

Mitigating against the loss of species by adding artificial intertidal pools to existing seawalls

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ABSTRACT: Over 80% of the money allocated to protect coastlines from climatic change is spent building new seawalls or increasing the stability, height and length of existing seawalls. Although this protects important infrastructure, it has serious consequences for intertidal biodiversity, because walls are built and maintained according to engineering and financial criteria, despite the fact that they are known to adversely affect intertidal biodiversity. We tested the predictability and reliability of adding pots, designed to simulate rockpools, to seawalls as an artificial habitat to mitigate against loss of intertidal species. Two sizes of concrete pots were attached at mid- and highshore tidal levels to sandstone seawalls at 2 locations in Sydney Harbour, Australia. After 7 mo, pots increased intertidal biodiversity on the seawalls by adding additional species. They also supported greater covers and densities of algae and many invertebrates compared with established assemblages on the seawalls. The size of the pot, its height on the wall and its location affected the assemblages that developed, with greater abundances and diversity of organisms in shallower pots and those at midshore levels. Although there were slight differences between locations for some taxa, these results show an easy cost-effective method that authorities can use to try to mitigate the adverse effects on intertidal assemblages of armouring shorelines with featureless, vertical walls.

KEY WORDS: Biodiversity · Climatic change · Coastal squeeze · Surrogate habitat · Seawall · Succession · Urbanization

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INTRODUCTION

Cities create wealth, technology, governance, arts and science necessary for modern civilization (Hall 1998, Florida 2004, Baird 2009). Urbanization has, however, also been responsible for large ecological impacts. In the past 40 yr, the number of urban-dwelling people has doubled, with urbanized areas quadrupling in size, replacing ~58 000 km² of natural habitats (Seto et al. 2011). This loss is predicted to increase, with up to 12.5 million km² of natural habitats forecast to be replaced by built structures by 2030 (Seto et al. 2011). Coastal areas are particularly

affected, as they often contain large populations of people. For example, >50% of people in the USA live in coastal areas, which make up <5% of the land occupied by the USA (Suchanek 1994). Similarly, 60% of the ~300 million people living in countries bordering the Mediterranean Sea live on the coast (Suchanek 1994).

Urbanized shorelines are important for recreation, they provide habitats for wildlife and are natural defences against flooding and erosion. Yet rapid coastal development, driven by growing populations, rising sea levels and climatic change, is reducing the quality and quantity of coastal habitats through

'coastal squeeze' (sensu Pethick 1993, Jackson & McIlvenny 2011). At present, 70% of countries with coastlines have their largest urban areas (>6000 km⁻²; Harris 2012) built on the coast or on 'reclaimed' land (McGranahan et al. 2007). Where this is extensive, natural shores have disappeared completely. Elsewhere, natural shores have been 'armoured' with breakwaters, seawalls, riprap and boulders (see reviews by Attrill et al. 1999, Airoidi & Beck 2007, Bulleri & Chapman 2010, Chapman & Underwood 2011, Dugan et al. 2011), strongly modifying natural habitats. Building expensive infrastructure (worth >\$US25 trillion globally; Lenton et al. 2009) close to the sea can cause subsidence, erosion (Bird 1996) and flooding (Klein et al. 2003). Over the next 17 yr, to cope with the expected 6 cm sea-level rise (Nicholls et al. 2007), accelerated climatic changes (Burrows et al. 2011) and a human population predicted to reach 8.2 billion people (UN 2006), \$US144 billion each year will need to be spent building new seawalls or increasing the stability, height and length of existing walls (based on seawalls making up 80% of funds for coastal defences; IPCC 2007). Although this will assist in human welfare, it will have serious consequences for intertidal biodiversity and its functions.

When artificial shorelines replace soft sediments, there is usually a change of species locally as sedimentary habitat is replaced with hard substratum. Although many native species live on the hard substratum, they are not usually the same species that live in or on soft substratum. Replacement of natural rocky substrata with built infrastructure has been considered to have little impact on natural intertidal assemblages, which make use of the additional habitat offered by the built structures (Thompson et al. 2002). Many marine species rapidly colonize natural and artificial surfaces (Sutherland 1980, Anderson & Underwood 1994, Glasby 1999), hence the use of artificial material in the construction of reefs to enhance fish populations (Baine 2001). In some areas, seawalls do not, however, support natural levels of intertidal diversity (Chapman 2003). In addition, assemblages may differ on artificial structures because of changes to competitive interactions (Espinoza et al. 2006, Iveša et al. 2010), use of microhabitat (Moreira et al. 2007, Klein et al. 2011) and the arrival of invasive species (Bulleri & Airoidi 2005).

Changes to abundances, diversity and ecological interactions may be caused by the narrow intertidal area on steeply sloping built structures, especially where the tidal range is small. Alternatively, walls may lack important intertidal microhabitats. The

most obvious are rockpools (Chapman & Underwood 2011), although cracks and crevices and biogenic habitat created by sessile organisms may also vary considerably between natural and artificial intertidal shores, affecting associated assemblages (Moschella et al. 2005, Jackson et al. 2008, Browne & Chapman 2011, Chapman & Underwood 2011, Klein et al. 2011). Larger mobile animals, without strong powers of adherence (e.g. starfish, urchins, large gastropods), are less abundant or absent from steep seawalls (Chapman 2003).

