Short-term effects of bank-stabilising restoration works on macroinvertebrate and meiofaunal communities in the Kalang estuary, NSW.

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Abstract

Catchment wide disturbances and local land use pressures often result in upper estuaries being a focal point for the degradation of physical habitats, reduced biodiversity and poor water quality. Many environmental restoration projects in estuaries focus on improving the physical structure of estuaries. This often comprises bank stabilisation works to control erosion, in conjunction with stock exclusion and riparian revegetation. The construction of fillets using rock and timber is an increasingly common restoration technique used in estuaries to stabilise banks and promote mangrove growth to reduce wave energy. Restoration success usually focuses on riparian measures such as the reduction of bank erosion and survival of seedlings. However, rock fillets can also improve intertidal habitat for estuarine fauna by reducing fine sediment loads. Rock fillets and rock revetment were installed in the Kalang estuary on the NSW mid north coast in mid-2017. We sampled benthic macroinvertebrate and meiofaunal communities before and after restoration works using a BACI design (Before, After, Control, Impact). Benthic invertebrates were assessed six months before and six months after restoration works and compared with nearby control (actively eroding), reference (mangrove forest), and remnant Swamp Oak Floodplain Forest Endangered Ecological Community (EEC) sites. We found that the macroinvertebrate diversity and meiofaunal abundance significantly increased at the treatment site. This suggests that bank stabilisation structures can significantly improve instream habitats and assessments that focus on riparian variables alone may miss important ecosystem services and biodiversity improvements provided by these structures.

Keywords

Bank restoration; BACRI (before, after, control, reference, intervention) rehabilitation monitoring; macroinvertebrates; meiofauna; estuaries

Introduction

The estuarine environment is a zone of transition where the river and sea meet to create a constant flux of water physico-chemistry, and changing soft sediment habitats. There are approximately 154 large and medium sized estuaries along the NSW coast (www.dpi.nsw.gov.au, 2018). These highly productive environments provide important habitat for aquatic animals and are key areas for important ecological communities such as seagrass beds, mangroves, and salt marshes (Day et al., 2012). These three vegetation communities dominate the provision of organic matter to estuarine food webs. Benthic invertebrates including macroinvertebrates (<1mm in size) and meiofauna (0.063 – 0.5mm in size), play important roles in breaking down the organic matter and facilitating nutrient cycling within estuarine habitats (Coull, 1999).

Estuaries provide many ecosystem services such as the provision of nursery habitat for many commercially and recreationally important fish species (REF), but have been the focus of significant human disturbance, both within their catchments and localized to the coastal zone (Barbier et al, 2011). Restoration methods such as rock revetment and rock-and-timber fillets are commonly used to provide bank stability to areas where the lack of riparian vegetation has led to bank erosion and sediment inputs (Wiecek, 2009). As such, bank restoration measures attempt to reinstate the physical attributes provided by natural riparian vegetation, large woody debris, and stable substrate (Elliot et al., 2016). This paradigm is reflected in the traditional measures of restoration success that concentrate on monitoring revegetation success and the improvement to bank stability. This is partly due to the focus on riparian attributes, and partly due to the common viewpoint in restoration projects that rehabilitation of habitat will lead to the re-establishment of desired biological communities over time (Hildebrand et al. 2005).

The aim of this study was to assess the intertidal benthic invertebrate communities in the Kalang Estuary, NSW, before and after bank restoration works designed to stabilize actively eroding grazing land were completed in 2017. We investigated the response of benthic invertebrate abundance and diversity to two different restoration measures (rock revetment and rock-and-timber fillets) compared to a nearby control and two reference communities: mangrove forest and remnant Swamp Oak Floodplain Forest EEC .

Methods

Site description

Bank stabilization measures were constructed on Newry Island, a small island lying in the lower estuary of the Kalang River upstream of the township of Urunga on the NSW north coast. Agriculture, particularly cattle grazing, and residential properties occupy much of the island. The island's physical characteristics are similar to the banks of the main channel, with large stretches of cleared and eroding banks interspersed with patches of remnant vegetation (Figure 1a, Telfer & Cohen, 2010).

