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Managerial decisions as experiments: an opportunity to determine the ecological impact of boat-generated waves on macrobenthic infauna

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Abstract

A previous correlative study showed that assemblages of macrobenthic infauna and abundances of common taxa on intertidal mudflats differed between a no-wash zone, where ferries had to minimize production of wash, and places where the production of wash was unrestricted (wash zone). This suggested that boat-generated waves (wash) are important in determining the structure of these assemblages. Causality between wash and the observed patterns could not, however, be unambiguously established, due to the absence of 'before' data. Here, a managerial decision to stop ferry services on the upper Parramatta River, Sydney, Australia during the 2000 Olympics was used as the basis for a manipulative experiment to examine the effects of changes in the amount of wash on these fauna. It was hypothesized that if wash is important in structuring infaunal assemblages, assemblages in the wash zone would become more similar to those of the no-wash zone following removal of the disturbing force, i.e. the ferry service. Similarly, if the smaller abundances of capitellids, nereids and spionids in the wash zone are caused by this disturbance, abundances should increase in the wash zone during the stoppage and decrease following the return of services. As hypothesized, assemblages within the wash zone became more similar to those of the no-wash zone following the temporary removal of the ferry services. Following the return of ferries, assemblages changed back towards (although not reaching) their previous state. Abundances of the polychaete families Nereididae, Capitellidae and Spionidae also increased at some sites during the cessation, although this pattern was not found in all sites and there was no general response to the cessation of wash as had been predicted. These results indicate that wash is important in structuring assemblages of macrobenthic infauna, although responses of individual taxa are more idiosyncratic. More importantly, they show that manipulations, resulting from managerial decisions, can be treated as testable hypotheses and utilized by scientists as experiments to test for causal relationships.

Keywords: waves; management; ecological impact; boating; infauna; Australia

1. Introduction

Waves are widely documented as important in determining the structure of intertidal assemblages in soft- and hard-bottomed habitats (e.g. Dayton, 1975; Menge, 1978; Underwood, 1981; Tamaki, 1987; Turner et al., 1999). Most studies examining effects of waves are, however, based on comparisons between assemblages of exposed or sheltered locations at a single time of sampling (e.g. McQuaid and Branch, 1985; Bustamante and Branch, 1996), or between times before and after storm activity at a single location (e.g. Dobbs and Vozarik, 1983; Posey et al., 1996). Few have used

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manipulative experiments (see Underwood, 1990) to demonstrate a causal relationship between wave-action and ecological variables because this would require manipulating the exposure of a shore or predicting the timing and scale of storms – virtually impossible tasks.

The production of waves by boats is, however, easily manipulated. Managers do this through the enforcement of no-wash zones, where vessels must minimize the production of waves, or by imposing regulations on where and when boating may occur. These decisions are manipulations that give rise to testable hypotheses (Hilborn and Walters, 1981; Underwood, 1989). They provide unique opportunities for ecologists to test for causal relationships at scales that would otherwise be beyond the scope of available resources. The designs of such experiments may be compromised to some extent by the timing or spatial scale of the decisions themselves, but, nevertheless, can provide useful information about the ecological consequences of managerial decisions.

In the relatively sheltered waters of estuaries, boat-generated waves are frequently of a similar magnitude as naturally-produced waves (Bhowmik et al., 1982). Natural and boat-generated waves, although not necessarily following the same hydrodynamic model, can have similar physical effects in coarsening sediments, eroding materials and increasing the tidal height of wetting. Therefore, determining the ecological impact of boat-generated waves on intertidal assemblages may not only enable managers to determine how to better manage this activity to minimize degradation of estuarine assemblages, but may also allow better predictions to be made about how naturally-produced waves may impact organisms.

Previous work along the upper Parramatta River, Sydney, Australia showed that assemblages of macrobenthic infauna in vegetated or unvegetated intertidal sediments differed between a no-wash zone, where 35 m RiverCat ferries must slow to speeds of less than 7 knots and an adjacent section of the river, where speed is unrestricted (wash zone; Bishop, 2004) and near-bed flows generated by wash are greater than in the no-wash zone (Patterson Britton and Partners, 1999). Abundances of common taxa, such as capitellid, nereid and spionid polychaetes, were also greater in the no-wash than in the wash zone. These patterns could not be directly attributed to wash from RiverCat ferries, because no data were available prior to the commencement of RiverCat services. Differences in assemblages may therefore be due to other intrinsic differences between the two zones, which are unrelated to wash.

During the Sydney Olympic Games, in September 2000, RiverCat ferry services to the west of Homebush Bay were suspended for 5 weeks. This managerial decision, implemented to free vessels for use on Sydney Harbour and intended to serve no ecological purpose, provided the manipulation for an experiment to determine whether patterns between the wash and no-wash zones of the upper Parramatta River were due to differences in the intensity of wash.

The recovery of assemblages at putatively impacted sites following the removal of a disturbance can provide evidence of an ecological impact where there are no 'before' data (see Rosenberg, 1972; Friberg et al., 1998). Although complete benthic recovery may be a slow process and take several years (e.g. Boesch and Rosenberg, 1981; Lu and Wu, 2000), not all taxa require long periods of time to recolonize sediments (see Wu and Shin, 1997; Flemer et al., 2002) and studies of shorter duration can still be useful in determining whether any recovery is initiated following the removal of the disturbance. If the previously described patterns in macro-invertebrates (Bishop, 2004) were indeed due to wash from RiverCat ferries, recovery of assemblages impacted by wash may therefore occur over the duration of the stoppage (6 weeks), even though this period of stoppage was not an ecological decision.