While it is important to restore and preserve natural habitats (Gaines et al. 2010), there is increasing recognition by the United Nations (Rode & Burdett 2011), World Bank (Suzuki et al. 2012), US Army Corps of Engineers (USACE 2012) and many scientists (Wilson 1992, Hobbs & Harris 2001, Palmer et al. 2005, Francis et al. 2008, Chapman & Blockley 2009, Browne & Chapman 2011, Brudvig 2011) that new technology is required to modify urban areas to support biodiversity and its desirable functions. This is important for not only nature itself (Rosenzweig 2003), but also because humans appear to function better with elements of nature in their surroundings (Maller et al. 2006, Pretty et al. 2007). Although most research has been in highly altered terrestrial habitats, the same principle applies to marine and estuarine habitats, which are readily accessible to people. Ecological engineering attempts to blend engineering criteria in the construction of infrastructure and ecological knowledge to create novel techniques to improve urban environments (Schulze 1996). Using these types of approaches, artificial structures have been modified to improve the numbers of marine organisms that can live on them (Moschella et al. 2005, Moreira et al. 2007, Langhamer & Wilhelmsson 2009, Martins et al. 2010).

Seawalls, the predominant form of artificial shoreline, provide poor-quality habitat for many species (Chapman & Underwood 2011), although recent work has shown that simple procedures can help mitigate these impacts. Chapman & Blockley (2009), Browne & Chapman (2011) and Chapman & Underwood (2011) describe simple modifications to relatively featureless seawalls that can increase the numbers of species living on the walls. Because of the costs and the need to work with engineers within the constraints of their workload, it has not always been possible to repeat experiments in multiple locations to test for generality of results. Such experiments need to be repeated to test for large-scale generality, so we can provide policy makers and managers with predictable, reliable and pragmatic strategies for restoring biodiversity.

Browne & Chapman (2011) described preliminary results from a study using concrete flowerpots attached to the surfaces of seawalls to mimic rockpools. Here, we describe in more detail the use of experimental concrete flowerpots added to replicate seawalls in Sydney Harbour to evaluate their potential as intertidal habitat. Because natural assemblages in rock pools vary with size of pool and height on the shore (Underwood & Skilleter 1996), we predicted that assemblages developing in these flowerpots would also vary according to the size of pot and the height of deployment on walls, although at each height, they would support species not found on the surface of the wall itself at that shore level. We also predicted that these effects would be similar among locations.

MATERIALS AND METHODS

Field methods

Concrete pots, resembling flowerpots, but built to withstand wave action (Fig. 1), were attached at mid- and highshore tidal levels (1.0 to 1.3 and 1.6 to 1.9 m above chart datum, respectively) to a sandstone seawall at Cremorne Point (33° 50' 50" S, 151° 13' 49" E) and Careening Cove (33° 50' 42" S, 151° 13' 6" E; locations described in Iveša et al. 2010) in Sydney Harbour in December 2009. Two sizes of pots (large, 10 l, and small, 6 l) were used. They had the same diameter at the top (360 mm), but tapered to different depths (380 and 220 mm, respectively) because natural rockpools of different depths have different assemblages (Astles 1993). The sizes were similar to small and medium pools on nearby natural shores, but pots that would



Fig. 1. Small and large flower pots attached at high- and midshore positions on the sandstone seawall at Careening Cove

mimic larger rockpools could not be used because their weight when filled with water during low tide damaged the walls. Six replicate pots of each size were deployed at each height in each location, although some pots were lost to wave action during the experiment. Only high- and midshore levels were used because lowshore assemblages on walls more closely resemble natural assemblages (Chapman & Bulleri 2003) and because some seawalls start above the lowshore level. All pots received a change of water during most high tides and retained water during low tide.

The pots were examined weekly until they started to be colonized by organisms and then sampled quantitatively 4.0, 5.5 and 7.0 mo after deployment, at which time the experiment unfortunately had to be terminated. Therefore, only early assemblages can be described. Pots were not stratified for depth as in Underwood & Skilleter (1996) because of the difficulty of sampling inside pots attached to a vertical wall, but the entire inside surface area of each pot was sampled each time. All sessile and mobile animals and most algae were identified to species, but *Polysiphonia* spp., Cladophorales and Spionidae were treated as groups as they could not be further distinguished in the field. Sessile organisms were counted under 100 points in a quadrat molded to fit inside each pot covering the bottom and the inner walls. All mobile animals in each pot were counted. At the same time, organisms were similarly sampled in a fixed plot of the same surface area on the surface of the wall within 1 m of each pot. These surfaces were not cleared at the start of the experiment, so the assemblage developing in the pots was compared with an existing assemblage on the wall.

Analyses of data

Pots were lost, particularly from Cremorne Point, so after 7 mo, there were 4 small (2 midshore, 2 highshore) and 9 large pots (5 midshore, 4 highshore) at Cremorne Point and 5 small and 5 large pots at each height at Careening Cove. Therefore analyses needed to be done on subsets of data to test different hypotheses.