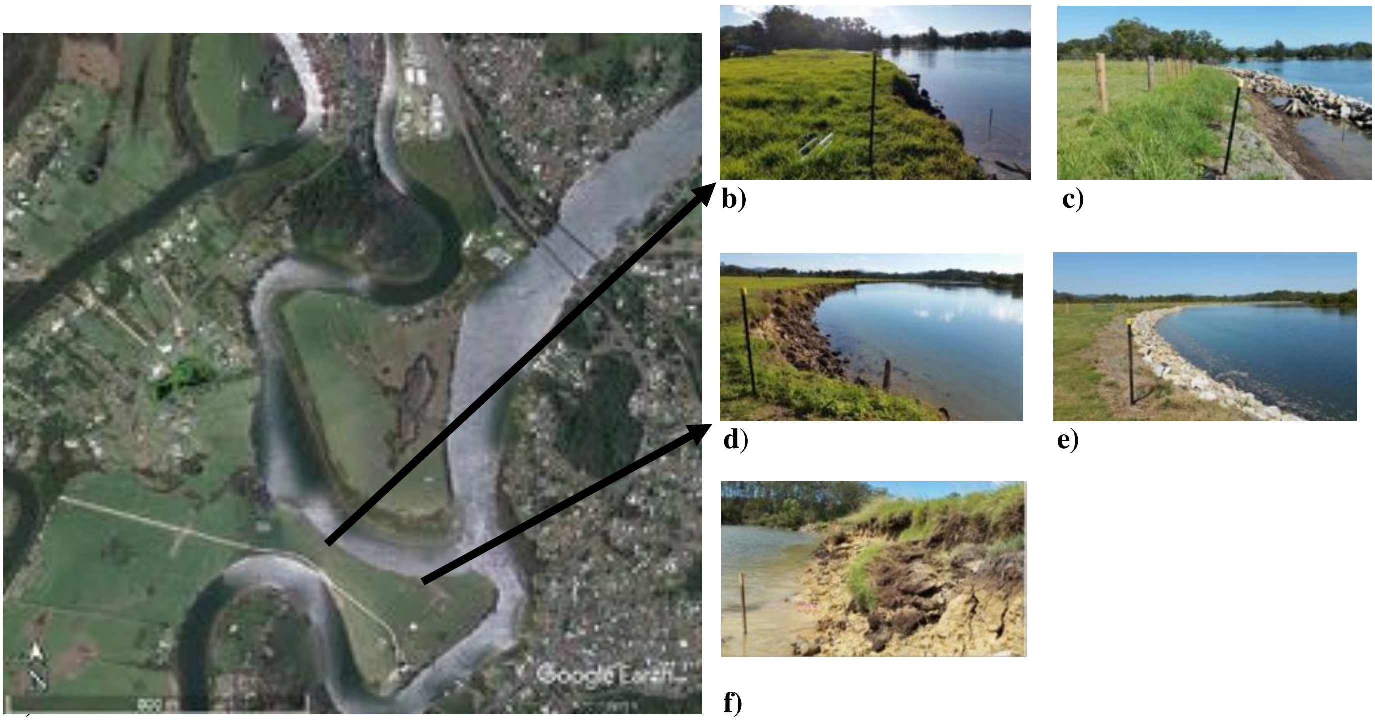


Fig 1. Map showing sampled habitat sites on Newry Island, NSW (a). With pre (b) and post (c) rock fillets treatment, pre (d) and post (e) rock revetment treatment, and control (f).

Restoration works

The restoration works comprised 250m of rock revetment (Figure 1b) and 320m of rock-and-timber fillets (Figure 1c), with the riparian zone fenced and planted with native vegetation. Baseline assessments of benthic macroinvertebrate and meiofaunal communities were completed in March 2017, approximately six months before the commencement of restoration works. Post-restoration assessments of benthic macroinvertebrate and meiofaunal communities were completed almost a year later in February 2018, approximately six months after the completion of the works.

