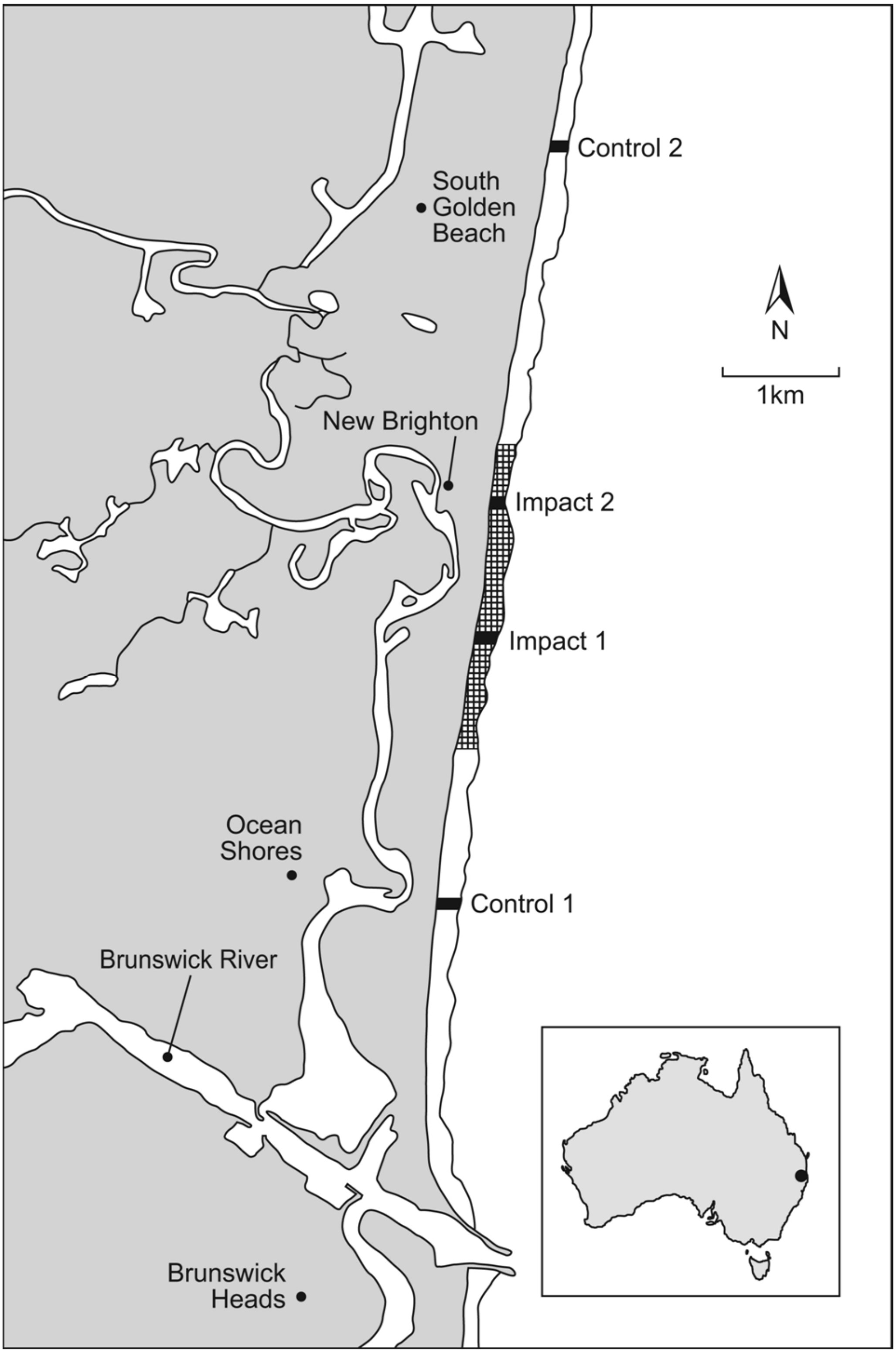


Fig. 4. Map of the study area showing the position of the sampling sites relative to the beach-scraping area (hatched).

Table 1. Coordinates for the mid-point of each site surveyed during the study.

Site name	Latitude (°S)	Longitude (°E)
Impact 1	28.51468	153.55204
Impact 2	28.50971	153.55174
Control 1	28.52491	153.55237
Control 2	28.49584	153.55174

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 (sampling dates shown in Table 2). 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.

Table 2. Dates of sampling for the assessment of the effects of beach scraping at New Brighton beach.

Sample period	Dates
Pre-impact	23-27 August, 2010
1st post-impact (1 day after scraping)	21-24 September, 2010
2nd post-impact (1 week after scraping)	28 September - 1 October, 2010
3rd post-impact (2 weeks after scraping)	6-9 October, 2010
4th post-impact sampling (4 weeks after scraping)	19-22 October, 2010

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. As indicated in the Introduction (see above), Schoeman et al. (2000) experimentally removed 200 m^2 of sediment to a depth of 0.3 m 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 1.31 km), 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 0.33 m) 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 5 m apart). Samples were taken to a depth of 0.25 m using a shovel; a metal collar, inserted into the beach to a depth of 0.3 m, 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 assessments 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 did not pass through 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.

Laboratory methods

All infaunal animals were removed from sample jars, 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. Given the financial and time constraints of the study, we were only able to provide genus and species names for some taxa – the rest were identified to family level and given a species code (see Appendix 1 for a full list of taxa). A full reference collection was retained at the NMSC, Coffs Harbour. In samples that contained large amounts of coarse particles, 25 ml of a 2.5% solution of Rose of 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 15 min. 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 3): the terms of interest in this three-way design were the interaction between time and treatment (Ti X Tr in Table 3), and time and site nested in treatment (Ti X Site(Tr) in Table 3). 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 (Table 3) 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 is 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 3. Design table 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).

The sampling design also allowed for assessment of the impact of beach scraping at each of the different beach levels. In this case, the data were analysed separately for each beach level with the replicates comprising the samples taken from each of the 5 transects at the nominated beach level. The statistical analysis for this design is identical to that shown in Table 3. The same protocol was adopted, in that short-term impacts were evaluated by comparing the pre-impact data with those from the immediate post-impact samples.