It was thus predicted that over the 6-week period of the stoppage, assemblages in wash zones, where the intensity of the disturbance is greatest, would become more similar to those in no-wash zones, even if complete bioequivalence was not reached. Similarly, it was predicted that they would change to resemble their previous state following the return of ferries. It was also predicted that any change to assemblages in the no-wash zone during cessation of ferry services would be smaller than changes to assemblages in the wash zone, because the former are subjected to smaller disturbance by wash.

Similarly, if the small abundances of capitellid, nereid and spionid polychaetes in the wash zone were also due to ferries, the abundances of these taxa in the wash zone should increase following the suspension of ferry services and decrease following the return of services. Any change to abundances in the no-wash zone should be smaller than in the wash zone.

2. Data collection and analysis

RiverCat ferry services operate along the Parramatta River, Sydney, Australia (151°13′E 33°52′S) between Circular Quay and Parramatta (Fig. 1). This 19 km stretch of river is tidal, having a spring range of approximately 2 m, 50–300 m wide and up to 15 m deep. Along most of the river, the speed at which RiverCats may travel is unrestricted and can reach 30 knots ($65\ km\ h^{-1}$). Between the Silverwater Bridge and the western terminus of services at Parramatta (no-wash zone; Fig. 1), RiverCats are, however, legally required to travel at speeds less than or equal to 7 knots ($15\ km\ h^{-1}$). New South Wales Waterways sporadically monitors adherence to this regulation.

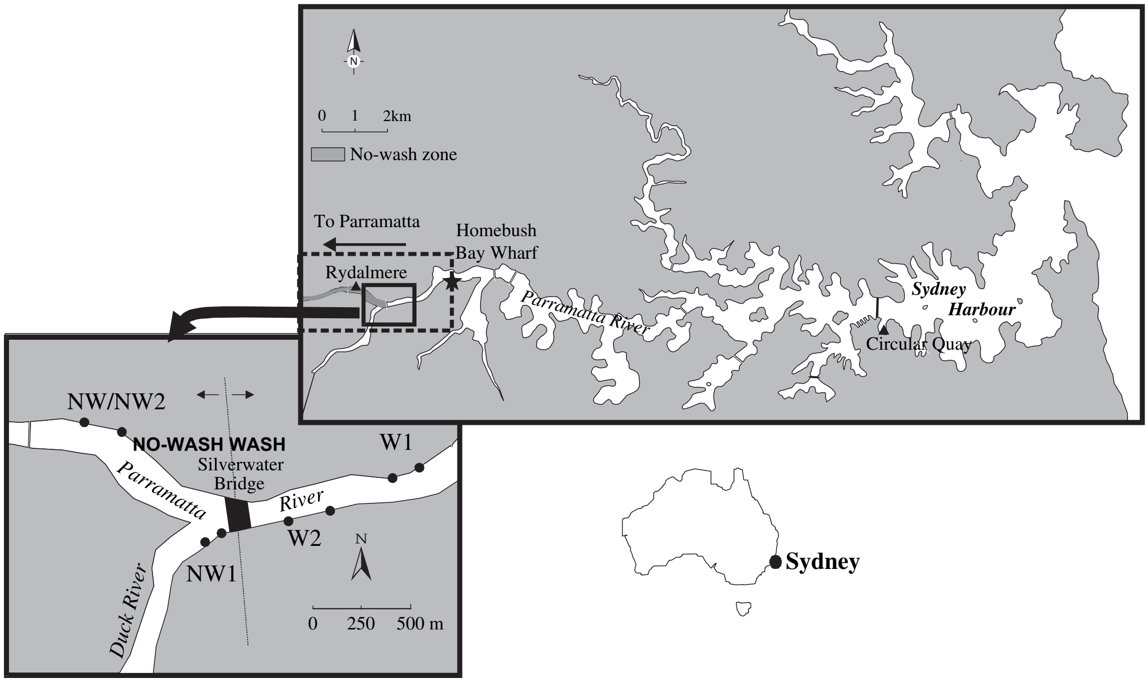

Fig. 1. Map of the Parramatta River showing the no-wash zone of the upper Parramatta River (grey), the area to the west of Homebush Bay where services were suspended during the 2000 Olympic Games and the locations that were sampled within the wash zone (W) and the no-wash zone (NW).

Along the upper Parramatta River, surface waters average 20 ± 3 ppt and range between 0 and 35 ppt in salinity (Laxton, 1999). Salinity, which is primarily determined by rainfall, does not follow a strong seasonal pattern. The temperature of surface waters ranges from a minimum of 10 °C in July to a maximum of 28 °C in February and is typically 17–19 °C in autumn and spring (Laxton, 1999). Intertidal sediments, which range from sands to muds and clays, vary across spatial scales of 10s and 100s of metres (Bishop, 2003). Grain-size does not differ between the wash and no-wash zone, although organic content can (Bishop, 2003).

RiverCat ferry services were temporarily suspended to the west of Homebush Bay from the 28th August to 2nd October 2000 (Fig. 1). The area affected by the stoppage included both the upstream wash and no-wash zones sampled by Bishop (2004, Fig. 1).

