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Comparison of benthic foraminiferal and macrofaunal responses to organic pollution in the Firth of Clyde (Scotland)

M. Mojtahid [a,b,*], F. Jorissen [a,b], T.H. Pearson [c]

[a] Laboratoire des Bio-Indicateurs Actuels et Fossiles (BIAF), UPRES EA 2644, Université d'Angers, 2, Boulevard Lavoisier, 49045 Angers Cedex, France
[b] Laboratoire d'Etude des Bio-Indicateurs Marins (LEBIM). Ker Chalon, 85350 Ile D'Yeu, France
[c] Akvplan-niva as, Polar Environment Centre, 9296 Tromsø, Norway

Abstract

By comparing benthic foraminiferal and macrofaunal responses to sewage sludge disposal in the Firth of Clyde (Scotland), we wanted to investigate the possibility of using foraminifera as bio-indicators of marine environmental degradation. Both groups present a similar distributional pattern, with poor faunas composed of species tolerant to strong oxygen depletion near to the disposal site, surrounded by high density of opportunistic species. Farther away, faunal density decreases and equilibrium taxa gradually replace opportunistic species. No more environmental impact is perceptible beyond 3 km. Nevertheless, some differences exist: foraminifera appear to be more impacted at the disposal site, probably as a consequence of the low pH, a supplementary stress factor for organisms provided with a calcareous test. At 3 km west of the disposal site, macrofauna is comparable to the reference station, whereas foraminifera still indicate environmental degradation, suggesting their higher sensitivity to this type of pollution. It appears that benthic foraminifera may add valuable information to open marine environmental monitoring.

Keywords: Benthic foraminifera; Macrofauna; Eutrophication; Bio-indicator; Opportunistic taxa; Firth of Clyde

1. Introduction

Since 1974, up to 1.5×10^6 tonnes of sewage sludge have been discharged annually in an area some 8 km south of Garroch Head in the Arran/Ayrshire Basin (Firth of Clyde; Scotland; Fig. 1). This activity ceased in 1998 (Webster and Campbell, 2002). In June 1988, benthic macrofaunal and foraminiferal assemblages were sampled at nine stations along two perpendicular sample transects centred around the disposal site. This study makes part of an environmental survey, based on macrofaunal analyses, carried out annually since 1979. This is the first time that the impact of sewage sludge on foraminiferal faunas has been studied at this site.

Essentially, disposal of sewage sludge at sea may create two types of environmental problems: (a) localised organic enrichment causing higher sedimentary oxygen consumption, often leading to hypoxic and ultimately anoxic conditions at the sea floor (Fenchel and Finlay, 1995) and (b) the potential toxicity or pathogenicity of the deposited material (Pearson, 1986). In hydrodynamically active open marine areas, organic enrichment is unlikely to cause more than temporary nuisance problems; nutrient and carbon inputs tend to be rapidly incorporated into the marine food web, which is well adapted to metabolize large quantities of organic carbon (DoE/WTD, 1984). In enclosed, shallow, or hydrodynamically less active systems, on the contrary, severe but localised problems may be created (Pearson, 1985). The realisation of this dichotomy has led to the present opinion, that dumping at sea should preferably take

* Corresponding author. Address: Laboratoire des Bio-Indicateurs Actuels et Fossiles (BIAF), UPRES EA 2644, Université d'Angers, 2, Boulevard Lavoisier, 49045 Angers Cedex, France. Tel.: +33 241735002; fax: +33 241735352.
E-mail addresses: meryem.mojtahid@etud.univ-angers.fr (M. Mojtahid), frans.jorissen@univ-angers.fr (F. Jorissen), thpearson@fsmail.net (T.H. Pearson).