Changes in beach granulometry

Separate analyses were undertaken for the granulometric data to assess changes in mean grain size across the sampling periods. These data were taken in order to help interpret any significant 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. In this case, as no significant biotic differences were evident, even after the first pre-impact sample period, analysis-of-variance was only conducted between the pre-impact and first post-impact samples, using the design shown in Table 3.

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 3 m in the week prior to sampling (12-16 October 2010) (Fig. 5). This changed the beach face considerably and eroded the beach across the full study area.

Fig. 5. Widespread beach erosion during heavy seas in October 2010, one week before the final post-impact sampling period (Photo: Ben Fitzgibbon, BSC, 12 October, 2010).

Immediate effects of beach scraping across the beach face

The results of PERMANOVA indicate that there was no consistent immediate effect of beach scraping (TixTr not significant – Table 4) on the community structure of beach infauna but that 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. 6), 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 4), 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 4. 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 (Appendix 1). 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 significantly different in the PERMANOVA (Table 4).

Table 4. 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 5). The variation across sites, treatments and times is evident from Fig. 7 which shows the full data set (over all sampling periods).

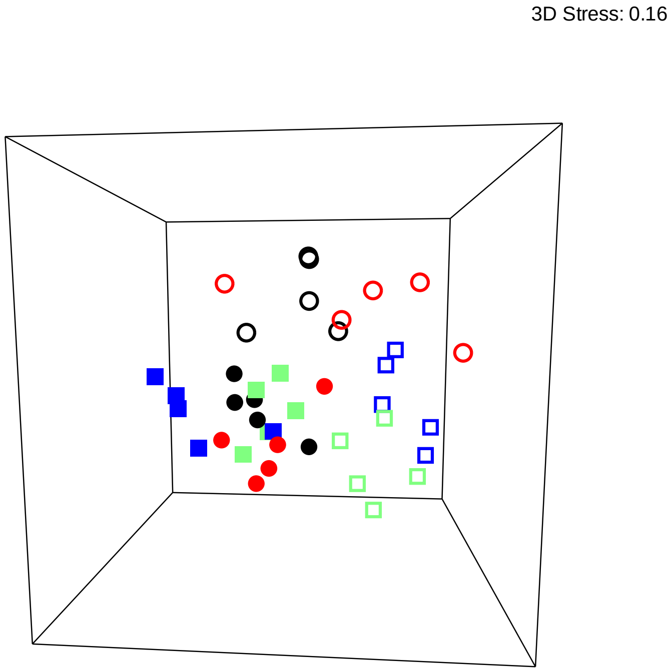
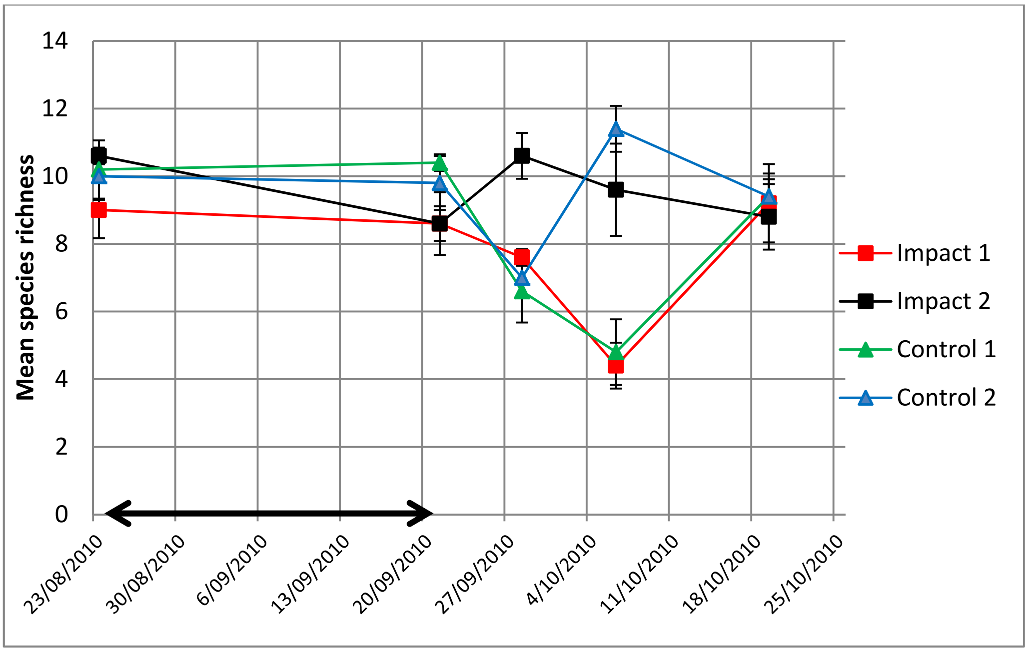


Fig. 6. Three-dimensional nMDS plot showing changes in community structure at each site before (filled symbols) and immediately after (unfilled symbols) beach scraping. Each point represents a single transect and symbols are colour-coded by site – red = Impact 1; black = Impact 2; green = Control 1; blue = Control 2. Transects that have similar community structure are placed close together and those that are dissimilar are spaced further apart.