In order to test the hypotheses of change in response to ferry stoppage, macrobenthic infauna were sampled in intertidal, unvegetated sediments in two locations within the upstream no-wash zone (NW1 and NW2; Fig. 1) and two locations within the wash zone (W1 and W2; Fig. 1), at two times before (28 April, 2000 [time 1] and 30 May, 2000 [time 2]), two times during (6 September 2000 [time 3] and 25 September [time 4], 2000) and two times after (26 October, 2000 [time 5], 10 February, 2001 [time 6]) the temporary suspension of services. Control sites that are never affected by wash from RiverCats could not be sampled because RiverCats travel along the entire navigable length of the river. To separate any change in assemblages due to the stoppage from seasonal change, unrelated to the production of wash, the four locations were also sampled in autumn (June 23) and spring (September 3) of 2001.

Because the no-wash zone extends to the upper navigable limit of the river, all sites within the wash zone were necessarily downstream of those in the no-wash zone (Fig. 1), making the design confounded (Hurlbert, 1984). To minimize the potentially confounding influence of an environmental gradient, locations within the wash and no-wash zone were separated by less than 1.5 km. Previous sampling of the eight sites included in the present study showed that, although there were significant differences between assemblages in the wash and no-wash zone, patterns in the abundances of taxa did not simply follow a gradient with distance upstream (Bishop, 2004). The locations, which all faced to the north or south, were similarly exposed to wind-generated waves, which are primarily produced by westerly winds from May to September and easterly winds from November to March (Smith, 1990). Samples were not collected from NW2 at time 1 because the 'before' data were being collected for another experiment, which did not include this location, when the decision to stop ferry services was made. The lack of sufficient notice of this managerial decision did not allow a more extensive design, with greater replication of sites and locations.

At each time of sampling, 5 cores of intertidal sediment, 10 cm in diameter and 10 cm deep, were collected from each of two sites in each location, as per Bishop (2004). Sites were approximately 15 m long and tens of metres apart, were situated adjacent to urban mangrove forest and were of similar slope and distance away from the RiverCat ferry route as one another. Cores were transported back to the laboratory where they were either immediately preserved with 7% formalin in sea water or stored overnight at 4 °C and preserved the next day. Animals were stained using Biebrich Scarlet.

Samples were sieved through a 500 μm mesh. Polychaetes were sorted to Family, crustaceans to Order and bivalves and gastropods to Species. Little taxonomic information on macro-invertebrates is available in Australia and there is great uncertainty associated with classification. Sorting animals to a mixed taxonomic resolution greatly sped the processing of samples and did not impair the detection of ecological differences between wash and no-wash zones (Bishop, 2004). Chapman (1998) also showed that spatial patterns of variation in nearby mangrove forests were similar, regardless of whether mixed or finer levels of taxonomic resolution were used to characterize assemblages.

Multivariate analyses and ordinations were done using Bray–Curtis coefficients of dissimilarity on untransformed data (Bray and Curtis, 1957). To test the hypotheses that the assemblages of wash or no-wash zones would change following the suspension of services and change would be greater in the wash zone than the no-wash zone, non-metric multi-dimensional scaling (nMDS; Shephard, 1962; Kruskal, 1964) of points representing the average assemblage at each site, at times 1–6, was plotted. Plotting the individual replicates increased the stress value of the plot unacceptably.

In addition, the average dissimilarity between assemblages of the wash and no-wash zone was determined for each time of sampling. This enabled us to test the hypothesis that the dissimilarity between the wash and no-wash zone would be smaller (i.e. assemblages would be more similar) during the cessation than at times before or after it. All possible pairings of replicates from the wash zone with replicates from the no-wash zone were used in the calculation of these averages.

Bray–Curtis dissimilarities, calculated from centroids of assemblages at the scale of sites (averaged across replicates), were formally analysed using non-parametric MANOVA (NP-MANOVA; Anderson, 2001), with two factors, time (2–6) and zone (wash vs no-wash). Time 1 was omitted because sites at NW1 were not sampled at this time. The analyses did not include the factors location and sites within location because interactions between more than two factors are difficult to interpret in multivariate space. If, as hypothesized, assemblages of the wash zone became more similar to those of the no-wash zone during the cessation, the term, Time × Zone, should be significant, with differences between the zones at times 2, 5 and 6 greater than at times 3 and 4.

To test whether any increase in similarity between the assemblages of the wash zone and no-wash zone during the suspension of services (see Section 3) was a seasonal pattern, unrelated to the removal of ferries, two-way ANOVAs comparing Bray–Curtis measures of dissimilarity between wash and no-wash zones between late autumn/winter and early spring in 2000 (the year of the cessation) and 2001 (a year when services ran year-round) were done. Data were paired randomly, with no data used more than once, to provide independent measures for analysis (Underwood and Chapman, 1998). If patterns are seasonal, similar increases in similarity should be seen between 30 May and 25 September 2000 (before and during the suspension) as between 23 June and 3 September 2001 (where there was no change in ferry activity). If any increase in similarity is due to the suspension of ferry services, increase in the similarity between the wash and no-wash zone from winter to spring should only be seen in 2000.