Sampling and analysis were conducted following a BACRI design (Before, After, Control, Reference, Intervention) with pre-and post-Treatment sites compared with Control (actively eroding), Reference (mangrove forest), and remnant EEC (Swamp Oak Floodplain Forest) sites. The decision to include rock revetment as well as the rock-and-timber fillets at the treatment site was made during construction. Hence, the pre-restoration assessment did not differentiate between the two treatments, while the post-restoration assessment distinguishes between the two. Additionally, the decision was made during the construction phase to fence the EEC to exclude cattle and remove weeds. On both occasions, the available habitat was randomly sampled, which led to different numbers of replicates of macroinvertebrate samples. Macroinvertebrates could not be sampled by quadrats in the rock revetment as the entire intertidal soft sediments were covered by rocks. The numbers of replicates for macroinvertebrate and meiofauna collected at each habitat pre-and post-restoration are included in Table 1.

Table 1. Numbers of replicates in each habitat before and after restoration works.

Habitat	Macroinvertebrate (n)	Meiofauna (n)
Pre		
EEC	2	10
Control	4	10
Reference	9	10
Treatment	8	10
Post		
EEC	2	10
Control	3	10
Reference	3	10
Fillets Treatment	3	10
Revetment Treatment	0	10

Macroinvertebrates were sampled at random points in the intertidal zone of each habitat type using a quadrat 0.5m x 0.4m x 0.3m (surface area of 0.94 m^2). The sediment was placed in a 1mm sieve and then wet-sieved in situ with all retained material was immediately preserved in 70% ethanol solution.

Benthic meiofauna was collected at ten randomly-located points in the intertidal zone of each habitat type using a sediment corer 3cm in diameter, 5cm deep, with a sediment volume of 61cm^3. This material was immediately preserved in a solution of 70% ethanol and Rose Bengal dye.

Macroinvertebrates were separated from retained material in the lab and identified under a dissecting stereomicroscope to genera where possible. Benthic meiofauna samples were washed through nested sieves to 125μm. Retained material was washed into a beaker and made up to 120ml with water, which was subsampled to 30ml in a Bogarov tray and individuals were identified under a dissecting stereomicroscope to order.

Data analysis

For each habitat, richness and abundance were calculated for pre- and post-restoration works. A two-way analysis of variance (ANOVA) with Time and Habitat as the main effects was used to assess diversity and abundance using R (www.r-project.org). Data were checked for normality using the Shapiro-Wilk test, and homogeneity of variances using Levene's test. Where necessary, a Log (x+1) transformation was applied to ensure normality. Macroinvertebrate and meiofaunal community composition were analysed using the multivariate analysis package PRIMER V6 (PRIMER-6, Plymouth Marine Laboratory, Plymouth, U.K. Clarke & Warwick, 2001). In PRIMER, non-metric multi-dimensional scaling (nMDS) ordination plots were used to graphically represent differences in communities over time and among habitats. A two-way analysis of similarities (ANOSIM) with Time and Habitat as the main effects was used to assess changes in community composition after restoration and among habitats. A Similarity Percentage-Species Contribution (SIMPER) analysis (Plymouth Marine Laboratory) was used to determine which taxa contributed most to differences among Times and Habitats.

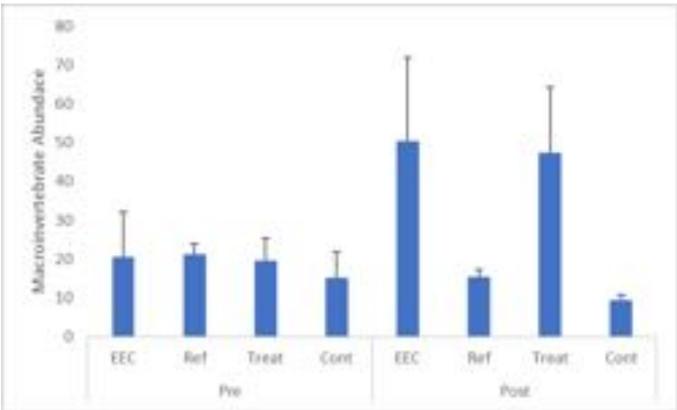
Results and Discussion

Abundance and richness

Estuarine restoration methods such as rock revetment, and rock and timber fillets were installed to provide bank stability to areas where a loss of riparian vegetation had led to bank erosion and sediment inputs. As such, bank restoration works were intended to reinstate the physical attributes provided by natural riparian vegetation, woody debris, and stable substrate. This study tested whether these bank stabilization structures also improved the richness and abundance of benthic macroinvertebrates and meiofauna.