Table 5. *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



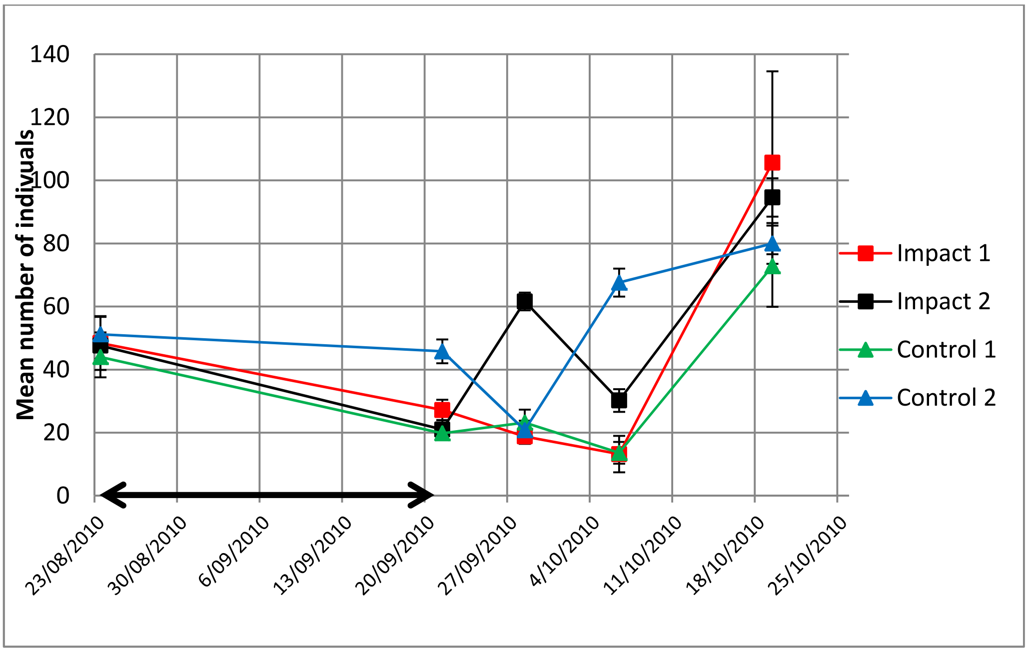


Fig. 7. Trends in mean species richness (top) and mean total abundance (bottom) for beach infauna across the full beach face at New Brighton beach. Error bars = standard errors. **Note**: beach scraping occurred from 28/8/2010 – 22/9/2010 and is indicated by the black arrows on the horizontal axis.

Immediate effects of beach scraping at different beach levels

There were no significant effects for species richness and consequently no evidence of an immediate impact of beach scraping at any level of the beach (Table 6). The data for Level 1 are presented in Fig. 8 – Levels 2-5 are show in Appendix 2. A consistent change (most probably a reduction) in species richness across impact sites relative to the controls would be predicted in the event of an impact. However, the most obvious feature of changes at each level was that there was no consistent pattern across sites (Fig. 8).

The results for total abundance were as variable as for species richness (Fig. 8). However, in this case, a significant TixSi(Tr) term was evident for levels 1-4 (Table 6). Examination of the plots (Fig. 8; Appendix 2) suggests that was due to considerable differences in trends across the control sites as much as across the impact sites. This effect did not, therefore, signify an impact of scraping.

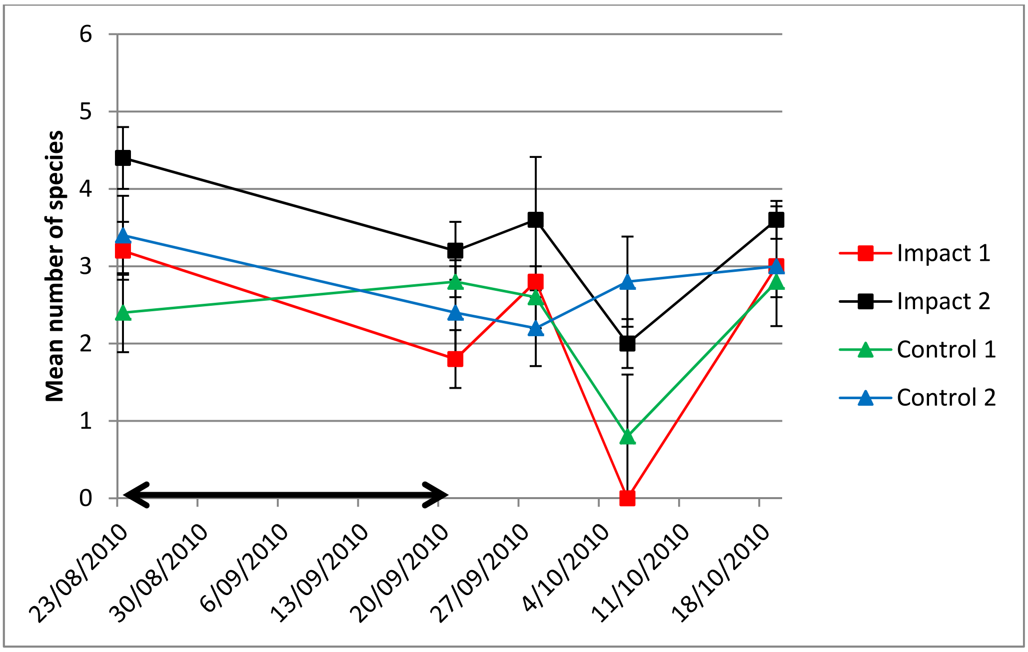
Table 6. The significance of different effects in the 3-way ANOVA assessing immediate impact of beach scraping on A) species richness and B) total abundance (*P*-values shown – significant values appear in bold).

A) Species richness

Source	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Ti	0.152	0.365	0.698	0.451	0.465
Tr	0.610	0.205	0.808	0.156	0.574
Si(Tr)	0.219	0.338	0.278	0.284	0.357
TixTr	0.293	0.937	0.216	0.451	0.216
TixSi(Tr)	0.300	0.063	0.238	0.470	0.257

B) Total abundance

Source	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Ti	0.075	0.667	0.523	0.508	0.189
Tr	0.809	0.085	0.532	0.722	0.716
Si(Tr)	0.323	0.880	0.587	0.492	0.209
TixTr	0.514	0.592	0.951	0.414	0.979
TixSi(Tr)	**0.009**	**<0.001**	**0.009**	**0.002**	0.284



