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Spatio-temporal changes of marine macrobenthic community in sub-tropical waters upon recovery from eutrophication. I. Sediment quality and community structure

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Abstract

A two-year study was conducted in the vicinity of a harbour in sub-tropical Hong Kong, to examine the progress of improvement in sediment quality and recovery of macrobenthic community upon cessation of organic pollution caused by sewage discharge. Median sediment particle diameter (Mdϕ) and levels of total organic carbon (TOC), total Kjeldahl nitrogen (TKN), ammonia–nitrogen (NH_3–N) and total phosphorus (TP), as well as macrobenthic species composition and abundance were determined bi-monthly at three inside-harbour and two outside-harbour locations. At the two inside-harbour locations, significantly higher levels of TOC, TKN, NH_3–N and TP in sediments were observed than the outside-harbour locations. However, no significant temporal change of nutrient levels was detected at all sampling locations during the two-year study, except a significant decrease in TKN and NH_3–N levels at one outside-harbour location and a decline in NH_3–N content at another outside-harbour location. Spatially, the highest in mean total species number, individual number, species diversity H' and lowest evenness J was found at one outside-harbour location, whereas the other four locations had relatively similar values. H' was negatively correlated with TOC, TKN, NH_3–N and TP content in sediments while J was positively correlated with MDϕ. Across the study period, the patterns of macrobenthic community were significantly different among all samplings and that the spatial difference of benthic community was best correlated with MDϕ, TOC, TKN and water depth. A weak sign of recovery in macrobenthic community structure was detected at inside-harbour locations, with replacement of opportunistic by ubiquitous species over the two-year study. The slow recovery of macrobenthic community was related to sediment characteristics. Results of a larval settlement bioassay using the polychaete *Capitella* sp. I also demonstrated that the inside-harbour sediments were still unfavourable for colonization and larval settlement of species sensitive to pollution. The slow biodegradation of the organic pollutants and continuous presence of heavy metals in the sediment may hinder settlement and colonization of benthic animals. However, increases of H' and J were observed in a longer time scale when comparing the present data with those obtained four years ago. This suggested that a detectable recovery of benthic community in the harbour may take at least three years and a complete recovery may even take longer duration.

Keywords: Macrobenthos; Sediment quality; Community structure; Recovery; Eutrophication

1. Introduction

The effects of eutrophication on the structure of benthic communities are well known, as exemplified by the Pearson–Rosenberg (P–R) model (Pearson and Rosenberg, 1978). This model is shown acceptable for coastal waters worldwide due to its frequent citations in the literature (Gray et al., 2002). Along a gradient from ‘low organic input’ to ‘high organic input’, the macrobenthic community undergoes several successional stages: from normal community structure with diverse fauna, transitional

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community composition with increase in opportunistic species, peak in arrival of opportunistic animals, and eventually to azoic sediment void of macrobenthos. However, the reverse of eutrophication, i.e., the recovery of a degraded benthic community from cessation of organic enrichment, is poorly documented (Macleod et al., 2004; Sanz-Lázaro and Marin, 2006).

There is no definite criterion to decide if an impacted macrobenthic community has recovered completely (Karakassis et al., 1999). It is logical to assume that the recovery of impacted macrobenthic community retraces the successional stages as described in the P–R model. Hence, the azoic sediment is first colonized by few opportunistic species in large abundance, which is regarded as a 'pioneer community'. The 'pioneer community' undergoes serial successions of 'intermediate community' and reaches a final point of 'climax community' (Rosenberg et al., 2002). It has been shown that the community at a control site, where is relatively free of pollution, is commonly regarded as the climax status of a benthic community recovering from cessation of eutrophication (Karakassis et al., 1999). For example, in Saltkällefjord on the west coast of Sweden, the pattern of benthic recovery was well demonstrated to fit the PR-model. The azoic sediment was colonized by a group of opportunistic infauna two-years after termination of sewage discharge from a sulphite pulp mill. Then the succession of macrobenthic community became indistinguishable from natural annual fluctuations after six years, in which the species composition was similar to the original macrobenthic community 40 years ago (Rosenberg, 1972, 1976).

