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Application of biological traits to further our understanding of the impacts of dredged material disposal on benthic assemblages

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ABSTRACT

While the effects of coastal disposal of dredged material on benthic assemblage structure have been well studied, our understanding of the mechanism of such responses, and their potential ecological implications, remain relatively unknown. Data from a licenced disposal site off the northeast coast of England are analysed to address this and improve our ability to make informed licencing decisions for this activity. Assemblages within the disposal site displayed reduced number of species and total invertebrate density, an altered assemblage taxonomic structure, and a shift towards a greater numerical dominance of less-productive individuals. Following separate analyses of biological response and effect traits, a novel approach for marine benthic trait analysis, we identify the traits responsible (i.e. response traits) for the observed structural alterations. Furthermore, analysis of the effect traits revealed that the assemblages characterising the disposal site possess a greater bioturbative capability compared to those not directly impacted by disposal.

1. Introduction

Studies quantifying the impacts of coastal disposal of dredged material on the invertebrate assemblages of the seabed (i.e., the 'benthos') are well documented (e.g., Van Dolah et al., 1984; Diaz, 1994; Flemer et al., 1997; Valente et al., 1999; Smith and Rule, 2001; Bolam and Rees, 2003; Bolam et al., 2006, 2011; Ware et al., 2010). In general, disposal often results in benthic assemblages exhibiting an altered taxonomic composition with a reduced number of species and diversity. Nevertheless, exceptions to this rule are observed as the actual response is ultimately governed by a number of factors including the amount, nature and frequency of disposal and the nature of the receiving environment (Bolam et al., 2006). One notable feature of these studies is the focus on structural attributes (e.g., taxonomic composition, number of species, diversity) of the benthos (although see Wilber and Clarke, 1998; Bolam et al., 2011 for exceptions); scientists are, however, increasingly being tasked with quantifying impacts on the functioning (e.g. productivity, transfer of energy, nutrient regulation) of benthic assemblages as opposed to their structural features. It has been observed that, following both natural and anthropogenic stressors, functional impacts and functional recovery trajectories of benthic assemblages are not always matched by their structural counterparts (Cooper et al., 2008; Grilo et al., 2011; Wan Hussin et al., 2012; Bolam, 2012). Thus, while we have some predictive capability regarding the impacts of dredged material disposal on assemblage structure, we have a comparatively limited knowledge of its functional consequences. Improvements regarding the latter would, undoubtedly, result in an enhanced ability to manage disposal activity in a manner which both further minimises impacts to ecosystem function (Nairn et al., 2004; Bolam, 2012, 2014) and aids compliance with contemporary policy drivers such as the Marine Strategy Framework Directive (CEC, 2008) which requires implicitly an understanding of both how function varies spatially and how it responds to anthropogenic perturbations.

Addressing this alternative focus, i.e., that of functional impacts, has been made somewhat more achievable through the timely development and increased application of biological trait analysis (BTA) to marine benthic data assemblages (Bremner et al., 2003; Bremner, 2008; Paganelli et al., 2012; Van Der Linden et al., 2012). BTA is a method proposed for describing ecological functioning (Dolédec and Statzner, 1994; Verberk et al., 2015) and uses a series of life history, morphological and behavioural characteristics of the species present in assemblages as a proxy of their ecological functioning. This approach, therefore, looks beyond the mere identity of taxa of the communities and focuses more on their contribution to ecosystem functioning. Furthermore, since shared biological traits may be exhibited by taxonomically-distinct organisms (Usseglio-Polatera et al., 2000) this approach may be applied to different taxonomic groups, thus reducing artificial separation in the dataset (Dolédec and Statzner, 1994), and over large geographical extents where inherent species composition gradients make traditional species-based methods problematic (Statzner et al., 2001; Verberk et al., 2015).

A number of studies have applied BTA to assess the impacts of a number of disturbance types on the seabed, notably that related to

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demersal trawling (e.g. Bremner et al., 2003; Tillin et al., 2006; Frid, 2011; de Juan and Demestre, 2012) and other pressures (Papageorgiou et al., 2009; Cesar and Frid, 2009; Oug et al., 2012; Wan Hussin et al., 2012). However, such studies have rarely considered the importance of the distinction between the two different classes of biological traits: *effect traits* and *response traits* (Hooper et al., 2005; Petchey et al., 2009), a concept that has been shown to be of fundamental importance to the application of BTA in the terrestrial realm (Diaz and Cabido, 1997). *Effect traits* affect ecosystem properties, e.g. increased mobility within the benthos will facilitate oxygen penetration through bioturbation and bio-irrigation, while *response traits* affect a species' response to a change in the physical environment, e.g. deep-burrowing species are less likely to be affected by a disturbance at the sediment–water interface (Lavorel and Garnier, 2002). Violle et al. (2007) highlighted that although there has been wide confusion in the use of these terms, an understanding of their distinction is of utmost importance as response traits may vary independently from effect traits. Inferences regarding the ecosystem functioning based on an observed alteration in assemblage trait composition may only be unequivocally undertaken when response and effect traits are partitioned.