To compare assemblages among pots at 7 mo, permutational multivariate analyses of variance (PERMANOVA; described as 'non-parametric MANOVA' in Anderson 2001) were used to test 2 hypotheses: (1) assemblages would vary according to the size of pot and height on the wall at Careening Cove and (2) assemblages would vary between heights in large

pots similarly at Cremorne Point and Careening Cove ($n = 5$). For the large, highshore pots at Cremorne Point, the 5th replicate was obtained from the average of the 4 remaining pots. These analyses used Bray-Curtis similarities (Bray & Curtis 1957) from untransformed data and, separately, measures of presence/absence, with significance determined from 999 permutations of the data. Data were not transformed because either the variances were homogeneous or most taxa were very sparse. Non-metric multidimensional scaling (nMDS; Clarke 1993) was used to produce 2-dimensional ordinations of similarity among samples. Size of pot and height on the wall were treated as fixed factors and location as a random factor. Assemblages in pots were not formally compared using PERMANOVA to the assemblages on the walls, because the walls had large covers of crustose algae, which would have dominated differences in the analyses, potentially masking subtler differences among the pots themselves.

Most individual species were very patchy among replicate pots, with many counts of zero, so individual species were not analysed, but grouped into taxonomic or functional groups for comparison with the assemblage on the wall. Covers and abundances of these taxa were compared among pots of the 2 sizes and the patches on the walls using analysis of variance. Data were transformed to $\sqrt{(x + 1)}$ because variances were generally heterogeneous ($p < 0.05$, Cochran's test). Student-Newman-Keuls tests were used to identify differences between relevant means when terms in the analyses were significant. For the large, highshore pots at Cremorne Point, there were only 4 replicates, so the data were averaged to provide a 5th replicate in this treatment for the comparisons between locations.

RESULTS

Assemblages in small and large pots at 2 shore levels at Careening Cove

After 7 mo, assemblages in large and small pots varied interactively with height (PERMANOVA; Size \times Height, $F_{1,16} = 1.94$, $p < 0.05$). Pairwise permuted t -tests showed that different assemblages developed at

mid- and highshore levels in each size of pot, and at midshore there were significantly different assemblages in small and large pots (Table 1, Fig. 2A). There was no effect of size of pot high on the shore. Similar results were found when presence and absence were analysed (Size \times Height, $F_{1,16} = 2.83$,

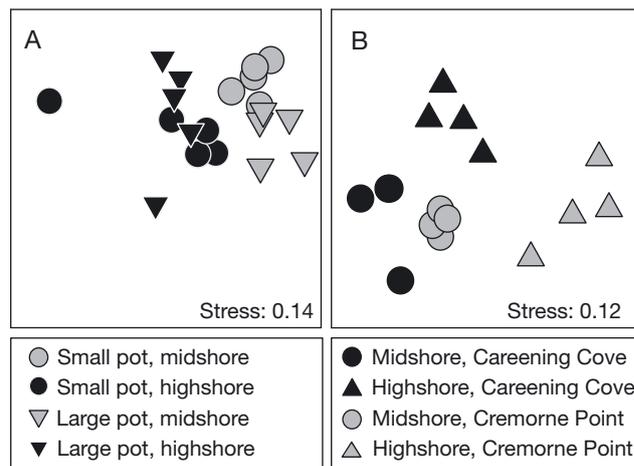


Fig. 2. Non-metric multidimensional scaling ordinations of assemblages in (A) small and large flowerpots at mid- and highshore levels at Careening Cove and (B) in large pots at mid- and highshore levels at Careening Cove and Cremorne Point

Table 1. *A posteriori* comparisons of average Bray-Curtis dissimilarities (%) following PERMANOVA of differences in assemblages after 7 mo in (A) small and large pots at high- and midshore levels at Careening Cove, using all data and with data converted to presence/absence; and (B) for large pots only at Careening Cove and Cremorne Point, using all data and data converted to presence/absence; * $p < 0.05$, ** $p < 0.01$

	Mid-shore	High-shore	Mid- vs. highshore	t -test
(A) Small and large pots at Careening Cove, all data				
Small	52	69	79	1.96**
Large	59	71	87	2.07*
Small vs. large	69	69		
t -test	1.85**	0.85		
Presence/absence				
Small	46	61	80	2.39*
Large	49	47	75	2.77**
Small vs. large	55	56		
t -test	1.58*	1.03		
(B) Large pots at Careening Cove and Cremorne Point, all data				
Careening Cove	53	59	85	2.37*
Cremorne Point	41	61	91	2.89*
Careening Cove vs. Cremorne Point	70	93		
Presence/absence				
Careening Cove	47	33	71	3.04*
Cremorne Point	21	44	80	4.22*
Careening Cove vs. Cremorne Point	61	87		

$p < 0.01$; Table 1), indicating that the differences were not simply due to variations in abundances of the same set of species.