Over 75% of change in assemblages among times was due to the taxa Nereididae, Capitellidae and Spionidae (see Section 3). Changes in the abundance of these taxa were consequently examined with ANOVAs. These had four factors – time (2–6), zone (wash vs no-wash), location within zone and sites within location. If, as predicted, the abundance of capitellids, nereids and spionids increased in response to the temporary cessation and this increase was greater in the wash than the no-wash zone, a significant Time × Zone interaction would be found in each of the ANOVAs. In the wash zone, differences in the abundances of taxa between 'before' and 'after' times would be smaller than between times 'before' and 'during', or between times 'during' and 'after' the temporary cessation. Significant Time × Zone interactions were examined using Student–Newman–Keul (SNK) tests. All data used in these ANOVAs were ln $(x + 1)$ transformed. Prior to each analysis, Cochran's (1951) *C*-test was done to test for heterogeneity of variances. In some analyses, variances were heterogeneous despite transformation. Data were still analysed because analysis of variance is relatively robust to heterogeneous variances if there are many independent estimates of variance (Box, 1953; Underwood, 1997). Heterogeneity of variances does, however, increase the probability of committing a Type I error. Thus, in the case of a significant Cochran's test, only terms of the ANOVA significant at $p < 0.001$ were interpreted using SNK tests.

3. Results

3.1. Changes to assemblages

Contrary to the hypothesis, the Time × Zone interaction of analysis of Bray–Curtis dissimilarities using the centroids of sites as the replicates, was not significant (NP-MANOVA, $p = 0.11$), although there was a persistent difference between the wash and the no-wash zone across time ($p < 0.001$). Because these analyses are sensitive to differences in variances in addition to locations, they are best interpreted in conjunction with nMDS plots (M.J. Anderson, pers. comm.).

When centroids, representing average assemblages in each site within the wash or no-wash zone were ordinated (Fig. 2a), points generally formed two groups corresponding to wash and no-wash zones, although there was overlap for some sites at times 3, 4 and 5. The groups therefore converged to some extent during the suspension of services (squares). Extractions from this nMDS (Fig. 2b–d) indicate that this was primarily due to assemblages of the wash zone (filled symbols) becoming more similar to (plotting closer to) those of the no-wash zone (open symbols) during the suspension of services.

The difference in assemblages between wash and no-wash zones was greatest at times prior to the cessation of services (t1, t2) and smallest at time 4 (during the cessation) and time 5 (immediately after the reintroduction of services; Fig. 3). In contrast to 2001, when differences between the assemblages of the wash and no-wash zone were similar in June and in September, in 2000, the year of the Olympic Games, dissimilarity between the wash and no-wash zone was greater in late May (prior to the suspension of ferry services) than in September (during the suspension of services; Table 1; Fig. 4).

Patterns of change in assemblages were also examined through separate ordinations of the data from each site (Fig. 5). These ordinations enabled the temporal change within each site to be seen without distortion of the plot by points from the other sites. Within the wash zone, three of the four sites changed following the removal of ferries (shortly after time 2) and became more similar to their initial state following the return of services (times 5 and 6; Fig. 5b–d). The assemblage at the fourth site, W1(S1), had no clear pattern of change following the return of ferries (Fig. 5a). Although assemblages at three out of the four sites within the no-wash zone also displayed cyclic change consistent with the removal and then the return of services (Fig. 5f–h), these changes were relatively small compared to changes in the assemblages of the wash zone over the same period. Sites within the no-wash zone displayed greatest change between times 5 and 6, well after the return of services.

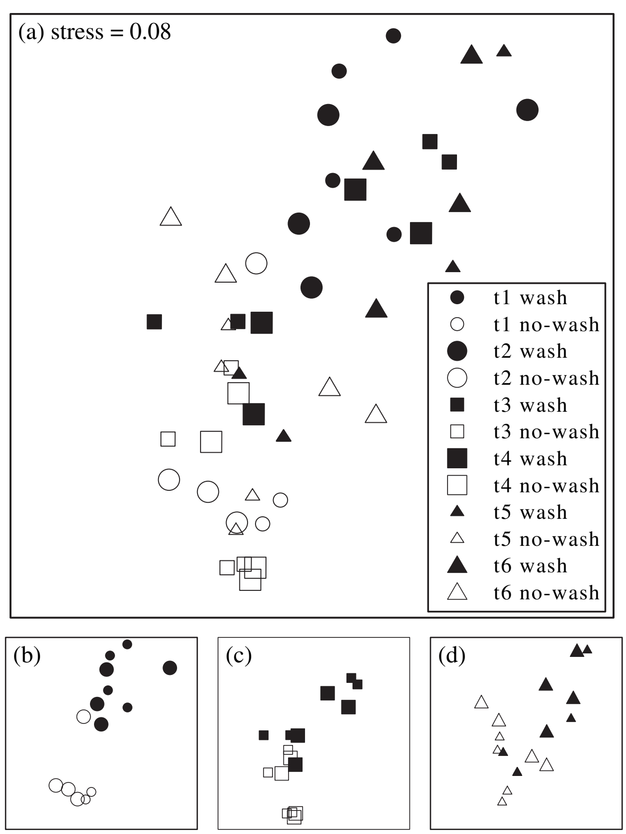

Fig. 2. nMDS ordination of assemblages of macrobenthic infauna in the wash (closed symbol) and no-wash (open symbol) zone of the upper Parramatta River at (a) all times and extractions from this plot showing (b) times before (t1, t2; circles), (c) times during (t3, t4; squares) and (d) times after (t5, t6; triangles) the temporary suspension of RiverCat ferry services to the west of Homebush Bay. Points represent centroids of untransformed data from each site. Bray–Curtis measures of dissimilarity were used ($n = 5$).