The succession of 'intermediate community' is unpredictable during the recovery process as shown by Rosenberg et al. (2002) and the rate of development of succession to a 'climax community' is often influenced by secondary disturbances (Sanz-Lázaro and Marin, 2006). For example, in Cephalonia Bay, Greece where maricultural activities ceased for 23 months, the locations beneath the previous cages were still colonized by opportunistic fauna while the locations 10 m away from the cage had shown clear succession with community structure similar to the control locations far away from the culture area. The succession was, however, affected by benthic algal bloom, which was triggered by seasonal release of phosphate from the sediment (Karakassis et al., 1999). In Valli di Comacchio, northern Adriatic Sea, Italy where sewage discharge had been stopped for 11 years, the macrobenthic community had not recovered completely at the impacted area. This was due to limited water circulation, rapid fluctuations of salinity and temperature, and releases of toxic substances from the sediment (Munari et al., 2003). In Western Mediterranean, Spain where sea fish farming ceased, the pattern of recovery differed among the four sampling stations due to its unique environmental parameters on topography, hydrodynamic conditions, water turbidity and water exchange patterns (Sanz-Lázaro and Marin, 2006). While attempts on describing the pattern of benthic recovery have been reported, all these studies were confined to temperate waters. Very limited information on the recovery of macrobenthic community from abatement of organic pollution is available in tropical or sub-topical waters (Lu and Wu, 1998), where the climate and hydrographical conditions are markedly different. One important point noted is that from existing literature (Karakassis et al., 1999; Lardicci et al., 2001; Munari et al., 2003; Macleod et al., 2004; Brooks et al., 2004), the recovery of benthic communities from pollution abatement would take more than two-years to even more than 11 years in temperate waters. Recent experimental studies, however, suggested that such recovery of benthic communities can be much faster in tropical and sub-tropical waters (Lu and Wu, 1998) due to warmer temperature, higher turnover rate and more larval supply.

The present study aimed to examine the recovery of sediment quality and marine macrobenthic community in subtropical Hong Kong in spatio-temporal scale where water quality is recovering from eutrophication resulting from the implementation of a large-scale sewage treatment project. In addition to investigating community structure, a bioassay of larval settlement of polychaete *Capitella* sp. I was conducted to test on the suitability of sediment quality for colonization of benthic infauna.

2. Materials and methods

2.1. Study site

The study site was located in Victoria Harbour, Hong Kong (22°20′N; 114°21′E). By 2001, the Victoria Harbour had received some 1.7 million tonnes of partially screened sewage everyday from three million people. Despite strong tidal movement, the water quality within the harbour area was characterized by high loadings of nutrients and suspended solids, and low levels in dissolved oxygen (DO) (Yung et al., 1999; EPD, 2007). The sediments suffered from serious organic enrichment that total organic matter increased from 2% to 4% in 1977 (Shin and Thompson, 1982) to 3.6–7.5% in 2001 (Shin et al., 2004). The sediments were also contaminated with heavy metals (Wong et al., 1995; Tanner et al., 2000; Zhou et al., 2007a,b) and trace organics (Hong et al., 1995).

Since 2001, sewage discharge to the centre of the harbour has been substantially abated, with over 1.4 million tonnes of the sewage being centrally collected and treated, and discharged at the western end of the harbour via a submarine outfall (Fig. 1). The treatment can achieve reductions of 70% organic matter in terms of 5-day biochemical oxygen demand (BOD_5) and 80% suspended solids (EPD, 2007). After the implementation of this large-scale sewage treatment project, the water quality has improved significantly. In comparison of mean water qualities between year 2001 and 2002 and year 2002–2005, the DO increased by 10% in the main channel of the harbour. The ammonia, inorganic nitrogen and