To determine whether the pots supported more species than found on the wall itself, taxa were compared across patches of wall and the small and large pots (hereafter referred to as habitats). There was little difference between the numbers of taxa/species of algae in the different sized pots or on the wall (11 taxa overall, Table 2), but the identity of the taxa differed. The covers of the ephemeral, opportunistic algae *Enteromorpha intestinalis*, *Ulva lactuca*, *Polysiphonia* spp. and Cladophorales were combined for analysis. There was a significant effect of habitat ($F_{2,24} = 7.99$, $p < 0.01$), but, despite greater cover in large pots (Fig. 3), the only significant difference was between the wall (where cover was zero) and the pots. Only the crustose algae *Hildenbrandia rubra* and *Ralfsia verrucosa* were found on the walls, occupying up to 50% of the space in some patches. There was less cover of crustose algae in pots, but greater diversity because they included coralline crust and *Peyssonnelia gunniana*. Cover of all crusts combined varied significantly among habitats ($F_{2,24} = 20.21$, $p < 0.001$), but again, the only significant difference was between the pots and the wall, with similar covers in large and small pots at each height. The only other macroalgae found were *Corallina officinalis* and *Gelidium pusillum*, each of which was only found in small pots at the midshore level.

Only 2 species of sessile animals were present on the wall at Careening Cove: the barnacle *Chthamalus antennatus* high on the shore and the oyster *Saccostrea commercialis* at the midshore level. A few barnacles settled in small, midshore pots, but no oysters settled in the pots. Instead, the pots were colonized by calcareous polychaetes (*Galeolaria caespitosa*, *Hydroides elegans* and Spionidae) and more sparsely by 3 unidentified species of ascidians. There was a significant effect of habitat on cover of polychaetes ($F_{2,24} = 47.12$, $p < 0.001$), with greater cover in

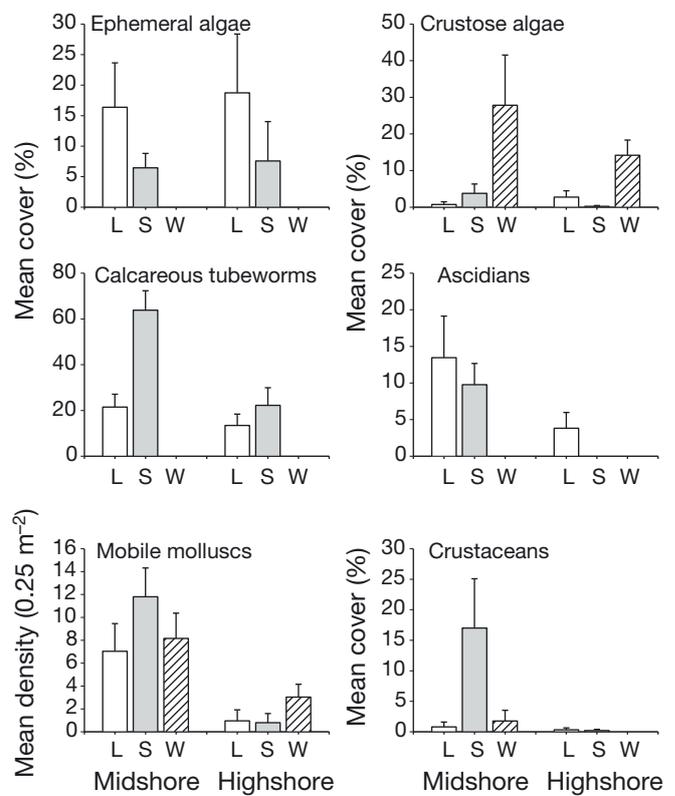


Fig. 3. Mean (+SE) percentage covers and densities of select taxa in small (S) and large (L) pots and on patches of the wall (W) at 2 shore levels at Careening Cove; $n = 5$

pots, although there was no significant effect of size of pot. There was also a significant effect of height ($F_{1,24} = 5.85$, $p < 0.05$), with significantly more polychaetes midshore (Fig. 3). Cover of ascidians varied interactively between height and habitat ($F_{2,24} = 4.58$, $p < 0.05$), with small abundances and no difference among habitats high on the shore, but significantly more in large pots at midshore (Fig. 3).

In contrast to the sessile animals, there were similar numbers of species of mobile animals in pots and on the wall (Table 2), but again the taxa differed.

Of the 22 species, 18 were molluscs. Densities of molluscs differed according to height ($F_{1,24} = 39.64$, $p < 0.001$), with significantly greater densities at the midshore level, but there were no significant differences across habitats at either height (Fig. 3). Very few mobile crustaceans were found, primarily amphipods, isopods and a few crabs. Densities of crustaceans varied interactively between habitat and height ($F_{2,24} = 4.16$, $p < 0.05$) because

Table 2. Numbers of species/taxa of algae, sessile animals and mobile animals in 5 pots of each size (small, SP, and large, LP) or on patches of the wall (W) at mid- and highshore levels at Careening Cove; data are for large pots only at Cremorne Point, after 7 mo; X indicates lack of data due to loss of pots

Taxa	— Careening Cove —						— Cremorne Point —					
	Midshore			Highshore			Midshore			Highshore		
	LP	SP	W	LP	SP	W	LP	SP	W	LP	SP	W
Algae	4	3	1	4	4	2	5	X	5	3	X	3
Sessile animals	4	7	1	4	2	1	7	X	3	0	X	1
Mobile animals	8	13	10	2	5	7	11	X	10	4	X	6

of very large densities in small pots at the midshore level (Fig. 3). Very few starfish were found, only *Patiriella exigua*, but all were found in pots.