3.2. Changes in abundances

It was predicted that, within the wash zone, abundances of important distinguishing taxa would increase during the cessation of services, whereas in the no-wash zone, changes would be smaller. A significant Time × Zone interaction, which would support this

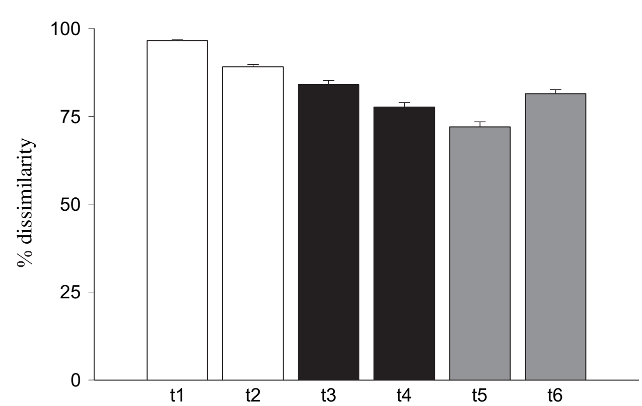

Fig. 3. Mean (+ SE) Bray–Curtis dissimilarity in assemblages of macrobenthic infauna between the wash zone and the no-wash zone, at times before (white), during (black) and after (grey) the temporary suspension of RiverCat ferry services to the west of Homebush Bay. $n = 200$ for time 1 and 400 for times 2–6.

Table 1
ANOVA comparing Bray–Curtis measures of dissimilarity for differences between the assemblages of wash and no-wash zones between late autumn/early winter and early spring of 2000 (the year in which ferry services were temporarily suspended in spring) and 2001 (when services ran throughout the year)

	df	MS	F	Sig.
yr	1	1372	4	***
se	1	2111	6	*
yr × se	1	4237	12	***
res	76	341		
Cochran's test		$C = 0.52$**		
Transformation		arcsine		
SNK		Yr 1: A > S		
		Yr 2: A = S		

yr = year (2 levels: 2000 [yr 1], 2001 [yr 2]; fixed), se = season (2 levels: late autumn/early winter [A], early spring [S]; fixed). $n = 20$.
NS $p > 0.05$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

hypothesis, was not, however, found for capitellid, nereid or spionid polychaetes (Table 2) despite their collective contribution to over 75% of multivariate change among times (SIMPER routine, PRIMER package, Clarke, 1993). Instead, there were significant interactions between Time and Site for all analyses, indicating that temporal change varied significantly between sites (only 10s of m apart) in the same location (Table 2). This idiosyncratic variation is illustrated for Nereididae in the 2 sites in W2 and NW1 in Fig. 6.

In contrast to the polychaetes, the other important distinguishing species, the mussel, *Xenostrobus securis*, which was previously absent from the wash zone, colonized W1(S1), W1(S2) and W2(S1) during cessation of ferry activity (Fig. 7a–d). This did not appear to be due to a widespread recruitment of this species because the same increase was not shown in sites in the no-wash zone (Fig. 7e–h). Following the return of services, *X. securis* was once again absent from sites within the wash zone. Nevertheless, this species was patchy and variable and these changes were not statistically significant.

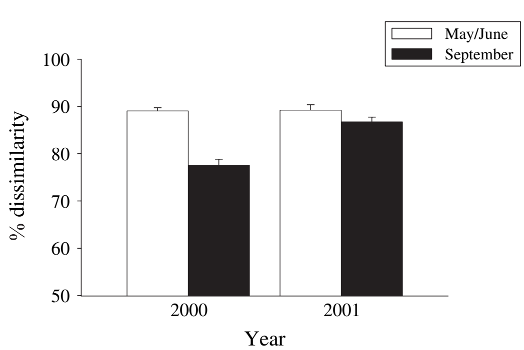

Fig. 4. Mean (+SE) Bray–Curtis dissimilarity in assemblages of macrobenthic infauna between the wash and the no-wash zone in late fall/early winter (30 May, 2000; 23 June, 2001) and early spring (25 September, 2000; 3 September, 2001), in 2000 when the suspension of ferry services occurred and in 2001 when services operated continuously ($n = 400$).