Before restoration, a total of 448 macroinvertebrates belonging to 22 taxa were found across all study sites. Overall, there were lower abundances and richness following restoration, with a total of 315 individuals belonging to 19 taxa across all study sites. Macroinvertebrate data were not normally distributed and a log(x+1) transformation normalised the data. A two-way ANOVA suggested that macroinvertebrate abundance did not significantly change over Time or among the four Habitats (Figure 2a), and this was likely driven by the increased variability in macroinvertebrate abundances in the EEC and Treatment sites after restoration. In contrast, macroinvertebrate richness significantly increased in all habitats after restoration ($F_{1,3} = 5.460$, $p = 0.027$, Figure 2b).

A.



B.

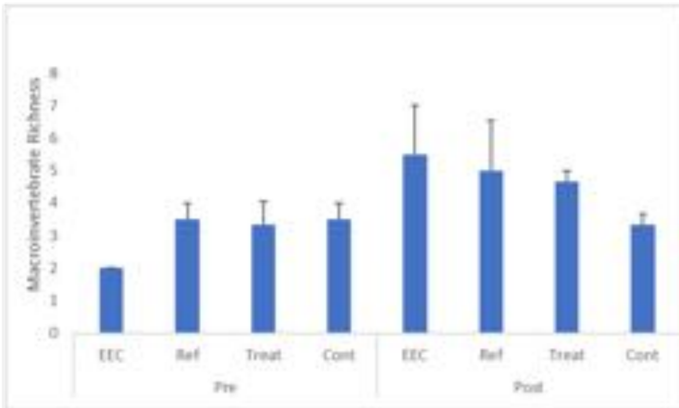


Fig 2. Mean macroinvertebrate abundance (a) and richness (b) sampled at the habitats pre-and post-restoration.

Meiofauna were significantly more abundant and diverse: a total of 4611 individuals representing 28 taxa were sampled across all habitats prior to restoration and 3529 individuals and 30 taxa across all habitats after restoration. Abundance decreased post restoration ($F_{1,81} = 27.695$, $p < 0.001$), although decreases were not consistent across habitats ($F_{4,81} = 3.816$, $p = 0.007$, Figure 3a). In contrast, meiofaunal richness increased over time ($F_{1,81} = 442.577$, $p < 0.001$), specifically in the rock revetment and rock fillet habitats ($F_{4,81} = 208.186$, $p < 0.001$). There were no significant changes in meiofaunal richness in the EEC, mangrove Reference or Control sites (Figure 3b).