This study specifically aims to assess the impacts of dredged material disposal on both benthic invertebrate assemblage structure and function at a licenced disposal site (North Tyne) off the northeast coast of England. We compare the nature and magnitude of the impacts on structure with those on function using estimates of total secondary production and assemblage trait composition. Furthermore, by attempting to differentiate between response traits and effect traits, we use BTA to understand both the mechanism and the potential functional significance of any structural change respectively. Ultimately, this study aims to advance our understanding of the impacts of dredged material disposal on the seabed to aid the licence decision-making process for the relevant authorities.

2. Methods

2.1. North Tyne licenced dredged material disposal site

The North Tyne dredged material disposal site (hereafter 'NT') covers 2.66 km^2 of seabed approximately 5.7 km off the Northumberland coast (Fig. 1) and receives 8.6–867.5 thousand tonnes of dredged material annually, from both capital projects and maintenance dredging (Fig. 2). NT is regarded as a dispersive site, and disposed material is transported by the residual tidal currents along a north-northwest to south-southeast trajectory (Fig. 1). Monitoring conducted by Cefas, on behalf of the licencing authority (currently the Marine Management Organisation), at NT and a number of other sites around the coast of England, has repeatedly demonstrated that biological alterations result from the physical changes at the seabed, as opposed to those due to trace contaminants associated with the disposed sediments (Bolam et al., 2006). This reflects, to some extent, the successful screening of material based on its known chemical loading prior to disposal.

2.2. Survey design and sample processing

The impacts associated with disposal at NT are monitored using data provided by time-series sampling (data from 2008, 2009, 2010 and 2013 are included in this present study) at seven monitoring stations; two stations from within NT ('Disposal'), two stations from within the near field potential impact zone ('NF') (i.e., outside of the licenced area yet within one tidal excursion), and three reference stations ('Reference'), (Fig. 2). Despite its proximity to the licenced disposal area, Station NT8 is classified as a Reference station as it is unlikely to be affected by disposal due to the direction of the prevalent tidal regime and the preferential use of the west of the disposal site by licence holders (Bolam et al., 2011, 2015).

Sediment samples were collected according to national guidelines and best practices on board of the RV *Cefas Endeavour* using a 0.1 m^2 Day grab (Ware and Kenny, 2011; Worsfold et al., 2010). Up to four replicate samples were collected from each station. However, three replicates samples was the most acquired during the 2013 survey and single samples were collected from NT2 and NT6 in 2008 and 2009 respectively. Sediment sub-samples (circa 50 ml^3) were taken from each replicate grab sample for particle size distribution analysis (PSA hereafter). The remaining sediment was sieved to retain all attached fauna and macrobenthic invertebrates greater than 1 mm and preserved in buffered 4% formaldehyde. Samples were processed according to national quality assurance standards for determining particle size distribution and benthic invertebrate community (Worsfold et al., 2010; Mason, 2011). Sediment sub-samples for PSA were classified into 0.5 phi bins using both wet sieving and laser granulometry techniques (Blott and Pye, 2001; Mason, 2011). All macrofauna retained on a 1 mm mesh were identified to the lowest possible taxon (78% to species; 13% to genus), enumerated and weighed as blotted wet weight (Worsfold et al., 2010).

2.3. Data analysis

2.3.1. Macrofaunal assemblages

2.3.1.1. Assemblage structure. The number of species (S) and their abundance (N) were recorded for all replicate samples collected over the course of the four survey years to allow more representative values for each particular station.

To prevent any bias regarding the estimation of multivariate structure due to inconsistencies in the level of replication (e.g., presence of rarer species), a single replicate from each station per year was randomly selected for multivariate analyses. Following the removal of biota not considered to constitute invertebrate macrofauna (e.g. algae, vertebrates), the abundance and biomass matrices were truncated to eliminate taxonomic inconsistencies between years.

Analysis of Similarities (ANOSIM) was performed on the square root transformed Bray-Curtis resemblance abundance matrix to generate a test statistic, *R* which ranges from 0 to 1. Values approaching 1 indicate dissimilar benthic assemblages while 0 indicate similarity between groups (Clarke and Green, 1988). Permutation tests with random group allocation generate probability values with which to determine the significance of the test statistic (Fisher, 1935). Non-parametric multi-dimensional scaling (nMDS) ordination was performed on transformed resemblance matrices to show the degree of similarity between stations (classified into disposal regimes) and among survey years (Clarke and Green, 1988).

2.3.1.2. Assemblage function

2.3.1.2.1. Secondary production estimates. Secondary production estimates (kJ m^2 y^{-1}) were derived in a stepwise approach from the raw abundance and biomass data following the methods described by Bolam et al. (2011, 2014) and Bolam (2012). Firstly, the biomass data were converted to energy values using published conversion factors. Energy values were then converted to production values using a spreadsheet freely available on the Internet http://www.thomasbrey.de/science/virtualhandbook/navlog/index.html (Brey, 2001). This method unifies habitat and taxonomic information which affect productivity of individuals from their size and biomass into a multiple regression model estimating annual production of macrobenthos. The Brey model was found to be one of the most reliable and robust models available during a critical appraisal of such methods (Cusson and Bourget, 2005; Dolbeth et al., 2005). However, one should remember that while these indirect methods have obvious applicability to ecological studies, the estimates obtained are not as accurate as those values obtained using more involved, direct methods of secondary production measurement. Additionally, as the biomass data used here are those