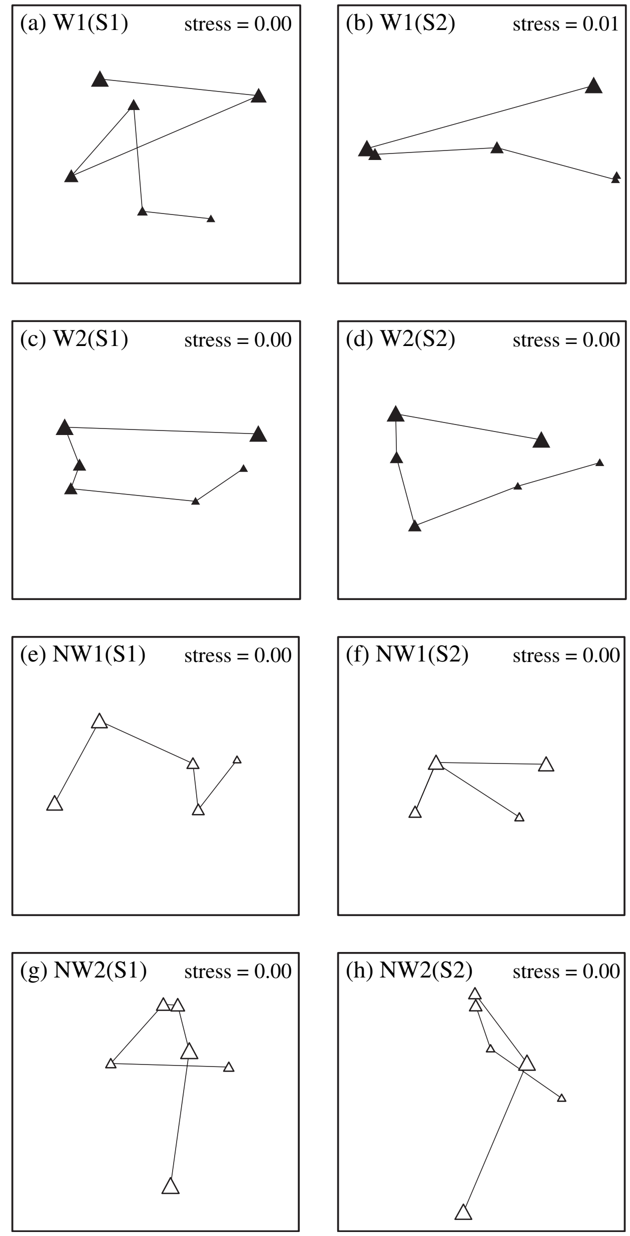

Fig. 5. nMDS ordinations of temporal changes to assemblages of (a–d) the wash zone (closed symbol) and (e–h) the no-wash zone (open symbol) of the upper Parramatta River at times prior to (small triangles), during (medium sized triangles) and after (large triangles) the temporary suspension of RiverCat ferries to the west of Homebush Bay. Points represent centroids of untransformed data, the distances between which have been scaled according to corresponding Bray–Curtis measures of dissimilarity so that they are comparable across all plots. Sites at NW1 were not sampled at time 1 ($n = 5$).

4. Discussion

Although not in each site, the assemblages of infauna at the majority of sites (i.e. 3 of 4 sites) within the wash zone changed to become more similar to those of the no-wash zone following the temporary suspension of River-Cat ferry services. Several months after the return of services, these assemblages had changed to be more like

Table 2
Analyses comparing spatial variation in the abundance of taxa of macrobenthic fauna in unvegetated habitat of wash (W) and no-wash zones (NW), among times of sampling

		Capitellidae			Nereididae			Spionidae			*Xenostrobus securis*		
	df	MS	*F*	Sig.	MS	*F*	Sig.	MS	*F*	Sig.	MS	*F*	Sig.
ti	4	7.51	5.68	**	25.22	6.95	*	9.5	2.99	ns	0.72	2.24	ns
zo	1	91.02	No test		334.17	No test		52.6	No test		6.28	No test	
lo(zo)	2	131.26	23.43	**	87.10	No test		14.2	No test		1.06	0.34	ns
si(lo(zo))	4	5.60	4.23	**	3.11	3.07	*	1.4	1.44	ns	3.11	9.66	***
ti × zo	4	3.50[a]	2.65	ns	6.13	1.69	ns	4.8	1.53	ns	0.61[a]	1.90	ns
ti × lo(zo)	8	1.33	1.01	ns	3.63	3.59	*	3.2	3.26	*	0.14	0.35	ns
ti × si(lo(zo))	16	1.32	2.72	***	1.01	4.42	***	1.0	4.66	***	0.41	2.60	***
res	160	0.49			0.23			0.2			0.16		
Cochran's test		$C = 0.10$ ns			$C = 0.18$ **			$C = 0.11$ ns			$C = 0.29$ **		
Transformation		$\ln(x + 1)$			$\ln(x + 1)$			$\ln(x + 1)$			$\ln(x + 1)$		
SNK		ti × si(lo(zo))			ti × si(lo(zo))			ti × si(lo(zo))			ti × si(lo(zo))		
		W1(S1), W1(S2), W2(S1), NW1(S1), NW1(S2), NW2(S2): t2 = t3 = t4 = t5 = t6			W1(S1), W1(S2), W2(S1), NW1(S2): t2 = t3 = t4 = t5 = t6			W1(S1), W1(S2), W2(S1), NW1(S2): t2 = t3 = t4 = t5 = t6			W1(S1), W1(S2), W2(S1), W2(S2), NW1(S2), NW2(S2): t2 = t3 = t4 = t5 = t6		
		W2(S2): t5 > (t4 = t6) > (t2 = t3)			W2(S2): (t3 = t4 = t5) > (t2 = t6)			W2(S2): (t2 = t4 = t5) > (t3 = t6)			NW1(S1): t2 > (t3 = t4 = t5 = t6)		
		NW2(S1): (t3 = t4 = t5) > t6 > t2			NW1(S1): t2 > (t3 = t4) > (t5 = t6)			NW1(S1): (t2 = t3 = t4) > (t5 = t6)			NW2(S1): (t2 = t3 = t4 = t5) > t6		
					NW2(S1): (t3 = t4) > (t2 = t5) > t6			NW2(S1): (t3 = t4 = t5) > t2 > t6					
					NW2(S2): (t3 = t4) > t2 >t5 > t6			NW2(S2): (t3 = t4) > (t2 = t5) > t6					

ti = time (5 levels: t2–t6; random), zo = zones (2 levels; wash, no-wash; fixed), lo(zo) = location (2 levels; random), si(lo(zo)) = sites (2 levels; random). $n = 5$.
NS $p > 0.05$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
[a] $SS_{location}/SS_{site}$ was not significant at $p = 0.25$, allowing $MS_{location}$ to be pooled with MS_{site} (Underwood, 1997).