A. **B.**

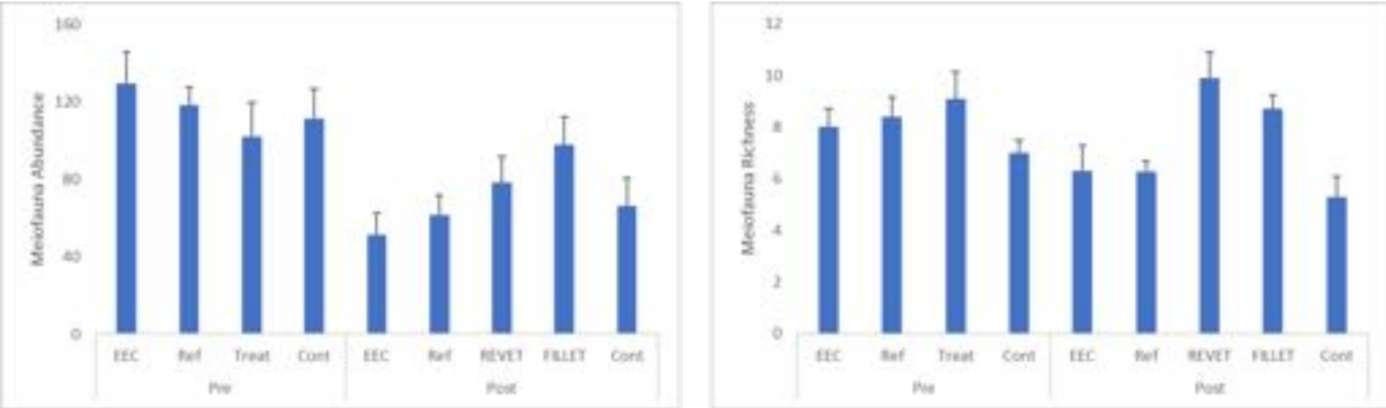


Fig 3. Mean meiofauna abundance (a) and richness (b) sampled at the habitats pre-and post-restoration.

Community composition

The composition of the macroinvertebrate community significantly differed after restoration (Figure 4a, Global $R = 0.246$, $P = 0.021$), as well as among habitat groups (Figure 4b, Global $R = 0.224$, $P = 0.007$). Pairwise comparisons revealed the difference between the Treatment and Reference communities ($p = 0.001$) were the main driver of differences among Habitats.

A. **B.**

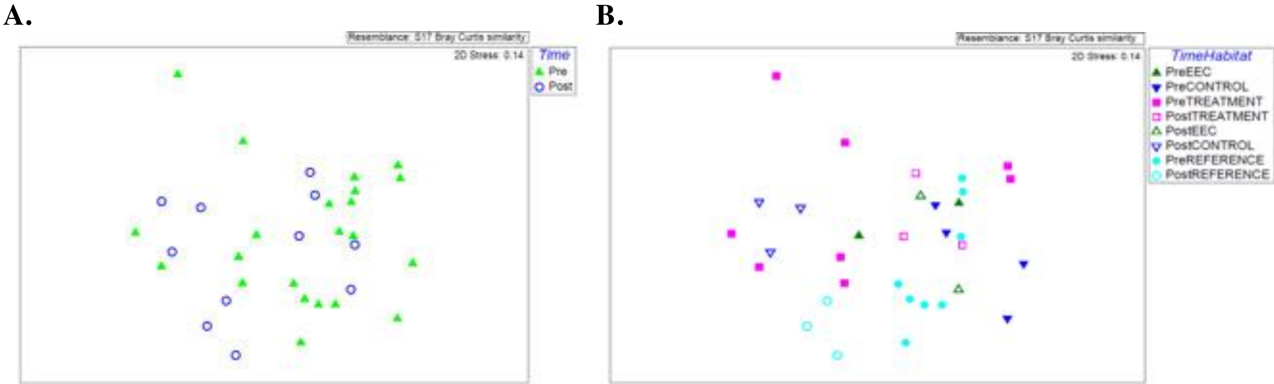


Fig 4 Multi-dimensional scaling ordination plot of macroinvertebrate community composition pre and post restoration (a), and between habitats over time (b)

Simper analysis revealed Brachyuran crabs *Mictyris* (Mictyridae) and *Uca* (Ocipodidae) contributed highest to community composition before and after restoration at 32.63% and 19.66% of the community respectively. *Uca* dominated pre-restoration communities across all habitats (44.26%), while *Helice leachii* (Grapsidae) contributed 26.25% of the post-restoration community across all habitats. *Mictyris* was the second highest contributor to differences in pre- and post-restoration macroinvertebrate communities. *Uca* contributed most to the composition of both the EEC and the Reference communities with 52.84% and 56.98% respectively, and was under represented in the Treatment and Control communities at 7.69% and 18.13%, respectively. While *Uca* increased at the Rock-and-timber fillets, it decreased at the Control site post-restoration works.

The community composition of benthic meiofauna significantly changed with Time (Figure 5a, Global $R = 0.324$, $P = 0.001$) and among Habitats (Figure 5b, Global $R = 0.066$, $P = 0.012$). A SIMPER analysis revealed that Nematodes dominated the meiofaunal communities at all habitats over the study period.

