**Title**

Response of a marine benthic invertebrate community and biotic indices to organic enrichment from sewage disposal

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**Supporting Information**

**Table S1** Details of sample points at Ironotter Point

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Station** | **Distance from discharge (m)** | **Depth (m)** | **Number of replicates in each year** | | | |
| **1989** | **1992** | **1995** | **1998** |
| **A1** | 100 | 23 | 3 | 3 | 3 | 3 |
| **A2** | 500 | 30 | 3 | 3 | 3 | 2 |
| **A3** | 750 | 30 | 3 | 3 | 3 | 2 |
| **A4** | 1000 | - | 0 | 0 | 3 | 0 |
| **B1** | 100 | 23 | 2 | 3 | 3 | 0 |
| **B2** | 500 | - | 0 | 0 | 3 | 0 |
| **B3** | 750 | 28 | 3 | 3 | 3 | 0 |
| **B4** | 1000 | - | 0 | 0 | 3 | 0 |
| **C1** | 100 | 20 | 3 | 3 | 3 | 0 |
| **C2** | 500 | 20 | 3 | 3 | 3 | 0 |
| **C3** | 750 | 25 | 3 | 3 | 3 | 0 |
| **D1** | 100 | 18 | 3 | 3 | 3 | 0 |
| **D2** | 500 | 18 | 2 | 3 | 3 | 0 |
| **D3** | 750 | 10 | 3 | 3 | 3 | 0 |
| **E1** | 100 | 20 | 3 | 3 | 3 | 3 |
| **E2** | 500 | 26 | 3 | 3 | 3 | 2 |
| **E3** | 750 | 20 | 3 | 3 | 3 | 2 |
| **E4** | 1000 | - | 0 | 3 | 0 | 0 |
| **F1** | 100 | 20 | 3 | 3 | 3 | 0 |
| **F2** | 500 | 28 | 3 | 3 | 3 | 0 |
| **F3** | 750 | 31 | 3 | 3 | 3 | 0 |
| **G1** | 100 | 22 | 3 | 3 | 3 | 0 |
| **G2** | 500 | 28 | 3 | 3 | 3 | 0 |
| **G3** | 750 | 30 | 3 | 3 | 3 | 0 |
| **G4** | 1000 | - | 0 | 0 | 3 | 0 |
| **H1** | 100 | 20 | 3 | 3 | 3 | 0 |
| **H2** | 500 | 24 | 3 | 3 | 3 | 0 |
| **H3** | 750 | - | 0 | 3 | 0 | 0 |

Notes on sampling

* The team of taxonomists did not change over the course of the surveys and had a common leader throughout, therefore bias in species identification by different taxonomists is assumed not be a factor in this study.
* The change in sampling regime in 1998 was due to a change in priorities and distribution of funding at this time, resulting in a minimal survey.

**Testing for effects of autospatial correlation**

Alternative models were fit to the data with and without an exponential spatial error term based on sample site coordinates using the ‘gls’ function within the ‘nlme’ package (Pinheiro et al. 2019) in R. A likelihood ratio test indicated that there was no significant difference between the fit of the two models (Likelihood ratio = 3.20 x10-8, p=0.9999). Alternative forms of the spatial error function (linear and spherical) did not affect the outcome.

A summary of the outcome of the two models is shown below.

**Non-spatial model**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Organic Carbon** | | |
| **df** | **F** | **p** |
| **Distance** | 8 | 2.56 | **0.023** |
| **Year** | 1 | 133.25 | **<0.0001** |
| **Transect** | 14 | 0.76 | 0.701 |
| **Distance\*Year** | 1 | 12.83 | **0.0009** |
| **Distance\*Transect** | 7 | 0.25 | 0.969 |
| **Year\*Transect** | 7 | 0.45 | 0.862 |
| **Distance\*Year\*Transect** | 7 | 0.12 | 0.996 |

**Exponential Spatial Error model**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Organic Carbon** | | |
| **df** | **Chi-squared** | **p** |
| **Distance** | 8 | 20.49 | **<0.001** |
| **Year** | 1 | 133.25 | **<0.0001** |
| **Transect** | 14 | 10.67 | 0.712 |
| **Distance\*Year** | 1 | 12.83 | **<0.0001** |
| **Distance\*Transect** | 7 | 1.75 | 0.972 |
| **Year\*Transect** | 7 | 3.16 | 0.869 |
| **Distance\*Year\*Transect** | 7 | 0.86 | 0.996 |

Reference:

Pinheiro J, Bates D, DebRoy S, Sarkar D, R Core Team (2019). \_nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-140, <URL: https://CRAN.R-project.org/package=nlme>.