Comparison across locations of assemblages in large pots

These analyses were restricted to large pots because of the loss of some small pots at Cremorne Point. PERMANOVA gave a significant interaction between height and location ($F_{1,15} = 3.73$, $p < 0.01$). Pairwise permuted t -tests showed different assemblages developed at the 2 heights on each shore, but differences between heights were greater at Cremorne Point than at Careening Cove (Table 1, Fig. 2B). In addition, although formal comparisons were not made between locations (they were a random factor), highshore pots showed greater location-to-location variability than midshore pots (Table 1). Similar results were found when the presence/absence data were analysed (Height \times Location, $F_{1,15} = 5.78$, $p < 0.01$; Table 1).

There were 13 algal taxa over all replicates, with little difference in numbers between pots and the wall (hereafter referred to as habitats) at either location (Table 2). There was no significant effects of habitat, height or location for cover of ephemeral algae ($p > 0.05$ for all terms in the analysis), despite the overall smaller amount of ephemeral algae at Cremorne Point compared with Careening Cove (Fig. 4). Covers of crustose algae, in contrast, varied interactively between habitat and location ($F_{1,32} = 6.94$, $p < 0.01$), with significantly less cover on the wall at Cremorne Point, but greater cover in the pots at this location (Fig. 4). The erect macroalga *Endarachne binghamiae* was found on the wall and *Corallina officinalis* was found in mid- and highshore pots at Cremorne Point.

As at Careening Cove, there were more species of sessile animals in the large, midshore pots than on the wall (Table 2). Also, although only *Chthamalus antennatus* was found on the wall high on the shore at Cremorne Point, *C. antennatus*, *Saccostrea commercialis* and *Mytilus galloprovincialis* occurred in small numbers midshore. The midshore pots at each location were settled heavily by the tubeworms *Galeolaria caespitosa*, *Hydroides elegans* and Spionidae, but none settled in the highshore pots at Cremorne Point, giving a significant Habitat \times Location \times Height interaction ($F_{1,32} = 5.42$, $p < 0.05$; Fig. 4). Cover of 4 species of ascidians varied in a more complex manner. There was a significant interaction

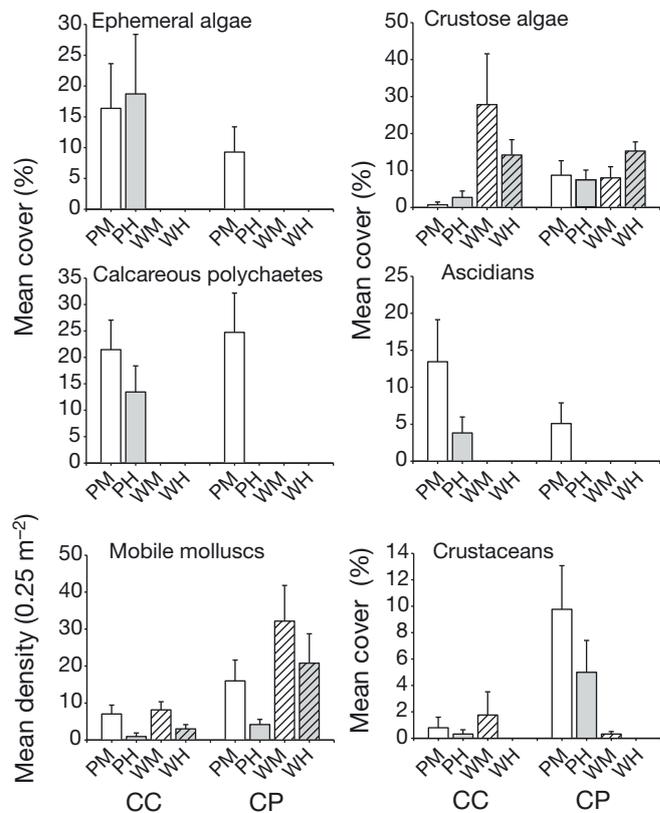


Fig. 4. Mean (+SE) percentage covers and densities of select taxa in large pots at midshore (PM) and highshore (PH) levels and on midshore (WM) and highshore (WH) patches of the wall at Careening Cove (CC) and Cremorne Point (CP); $n = 5$

between habitat and height ($F_{1,32} = 8.65$, $p < 0.001$, after eliminating the Habitat \times Location \times Height interaction, $p > 0.25$), with no ascidians settling on the wall and significantly more in midshore than in highshore pots in both locations (Fig. 4). The same pattern gave a significant interaction between location and habitat ($F_{1,32} = 6.70$, $p < 0.05$; Fig. 4).