A. **B.**

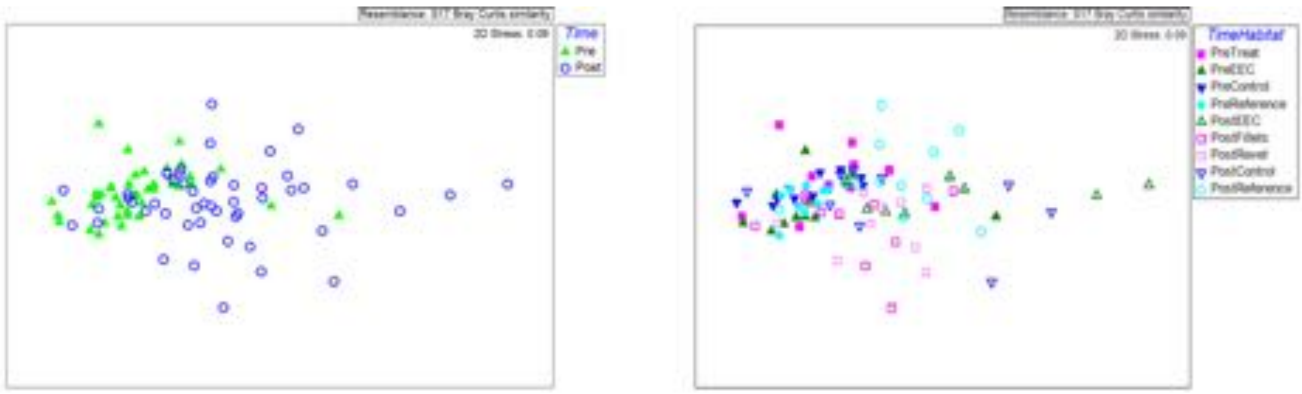


Fig 5 Multi-dimensional scaling ordination plot of meiofauna community composition pre and post restoration (a), and between habitats over time (b)

Overall, our results revealed that bank stabilization works can also increase abundance and richness of benthic invertebrate communities in adjacent soft sediment habitats, but monitoring may need to occur over longer timescales than ours. Macroinvertebrate richness increased with the installation of Rock-and-timber fillets. The SIMPER analysis suggests the macroinvertebrate community assemblage at the treatment site more closely resembled the Mangrove Forest Reference and EEC communities with an increased proportion of Ocypodid fiddler crabs (*Uca*). This genus is known to favour rich mud and sand areas of the intertidal zone in close proximity to mangroves and other vegetation (Crane, 2015). Brachyuran crabs of the families Ocypodidae and Grapsidae are important nutrient recyclers in mangrove forests (Poore, 2004) and both were well represented in the study sites. In the meiofauna, free-living nematodes play a significant role in breaking down organic matter and increasing nutrient regeneration in estuarine soft sediment habitats (Platt, & Warwick, 1980). It is also possible that the increase of benthic macroinvertebrate abundances observed at the EEC site in the sampling period post restoration was due to the construction of stock exclusion fencing above the riparian zone reducing the trampling effects of stock access. The reduction in meiofaunal abundance post restoration may be related to side-effects of chemical weed removal: longer post-restoration monitoring would be valuable in assessing the longevity of any restoration-related disturbances.

Benthic invertebrates are key to the ecological function of estuarine environments (Escapa et al, 2008), and previous studies have highlighted that bank instability can have deleterious effects on benthic invertebrates (Probert, 1984). Recovery of these communities following disturbance or restoration measures can be variable (Veríssimo et al., 2012a) and depends on the scale of degradation, restoration measures, and the biological resilience of the community (Veríssimo et al., 2012b). However, if restoration measures restore the physical structure of the environment, this may help promote the succession of ecologically important communities and in turn provide further measures of restoration success.

Conclusions

This study suggests that bank restoration in the Kalang river estuary may have had positive effects on benthic invertebrate communities. Benthic invertebrates are inherently patchy and further monitoring over a longer time scale post-restoration is needed to identify whether invertebrate communities in the restored sites become more similar to the reference sites.

Invertebrates are effective biological indicators of river health in freshwater systems and are used systematically worldwide. Continued developments towards using invertebrates as indicators of estuarine condition could prove to be valuable in measuring post restoration success in the future.

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