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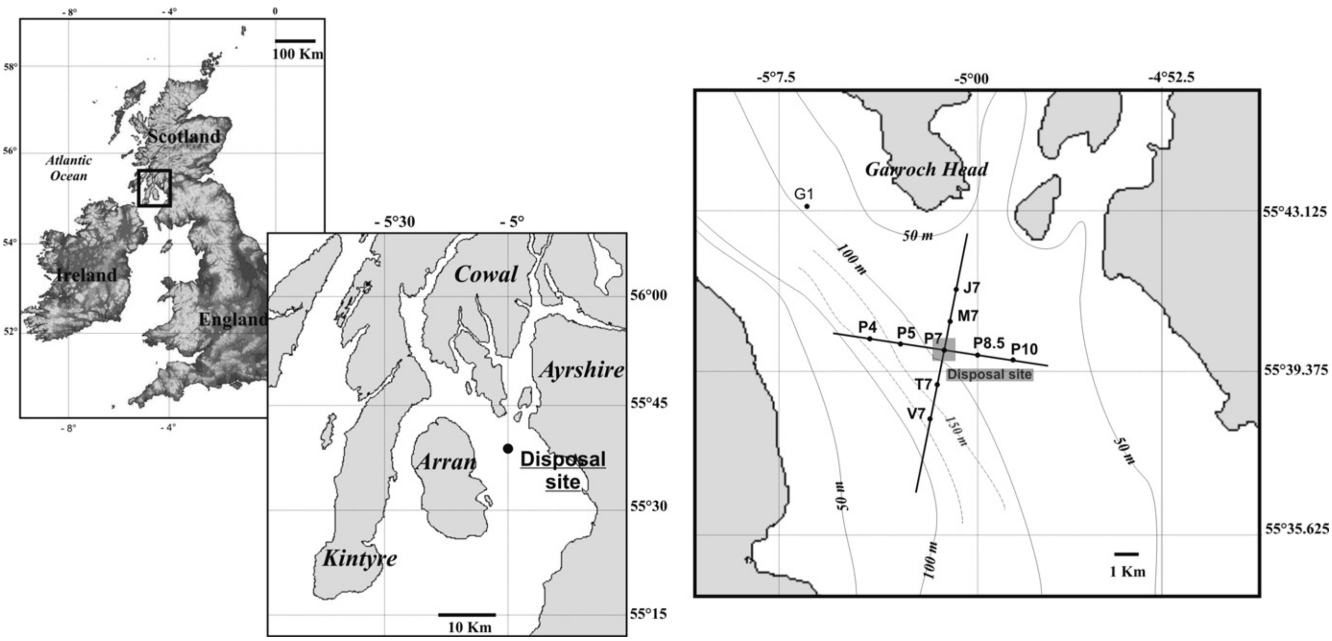

Fig. 1. Study area and sampling location (50 m and 100 m bathymetric curves are represented according to Matthews et al. (1999), whereas the 150 m bathymetric curve is tentatively indicated in function of our own depth measurements).

place in dispersive (hydrodynamically active) areas. At present sewage disposal by dumping at sea is prohibited in the EU.

The impact of sewage disposals on benthic macrofauna is well-documented (Mackay et al., 1972; McIntyre, 1977; Pearson and Rosenberg, 1978; Pearson et al., 1983, 1986; Pearson, 1986; Hellawell, 1986; Abel, 1989; Mason, 1991; Rosenberg and Resh, 1993 in Yong Cao et al., 1997) and has been measured using a variety of indicators, including biomass, species richness, and species density and composition. Foraminifera are among the most abundant protists in marine benthic environments (Murray, 1991). Because of their short life cycles, high biodiversity and the specific ecological requirements of individual species, foraminifera react quickly to environmental disturbance, and can be successfully applied as bio-indicators of environmental changes, such as those brought about by anthropogenic pollution (as defined by Kramer and Botterweg, 1991). Foraminiferal assemblages are easy to collect; they are commonly abundant, and provide a highly reliable database for statistical analysis, even when only small sample volumes are available. Furthermore, many foraminiferal taxa secrete a carbonate shell, and leave an excellent fossil record, that may be used to characterise baseline conditions, or to reconstruct the state of the ecosystem prior to the impact of pollution (Alve, 1995b). Studies of the effects of pollution on benthic foraminiferal assemblages, and their possible use as pollution indicators were initiated in the early 1960's by Resig (1960) and Watkins (1961). More recently, foraminifera have been increasingly used to monitor pollution in a wide range of marine environments, such as intertidal mudflats impacted by oil spillages (Morvan et al., 2004, 2006), tropical east Atlantic outer shelf environments impacted by drill cutting disposal (Durrieu et al., 2006; Mojtahid et al., 2006), harbours affected by heavy metal pollution (Armynot du Châtelet et al., 2004), and eutrophicated continental shelves (Sharifi et al., 1991; Yanko and Flexer, 1991; Platon et al., 2005).

The aim of the present paper is to use an intensively studied sewage disposal site in order to assess the applicability of foraminifera as bio-indicators of this type of environmental impact and to compare the foraminiferal response with that of macrofauna. In order to do so, we will concentrate on three subjects:

(1) changes of faunal density, composition and diversity along the sample transects;
(2) the relationship between these distributional trends and varying degrees of environmental disturbance;
(3) the quantification of foraminiferal and macrofaunal responses to sewage disposal and the development of a quantitive bio-indicator method based on foraminiferal distribution.

2. Study area

The study area is located in the western part of Scotland in the Firth of Clyde, at a water depth varying from 58 to 178 m (Fig. 1, Table 1). The disposal site itself is situated at a water depth of 79 m. Towards the north and the east, water depth remains rather stable, whereas towards the west and the south, the sea floor deepens considerably (with a maximum of 178 m at about 3 km WSW of the disposal site).

A general description of the surface sediments of the Firth of Clyde Sea was first provided by Deegan et al.