**Details of indices used in this assessment**

**Table S2** Assigned quality classifications according to index values for some commonly used indices

|  |  |  |
| --- | --- | --- |
| Index | Boundaries | Quality |
| AMBI (Borja, 2004) | AMBI≤1.2  1.2<AMBI≤3.3  3.3<AMBI≤4.3  4.3<AMBI≤5.5  AMBI>5.5 | High  Good  Moderate  Poor  Bad |
| BOPA (Dauvin and Ruellet, 2007) | 0.00000 ≤BOPA≤0.04576  0.04576<BOPA≤0.13966  0.13966<BOPA≤0.19382  0.19382<BOPA≤0.26761  0.26761<BOPA≤0.30103 | High  Good  Moderate  Poor  Bad |
| ITI (Word, 1979) | ≥80-100  ≥60-80  ≥30-60  0-30 | Reference conditions  Normal conditions  Changed conditions  Degraded conditions |
| IQI  (WFD-UKTAG, 2008) | ≥0.75  0.64≤IQI<0.75  0.44≤IQI<0.64  0.24≤IQI<0.44  IQI<0.24 | High  Good  Moderate  Poor  Bad |
| BQI (Rosenberg et al, 2004; Culhane, 2012) | >17.28  >12.96≤17.28  >8.64≤12.96  >4.32≤8.64  ≤4.32 | High  Good  Moderate  Poor  Bad |

**Effect of distance on index quality**

**Figure S1** Average values of indices with standard deviation. Blue line: shows all data from all years; Orange line: shows data only from transects A and E which were the only transects sampled in all years; Grey line: shows data only from sample points 100m and 500m from transects A and E (closest to the outfall where greatest impacts would be expected).1989 n= 64, 1992 n= 66, 1995 n= 84, 1998 n=14)

**Table S3** Quality classification based on average index value at each sample point in each year for Ironotter Point according to five indices

 

**Table S3 continued**

 

Heavy metal contamination data were only available for 1995. The mean, standard deviation, max and min are shown below.

Table S4 Trace metals concentration µg/g dry weight sediment for the <500µm fraction from 1995

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Cd** | **Cr** | **Cu** | **Mn** | **Ni** | **Pb** | **Zn** |
| **Mean** | 0.12 | 112.96 | 61.62 | 676.32 | 24.66 | 94.04 | 185.54 |
| **Standard Deviation** | 0.09 | 43.99 | 126.38 | 502.02 | 6.95 | 35.52 | 62.49 |
| **Max** | 0.40 | 196.00 | 703.00 | 2399.00 | 46.00 | 178.00 | 315.00 |
| **Min** | 0.00 | 46.00 | 15.50 | 235.00 | 14.20 | 50.00 | 90.00 |

**Supporting Information References**

Borja, A. 2004. The biotic indices and the Water Framework Directive: the required consensus in the new benthic monitoring tools. Marine Pollution Bulletin, 48, 405-408.

Culhane, 2012. The use of benthic communities in environmental health assessment. PhD Thesis, Edinburgh Napier University, UK.

Dauvin, J. C. & Ruellet, T. 2007. Polychaete/amphipod ratio revisited. Marine Pollution Bulletin, 55, 215-224.

Rosenberg, R., Blomqvist, M., Nilsson, H. C., Cederwall, H. & Dimming, A. 2004. Marine quality assessment by use of benthic species-abundance distributions: a proposed new protocol within the European Union Water Framework Directive. Marine Pollution Bulletin, 49, 728-739.

WFD-UKTAG, 2008. UKTAG coastal water assessment method benthic invertebrate fauna. Invertebrates in soft sediments (Infaunal quality Index (IQI)). Edinburgh, Scotland.

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