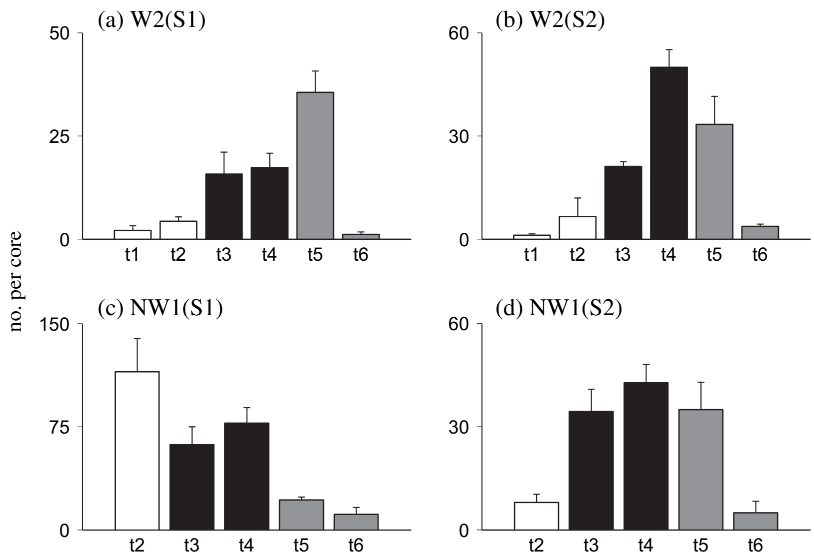

Fig. 6. Mean (+SE) abundance of Nereididae in unvegetated habitat of sites (S1, S2) at W2 (wash zone) and NW2 (no-wash zone) at times before (t1, t2; white), during (t3, t4; black) and after (t5, t6; grey) the temporary suspension of ferry services. Sites at NW1 were not sampled at t1. $n = 5$ for each site at each time.

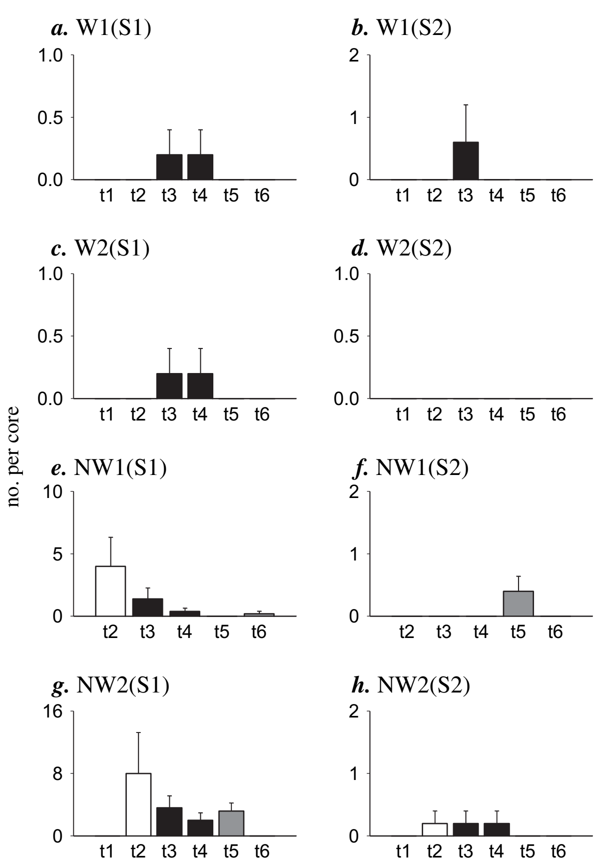

Fig. 7. Mean (+SE) abundance of *Xenostrobus securis* in unvegetated habitat of sites in the wash (W) and the no-wash (NW) zone of the upper Parramatta River at times before (t1, t2; white), during (t3, t4; black) and after (t5, t6; grey) the temporary suspension of ferry services. Sites at NW1 were not sampled at t1. $n = 5$ for each site at each time.

their previous state. The assemblages in some sites of the no-wash zone also changed coincident with the temporary cessation, but these changes were much smaller than those in the wash zone, as was predicted. Following the return of services, the assemblages in the no-wash zone started to change back towards their previous state, but then changed along a different trajectory. Therefore, the smaller magnitude of the disturbance in the no-wash zone meant that less change was apparent when the disturbance was initiated and the re-instatement of the disturbance allowed more variable responses on the part of the assemblage.