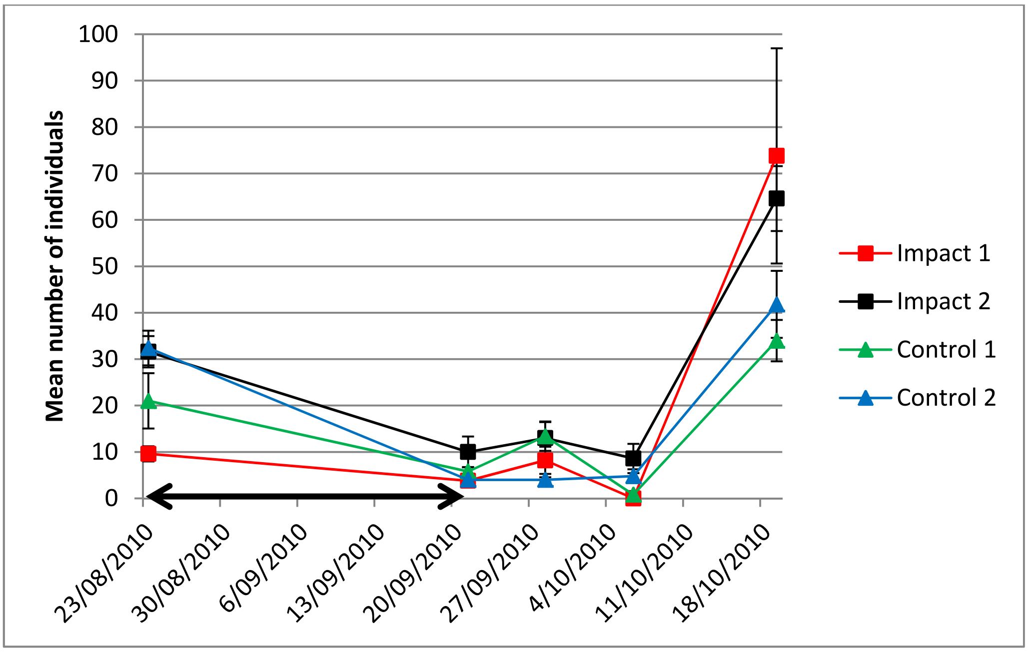


Fig. 8. Trends in mean species richness (top) and mean total abundance (bottom) for beach infauna sampled from Level 1 at New Brighton beach. Error bars = standard errors. **Notes**: i) beach scraping occurred from 28/8/2010 – 22/9/2010 and is indicated by the black arrows on the horizontal axis; ii) plots for Levels 2-5 are shown in Appendix 2.

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. 9). This is consistent with habitats on the lower shore being more continuously exposed to wave action which effectively removes finer-grained sands resulting in greater grain 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 and aeolian forces re-established the natural gradient).

Both of these patterns are 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. 9). In the formal tests for changes in grain size attributable to beach scraping, the TixTr term was significant for Level 1 but not for Level 2 (Table 7). The only other level to show a significant term for this effect was Level 5 but, in this case, all of the effects were highly significant indicating large dynamism across all levels of the 3 factors (Table 7).

Table 7. The significance of different effects in the 3-way ANOVA assessing immediate impact of beach scraping on mean grain size (*P*-values shown – significant values appear in bold).

Source	Level 1	Level 2	Level 3	Level 4	Level 5
Ti	0.702	0.275	**0.027**	0.060	**<0.001**
Tr	**0.001**	**0.023**	**0.013**	0.123	**0.001**
Si(Tr)	0.900	0.515	**0.029**	0.087	**0.001**
TixTr	**0.003**	0.346	0.237	0.125	**0.002**
TixSi(Tr)	0.798	0.997	0.368	0.056	**<0.001**

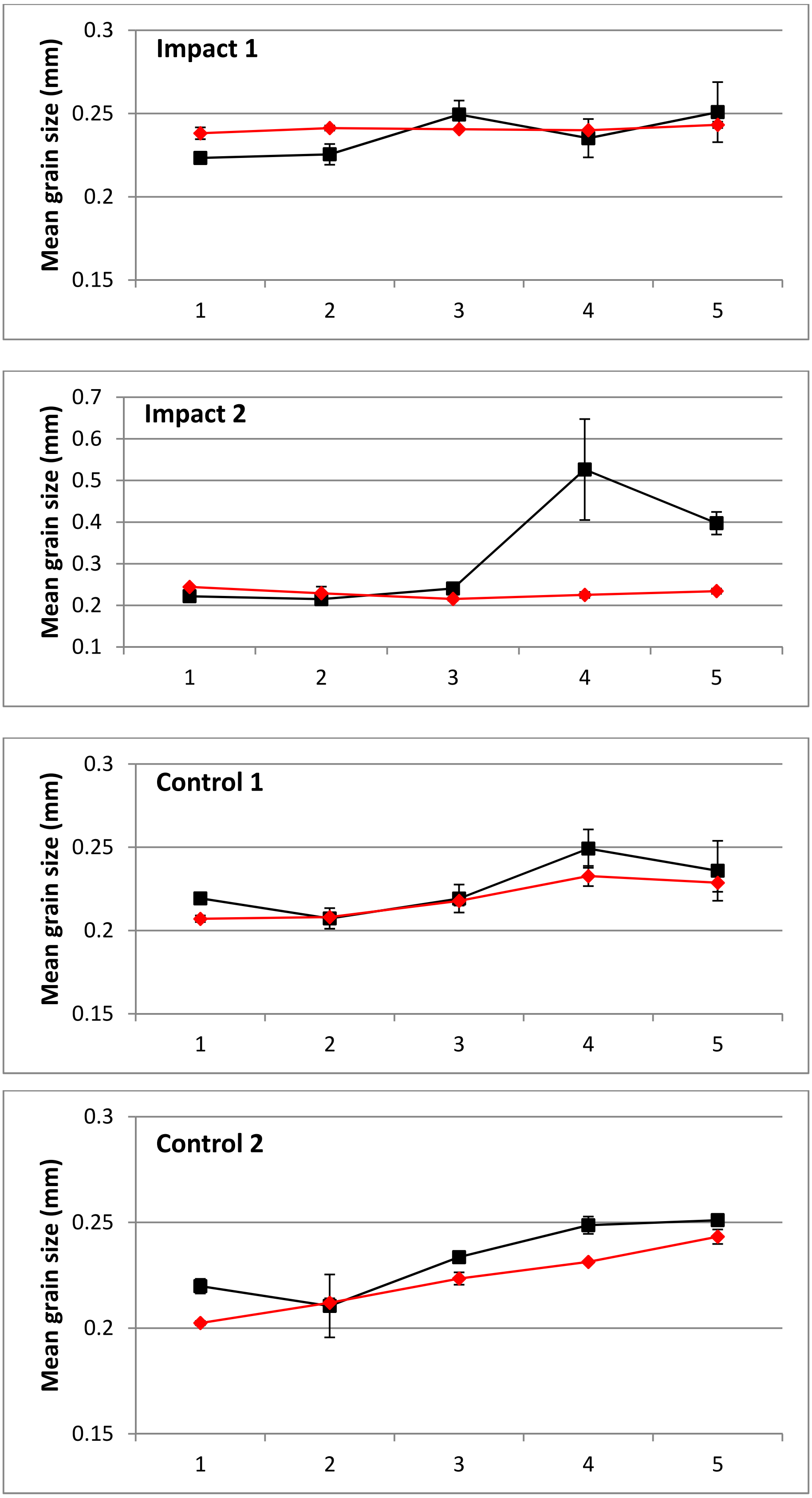


Fig. 9. Mean sediment grain size (± SE) at each beach level (horizontal axis) for each site in the pre-impact and immediate post-impact sampling periods. Pre-impact = black symbols; post-impact = red symbols. **Note** different scale on the vertical axis for Impact 2.