Densities of the 18 species of mobile molluscs differed across locations ($F_{1,32} = 18.80$, $p < 0.001$) and habitat ($F_{1,32} = 11.43$, $p < 0.001$), each tested against the Residual after pooling interaction terms with $p > 0.25$. There were fewer molluscs in the pots than on the wall at both locations, with generally larger densities at Cremorne Point (Fig. 4). There were significant interactions between habitat and height in densities of crustaceans ($F_{1,32} = 8.39$, $p < 0.01$, after eliminating the Habitat \times Location \times Height interaction, $p > 0.25$, and testing against the Residual) and between location and habitat ($F_{1,32} = 6.70$, $p < 0.05$) due to more crustaceans in pots at midshore, but not highshore, levels. There were also more crustaceans

in pots at Cremorne Point, but no difference between locations for densities on the wall (Fig. 4). The crustaceans at Cremorne Point also included numerous amphipods, which did not colonize the pots at Careening Cove.

Short-term temporal changes in assemblages

To compare development of the early assemblages between locations and pots of different size, nMDS ordinations were plotted for each size of pots at each level in each location using Bray-Curtis similarities and the centroids of each set of replicates. In each location, assemblages in large and small midshore pots diverged over time (i.e. points were further apart in the nMDS plot in July than in March; Fig. 5A,B). The same was true of highshore pots at Cremorne Point (Fig. 5B), but not at Careening Cove, where the assemblages became more similar over time.

Comparing the locations directly, assemblages showed greater change over time at Cremorne Point than at Careening Cove, irrespective of height on the shore (Fig. 5C,D). In addition, in both locations, assemblages in large and small pots diverged over time, except for highshore pots at Careening Cove.

DISCUSSION

Overall, the addition of concrete flowerpots to seawalls at 2 locations in Sydney Harbour increased the number of species living at high- and midshore levels compared with the number living on the wall itself. The seawalls on which the experiments were done were some decades old and, because the walls are not regularly cleaned, one can assume that the assemblage was fairly mature. At mid- and highshore levels, the assemblage was composed mostly of crustose algae *Hildenbrandia rubra* and *Ralfsia verucosa*, the barnacle *Chthamalus antennatus*, a few oysters and mussels, with the mobile fauna predominantly limpets. This is a typical assemblage for high- to midshore levels on seawalls in Sydney Harbour (Chapman & Bulleri 2003, Bulleri et al. 2005), although lower on the shore on some walls there is greater diversity of algae and invertebrates, including many calcareous polychaetes, sponges and ascidians. Therefore, these experiments were specifically done at levels on walls where the extant assemblage was minimal.

Unfortunately, for reasons beyond our control, the experiment had to be halted at 7 mo, although previous research on other artificial habitats added to seawalls indicates that trends should persist, as long as