Despite these clear patterns in the nMDS plots, the multivariate analyses of variance did not provide significant results to support this model. These analyses were not, however, very powerful. Reducing the analysis to two factors so that the interaction between Zone and Time could be clearly interpreted, necessitated using sites as replicates with $n = 4$. In addition, the number (and positions) of sites and locations were determined prior to the study, as part of a larger study of effects of RiverCat ferries on benthic fauna and could not be modified with the small amount of notice given by authorities before they changed the timetable of ferry services. Nevertheless, this level of replication (2 locations in the wash and no-wash zone, with 2 sites in each) was entirely adequate to identify significant differences between fauna in wash and no-wash zones (Bishop, 2004) and therefore is a logical basis for this study.

In addition, the conclusion that the cessation of ferry services did decrease the difference between assemblages in wash and no-wash zones is also supported by the decrease in Bray–Curtis dissimilarities between wash and no-wash zones during and immediately after the cessation of services and subsequent increase in dissimilarities at time 6 (Fig. 4). Because changes in assemblages over the period of the stoppage are potentially confounded by season, or other long-term temporal trends, the patterns of change were compared to those over a similar period of time the next year. The greater similarity between assemblages of the wash and no-wash zone in September 2000 (when ferries were stopped) than was found in May 2000 (when ferries were running) was not replicated when ferries ran to timetable in 2001. Thus, these data also support the contention the change in assemblages of the wash zone, observed during the cessation of services, was indeed due to the removal of wash during this time.

The fact that assemblages in the wash zone changed more than of those in the no-wash zone is consistent with the premise that the disturbance of wash from the ferries directly affects these assemblages. During the operation of RiverCat services, greater near bed-flows are generated by wash along sections of the river where speed is unrestricted than in the no-wash zone (Patterson Britton and Partners, 1999). Other disturbances associated with ferries (e.g. the emission of fuel or exhaust) are similar between the two zones because the number of ferries traveling along these sections of river is identical. Thus, the pattern of change supports the model that wash was responsible for the differences between assemblages of wash and no-wash zones.

Control locations were not directly required by the hypotheses examined in this study because they directly related the magnitude of changes in the wash-zone relative to that in the no-wash zone. Although measures of natural temporal variation without a change to management would have provided useful data, the ferries were stopped throughout the length of the upper Parramatta River during this time (i.e. all sites were subjected to the manipulation). Nevertheless, the hypotheses were about comparative changes to disturbance between sites subjected to different intensities of wash and, therefore, the lack of control locations does not nullify interpretation of the results obtained.

In contrast to clear patterns of changes of entire assemblages, opportunistic polychaetes did not show any change that was consistent with the cessation of services, although they are numerically important contributors to these assemblages. Increases or decreases in abundance were site-specific, i.e. varied at the scale of 10 m within locations and apparently idiosyncratic. The cessation did, however, apparently enable the mussel, *Xenostrobus securis*, to colonize several sites within the wash zone where it was previously absent, although this was not, however, of sufficient magnitude to be statistically significant. Thus, the stronger pattern of multivariate changes in these assemblages appears to be the result of cumulative univariate changes, none of which by themselves were large enough to be statistically significant.

Had the study extended over a longer period, the hypothesized change in abundances may have become apparent, if increases in abundance need increased settlement and growth to a sufficient size (>500 μm diameter) to be retained on the sieve. This study was constrained by the time-course of the managerial decisions, which had nothing to do with the scales of relevant ecological changes. The data do, nevertheless, strongly infer benthic responses to both the removal of ferry-wash and its re-instatement and provide useful measures of spatial and temporal variation that should be included in any more extensive or longer term study.

Site-specific differences in the response of polychaetes to the removal of the disturbance suggest that very small-scale features of the habitat may modify rates of recovery. Along the upper Parramatta River, content and grain-size of the sediment vary across spatial scales of metres, tens of metres and hundreds of metres (Bishop, 2003). If sediment-related variables are important in determining recruitment of infaunal organisms as suggested by the literature (e.g. Scheltema, 1974; Snelgrove and Butman, 1994), site-specific responses to the removal of the disturbance may be attributed to variability in sediment grain-size and organic content along the Parramatta River.

Changes in the abundances of macrobenthic infauna following the suspension of RiverCat services suggest that these are not permanently altered by this disturbance and do 'recover' following its removal. Work by Davidson (1996, 1997) also suggested that changes to abundances of taxa, caused by boat-wash are not permanent. Abundance of molluscs on intertidal boulders in the Tory Channel and Queen Charlotte Sound, New Zealand, increased, coincident with the off-seasons of the fast ferry, Condor 10. Although the off-season always coincided with the cooler months of the year, seasonal change was not observed in assemblages of control sites sheltered from wash, suggesting that the ferries were responsible for the pattern seen. In this study, the ability of populations of macro-invertebrates to rapidly recover from the disturbance of wash following its removal suggests that exposure to wash should not be a major consideration in their conservation. Reductions of abundances of infauna by wash may, however, be of concern if they form the base of important food-chains.

This study, like that of Davidson (1996, 1997), has demonstrated how managerial decisions, not necessarily intended to serve any ecological purpose, may be used as experiments to assess the ecological impact of an anthropogenic disturbance. In this case, the decision to temporarily suspend ferry services was used as the basis of a manipulative experiment to establish causation between wash and the structure of infaunal assemblages. Without the use of this managerial decision, a manipulative experiment of this scale would have been outside the scope of available resources.

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