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. 10) 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 (>3 km – Fig. 4) 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 of the plot at time 3, back to the left of the plot at time 4, and to the bottom left of the plot at time 5.

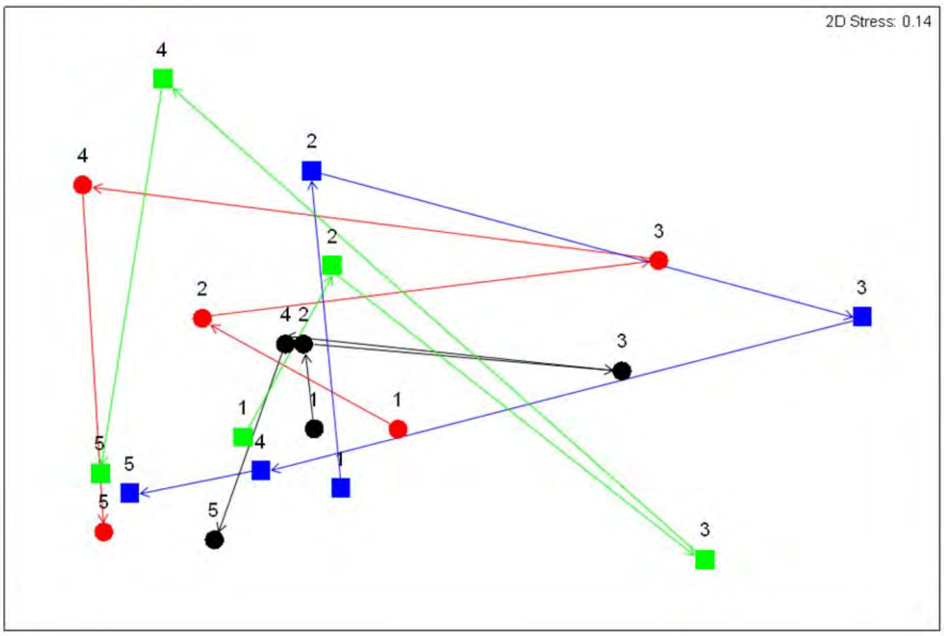


Fig. 10. Two-dimensional nMDS plot showing the temporal trends across the study for each site. Note that data points represent the average across 5 transects at each site at each sample time. Numerals represent sample times and colours, specific sites (red = Impact 1; black = Impact 2; green = Control 1; blue = 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; and iii) the study was not sufficiently robust to detect changes.

Beach dynamism

As reviewed in the introductory sections, 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 up to 0.5 m 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 0.1 m or so), this would have resulted in the complete defaunation of the impacted areas. However, the lower beach/very 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 (Appendix 2), are scavengers and have the ability to move to food sources washed in by the tide. These are also the taxa that show the greatest level of natural migration with tidal movement (Hacking, 1996).

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 – Fig. 9), 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. The wave and tide regime immediately following the completion of beach scraping resulted in complete inundation of the beach berm up to the scraped dune limit, on a daily basis for several days. This inundation was observed to alter the post-scrape beach profile such that it was likely that the beach slope had returned to equilibrium, or near equilibrium, prior to the completion of the sampling.

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. For the whole of beach-face assessment, this generated samples that comprised a single 0.33 x 0.33 m sample, dug to a depth of 0.25 m, from each of the 5 beach levels which were spaced approximately 5 m apart. While this is suboptimal in comparison to the recommendations of the most critical authors (who recommended sampling at fixed intervals of 3 m down the beach - Schoeman, et al., 2003), it resulted in the absence of zero counts and provided a clear indication of trends (see *Results*). The latter is of particular importance as, if trends suggested that an impact had occurred, and a lack of adequate replication caused this not to be significant, the conclusions of the study need to be questioned. This was not the case, however, as there were few if any trends suggestive 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 impact.

The results of this study clearly suggest that beach scraping, in this case, has no detectable effect on the biodiversity and assemblage patterns of beach infauna at New Brighton beach. 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.

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Appendix 1

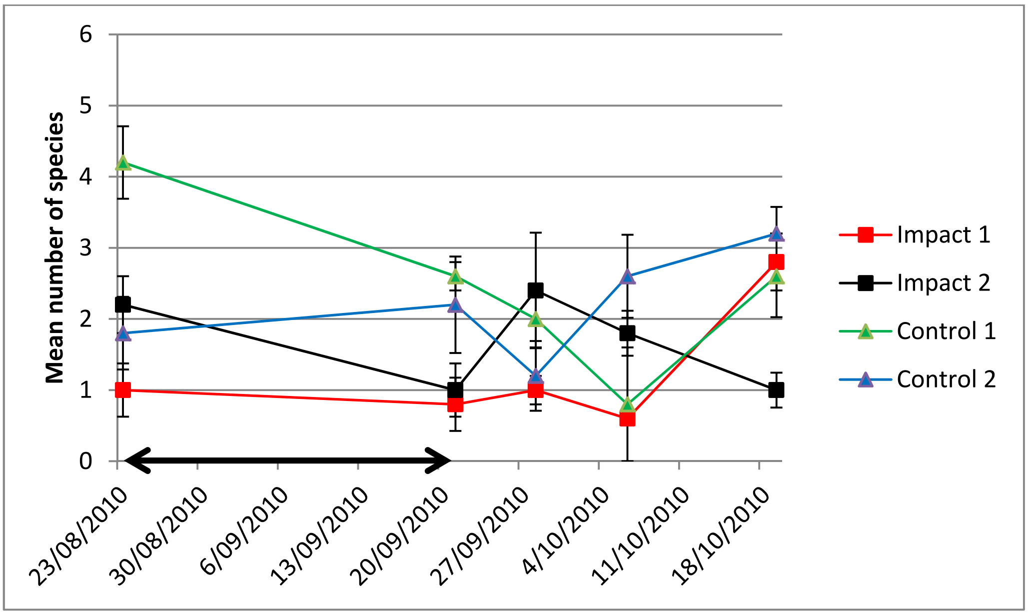
List of taxa recorded during the study. Animals were identified to recognisable taxonomic units (i.e. separated by anatomical characteristics) with most identified to species. The species codes for each taxon are listed, together with their broad taxonomic group, Family, and total abundance (N) across the full study. A reference collection has been retained at the NMSC.