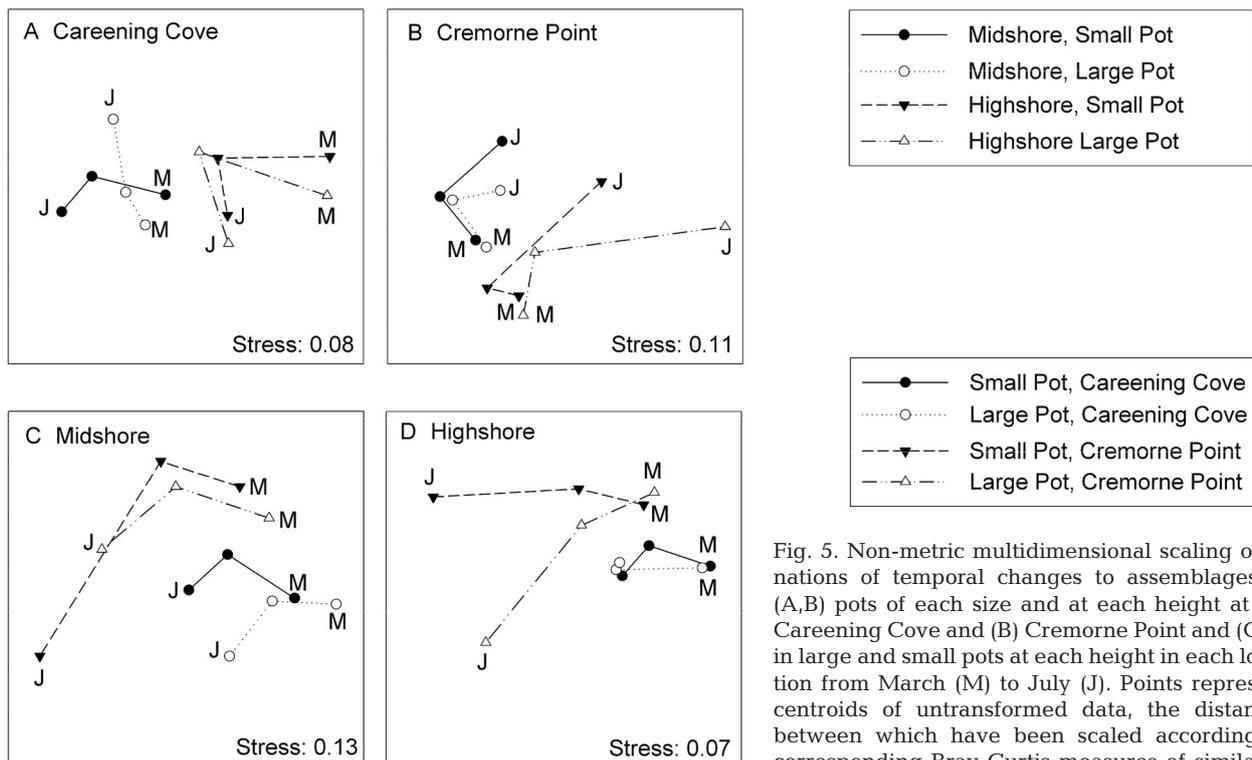


Fig. 5. Non-metric multidimensional scaling ordinations of temporal changes to assemblages in (A,B) pots of each size and at each height at (A) Careening Cove and (B) Cremorne Point and (C,D) in large and small pots at each height in each location from March (M) to July (J). Points represent centroids of untransformed data, the distances between which have been scaled according to corresponding Bray-Curtis measures of similarity

the additional habitats are relatively large, like these flowerpots (Chapman & Blockley 2009). The addition of much smaller cracks, crevices and holes had a limited long-term effect on biodiversity, as they were rapidly completely occupied and, thus, unavailable for slower colonists (Chapman & Underwood 2011). The flowerpots used in this study are comparable in size to small- and medium-sized natural rockpools on nearby shores, which support a diversity of flora and fauna (Underwood & Jernakoff 1984, Astles 1993, Underwood & Skilleter 1996).

Nevertheless, after only 7 mo, there were species of algae, polychaetes, ascidians, crustaceans and starfish in these artificial habitats that were not present in the established assemblage on the seawall at equivalent tidal levels. By comparing our results with those for assemblages in natural rockpools from Chapman & Blockley (2009), we found our midshore pots had species that were in common (e.g. red alga *Corallina officinalis*, brown alga *Endarachne binghamiae*, polychaetes *Hydroides elegans*, limpets *Siphonaria virgulata*), and some which are found in pools elsewhere (authors' pers. obs.), but were not listed in Chapman & Blockley (2009) (e.g. snails *Alaba opiniosa*, crabs *Leptograpsus variegates*). Some species listed by Chapman & Blockley (2009) were not found in the pots (e.g. anemones *Actinia tenebrosa*, sea hares *Aplysia* sp., snails *Nerita atramentosa*). Therefore longer-term work, over many years, is needed to determine whether these species recruit into the pots and also to examine how stable these assemblages are over time. Because of local government requirements, we were unable to clear assemblages from walls. It is therefore likely that differences in the age of the assemblages could also account for some of the differences between the assemblages living on walls and within flowerpots. So further work should (where possible) control for this by clearing organisms from both habitats or by adding plates to both habitats.

Other research has shown that pools that develop on coastal defence structures increase intertidal biodiversity, particularly at midshore levels (Firth et al. 2013) and that engineered habitats, which have some features of natural rockpools, have similar effects (Chapman & Blockley 2009). It is difficult to identify features of natural habitat that may affect diversity, e.g. size, shape and position of the patch of habitat, because features of habitat often vary naturally from place to place. Rockpools are generally of different sizes at different shore heights and on exposed or sheltered shores (Astles 1993). Hence, Underwood &

Skilleter (1996) tested the effects of pool diameter on assemblages in pools of different depths by creating de novo a series of rockpools to meet certain criteria. Similarly, Chapman & Blockley (2009) created replicate artificial habitats at 3 heights on adjacent patches of seawalls to unconfound effects of tidal height and features of habitat. They showed a greater effect on biodiversity higher on the shore and on the sessile, but not the mobile, component of the assemblage.

In this study, flowerpots were used to mimic rockpools more closely (i.e. less shaded and rounder) than the artificial habitats created by Chapman & Blockley (2009), but, again, structures of similar construction were deployed at 2 tidal heights on 2 separate seawalls to test for the effect of height between locations, while keeping features of the habitat consistent. Different assemblages developed in mid- and highshore pots on each shore, but, in contrast to Chapman & Blockley (2009), there was a greater effect on the diversity at midshore than at highshore levels. As on natural rocky shores (Martins et al. 2007), the highshore assemblages were not diverse, although the highshore pots provided habitat for numerous animals and plants that did not live on the wall at either mid- or highshore levels. Midshore pots, however, supported greater diversity and larger abundances or covers of a variety of taxa, including sessile polychaetes, ascidians, molluscs and crustaceans.