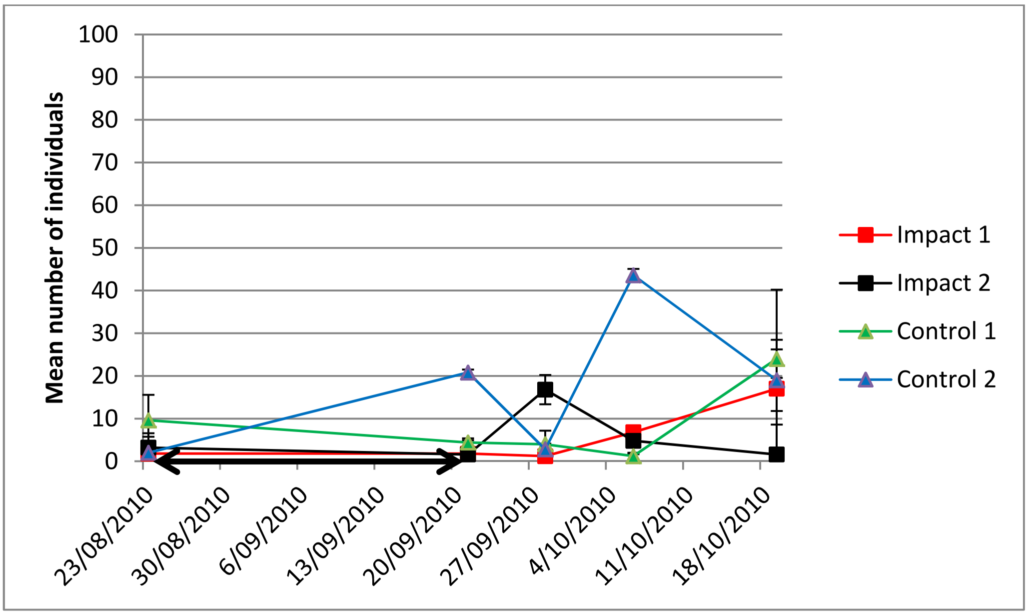
Species code	Broad taxon	Sub-group	Family	N
Capitellidae 1	Annelid	Polychaete	Capitellidae	197
Capitellidae 2	Annelid	Polychaete	Capitellidae	17
Cirratulidae 1	Annelid	Polychaete	Cirratulidae	80
Cirratulidae 2	Annelid	Polychaete	Cirratulidae	8
Glyceridae 1	Annelid	Polychaete	Glyceridae	135
Glyceridae 2	Annelid	Polychaete	Glyceridae	61
Orbiniidae 1	Annelid	Polychaete	Orbinidae	12
Spionidae 1	Annelid	Polychaete	Spionidae	3
Sigalionidae 1	Annelid	Polychaete	Sigalionidae	4
Leptonchidae 1	Nematode	Nematode	Leptonchidae	32
Amphiporidae 1	Nemertean	Nemertean	Amphiporidae	3
Urohaustoriidae 1	Crustacean	Amphipod	Urohaustoriidae	266
Urohaustoriidae 2	Crustacean	Amphipod	Urohaustoriidae	115
Lysianassidae 1	Crustacean	Amphipod	Lysianassidae	125
Lysianassidae 2	Crustacean	Amphipod	Lysianassidae	56
Melitidae 1	Crustacean	Amphipod	Melitidae	6
Platyischnopidae 1	Crustacean	Amphipod	Platyischnopidae	78
Phoxocephalidae 1	Crustacean	Amphipod	Phoxocephalidae	27
Cirolanidae 1	Crustacean	Isopod	Cirolanidae	387
Cirolanidae 2	Crustacean	Isopod	Cirolanidae	191
Cirolanidae 3	Crustacean	Isopod	Cirolanidae	1338
Cirolanidae 4	Crustacean	Isopod	Cirolanidae	471
Cirolanidae 5	Crustacean	Isopod	Cirolanidae	661
Cirolanidae 6	Crustacean	Isopod	Cirolanidae	66
Portunidae 1	Crustacean	Decapod	Portunidae	2
Portunidae 2	Crustacean	Decapod	Portunidae	1
Mysidae 1	Crustacean	Mysid	Mysidae	39
O: Coleoptera 1	Arthropod	Coleopteran larva	Coleoptera	40
O: Coleoptera 2	Arthropod	Coleopteran larva	Coleoptera	5
O: Coleoptera 3	Arthropod	Coleopteran larva	Coleoptera	5
O: Coleoptera 4	Arthropod	Coleopteran larva	Coleoptera	33
O: Coleoptera 5	Arthropod	Coleopteran larva	Coleoptera	5
Formicidae 1	Arthropod	Ant	Formicidae	6
Donacidae 1	Mollusc	Bivalve	Donacidae	35
Donacidae 2	Mollusc	Bivalve	Donacidae	21
Naticidae 1	Mollusc	Gastropod	Naticidae	4

Appendix 2

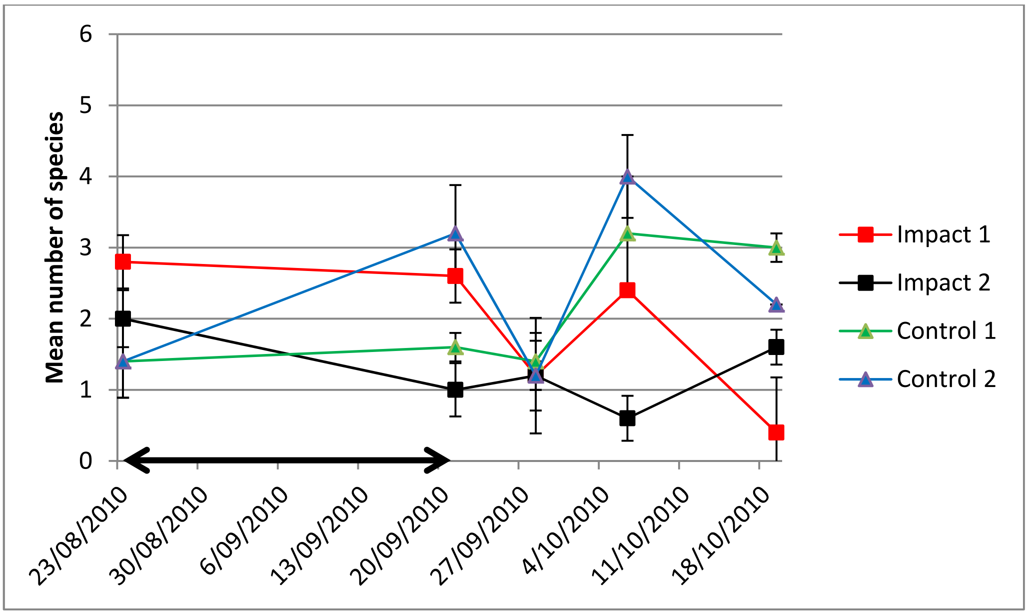
Graphs showing variation in mean species richness and mean abundance for beach Levels 2-5 (the graphs for Level 1 are shown in Fig. 8). The black arrow on the horizontal axis indicates the period of beach scraping (28 August to 23 September).

Level 2





Level 3



Mean number of species
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5
4
3
2
1
0
23/08/2010
30/08/2010
6/09/2010
13/09/2010
20/09/2010
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11/10/2010
18/10/2010
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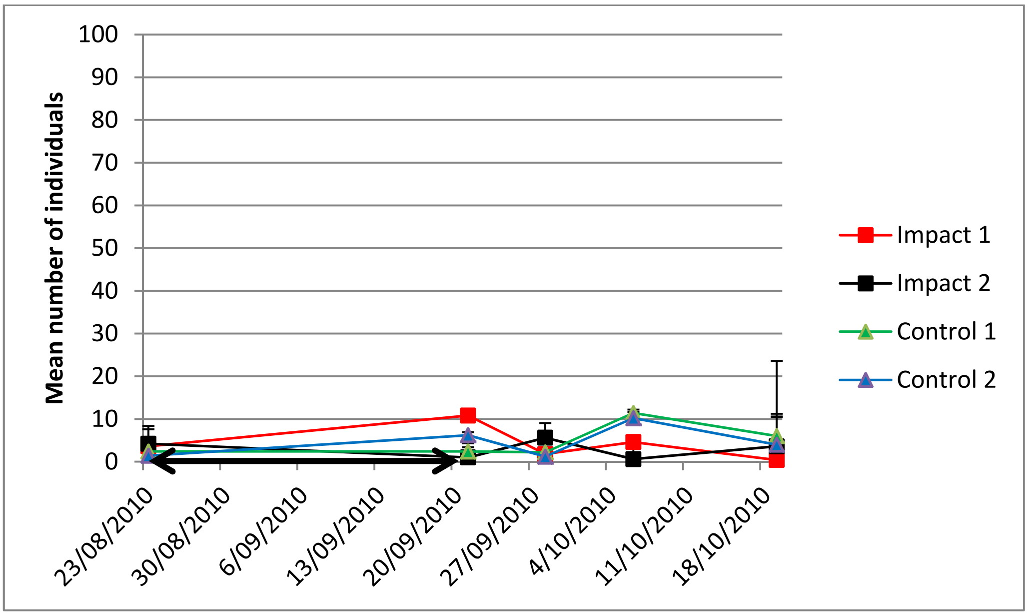
Impact 2
Control 1
Control 2



Mean number of individuals
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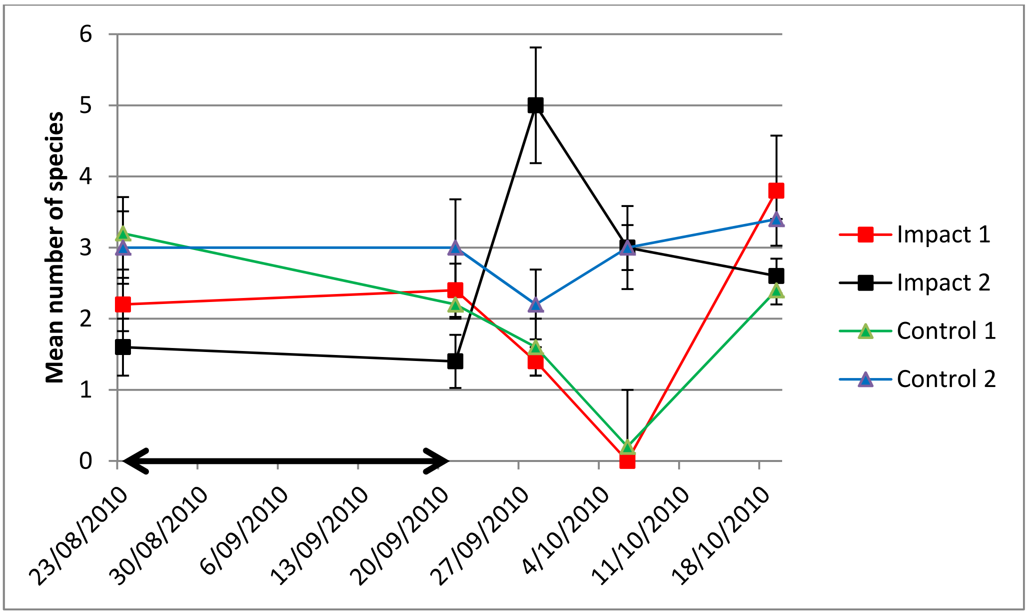
90
80
70
60
50
40
30
20
10
0
23/08/2010
30/08/2010
6/09/2010
13/09/2010
20/09/2010
27/09/2010
4/10/2010
11/10/2010
18/10/2010
Impact 1
Impact 2
Control 1
Control 2