The smaller numbers of organisms in highshore pots may have been due to less water replacement during high tide. This may have limited the number of recruits arriving in the habitat and/or produced water that was either too warm or contained too little oxygen during low tide for many organisms to survive (Taylor & Spicer 1991, Rummer et al. 2009). If these physical conditions were important in limiting highshore assemblages, we might expect greater abundances high on the shore in more wave-exposed conditions, as at McMahons Point (Chapman & Blockley 2009), which is exposed to wash from ferry boats. Cremorne Point was slightly more wave exposed than Careening Cove, hence the loss of many of the flowerpots from this location. It also had greater cover of crustose algae, more mobile molluscs and crustaceans than highshore pots at Careening Cove, although the opposite was found for other taxa. Caution is needed in interpretation of the differences between these 2 locations, however, because wave exposure was not a factor in the experiment and there was only one site for each level of exposure.

Unfortunately, due to the loss of many small pots at Cremorne Point, large and small pots could only be compared at both heights at Careening Cove. Assemblages in the pots of different size differed significantly at midshore, but not at highshore, levels, although these differences were small compared with differences between heights on the shore. There was little development of crustose algae within the pots, but larger, deeper pots developed greater cover of opportunistic species of algae than the small pots, which were shallower with a larger base. In contrast, calcareous tubeworms, molluscs and crustaceans were more diverse and more abundant in small pots, although differences were not always significant. The development of assemblages of algae in the pots is important, because many macroalgae are important biogenic habitat on natural shores (Kelaher et al. 2001, Olabarria & Chapman 2001). Whether that was the case in the pots was not examined, because sampling would have destroyed much of the developing algal assemblage; patches of algae on seawalls, however, also support a diverse associated biota (Chapman et al. 2005).

Although a similar suite of species recruited into the pots at the 2 locations, both high- and midshore assemblages in the large pots differed among locations. Highshore assemblages, in particular, differed nearly as much from location to location, as midshore assemblages differed from highshore assemblages at each location. In particular, at Cremorne Point, there was smaller cover of ephemeral algae than at Careening Cove and more cover of crustose algae. There was also less recruitment of sessile animals and more recruitment of mobile animals. Therefore, although these artificial habitats were identical from place to place, local environmental conditions were a major determinant in the developing assemblages. This suggests that deploying these or similar structures on featureless seawalls across a wide range of environmental conditions would enhance intertidal biodiversity, not only at a local scale, but also at a landscape scale, by supporting different assemblages under different environmental conditions.

One aim of deploying the flowerpots was to evaluate their use as habitat for some of the larger species, which are absent from walls (Chapman 2003). Unfortunately, these species did not recruit during the limited period of the experiment and could not move into the pots from the surrounding wall because they do not live on the surrounding wall. Therefore, a few individuals of the sea urchin *Heliocidaris erethrogramma*, the gastropods *Turbo undulatus*, *Nerita atramentosa* and *Scutus antipodes*, the starfish *Pa-*

tiriella calcar and the anemone *Actinia tenebrosa*, all of which live in natural pools on nearby shores, were added to some of the pots, to evaluate whether they could survive. This was not an appropriately designed experiment to fully evaluate the effects of transplanting adult animals into these habitats because of the limited time available (Chapman 1986), but the results may provide some guidance as to whether the pots could provide suitable habitat if these species recruited to them. After 10 d, all *H. erethrogramma* and *P. calcar* had died and the *N. atramentosa* had disappeared, but *T. undulatus*, *S. antipodes* and *A. tenebrosa* survived in the midshore pots at both locations. This suggests that pots at midshore levels are suitable habitats for some, but not all, species that naturally live in rockpools. Further manipulative experiments are urgently needed to identify the relative importance of ecophysiological processes versus the structure of the habitat itself in determining colonization and/or survival of organisms to flowerpots on seawalls, especially higher on the shore. These experiments will now be easier since we have improved the design of the brackets that attach the flowerpots to seawalls (see Chapman & Underwood 2011). The new design has a sturdier frame with a hydrofoil (cone-shaped piece of metal at base) that displaces vertical movements of water around the pots and together with a lip prevents pots from being removed from the walls.

Given that over half of the coastline in parts of Japan, USA, Europe and Australia is composed of artificial shores and that \$US144 billion will be spent each year on building and maintaining seawalls (IPCC 2007), there is a great opportunity for engineers and ecologists to work together to develop and test novel habitats to mitigate against loss of intertidal biodiversity by shoreline armouring. The question remains whether stakeholders and policy makers will recognise this cost-effective opportunity or not.

Acknowledgements. We thank North Sydney Council for access to study locations. A. Luck, B. Panayotakos, C. Myers, M. Day and M. Ellis are thanked for assistance and G. Deavin for photographs. The Centre for Research on Ecological Impacts of Coastal Cities (University of Sydney), ECS Services, Antique Stone and North Sydney Council provided support for this research. During preparation of this manuscript M.A.B was supported as a Post-doctoral Fellow at the National Center for Ecological Analysis and Synthesis, a Center funded by NSF (Grant #EF-0553768), the University of California, Santa Barbara, and the State of California, with additional support from Ocean Conservancy. We also thank A. J. Underwood and external reviewers for improvements to the original draft of this paper.

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Editorial responsibility: Lisandro Benedetti-Cecchi, Pisa, Italy

*Submitted: July 1, 2013; Accepted: October 10, 2013
Proofs received from author(s): January 7, 2014*