Level 4


Mean number of species
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5
4
3
2
1
0
23/08/2010
30/08/2010
6/09/2010
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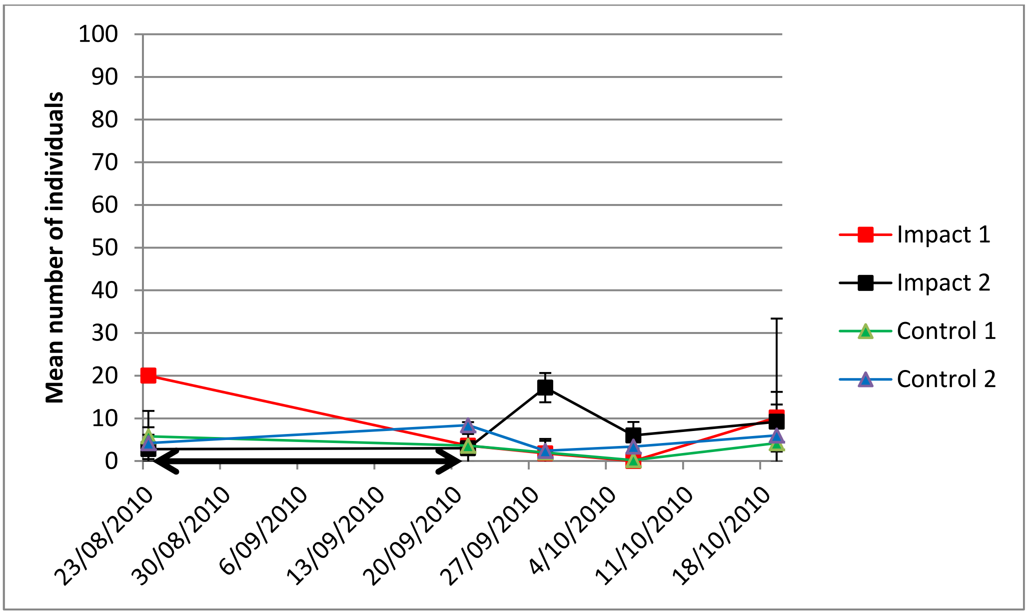
Mean number of individuals
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80
70
60
50
40
30
20
10
0
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30/08/2010
6/09/2010
13/09/2010
20/09/2010
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4/10/2010
11/10/2010
18/10/2010
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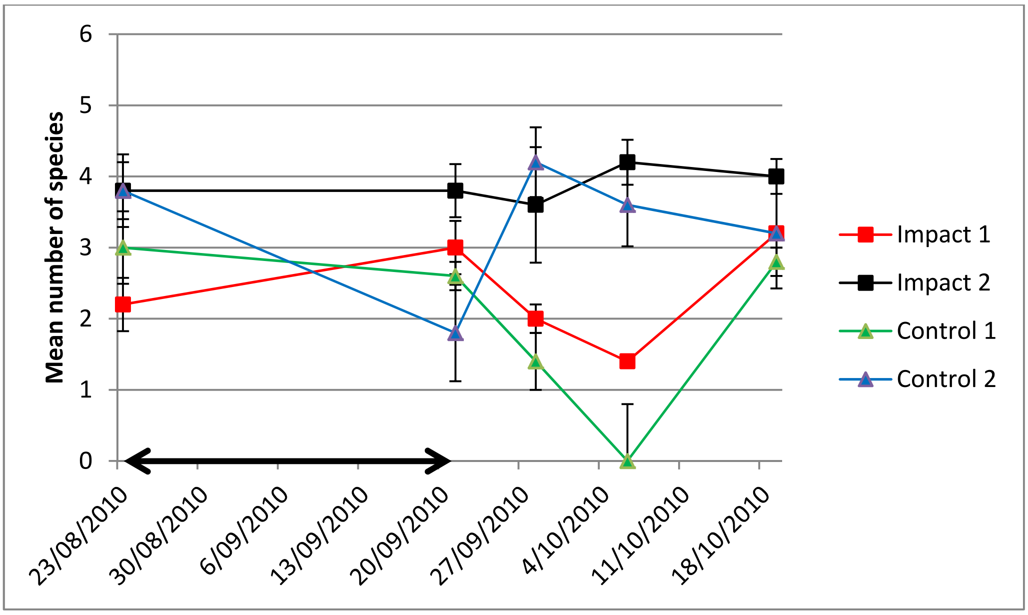
Control 1
Control 2

Level 5



Mean number of species
6
5
4
3
2
1
0
23/08/2010
30/08/2010
6/09/2010
13/09/2010
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Control 1
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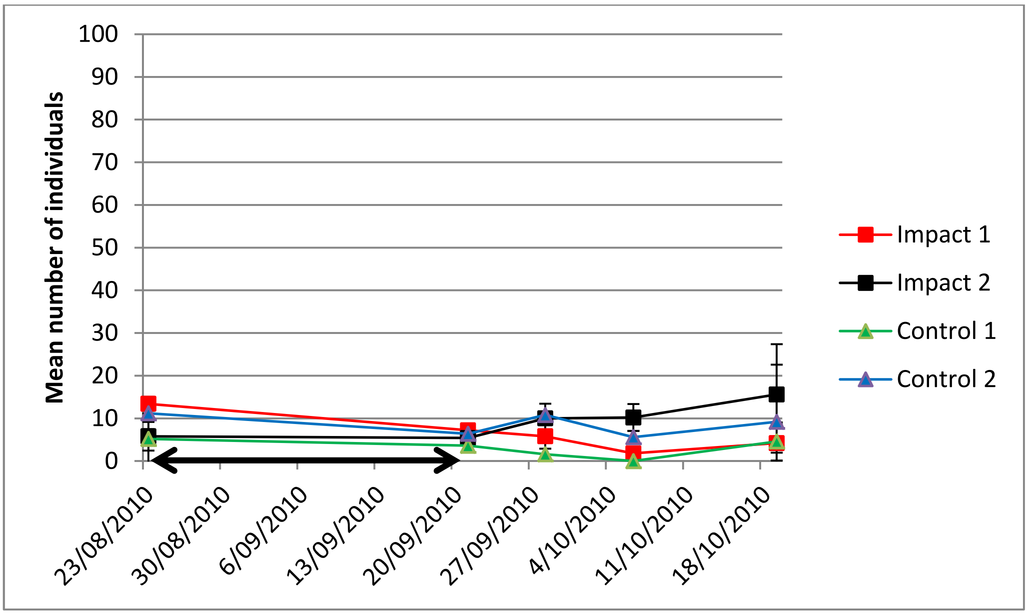

Mean number of individuals
100
90
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23/08/2010
30/08/2010
6/09/2010
13/09/2010
20/09/2010
27/09/2010
4/10/2010
11/10/2010
18/10/2010
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Control 1
Control 2

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