Deep-Sea Research II 110 (2014) 26–37

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Toxicity assessment in marine sediment for the Terra Nova environmental effects monitoring program (1997–2010)

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ARTICLE INFO

Available online 24 October 2014

Keywords:
Toxicity tests
Strontium
Particle size
Benthos
Environmental monitoring
Oil and gas fields

ABSTRACT

This paper discusses toxicity test results on sediments from the Terra Nova offshore oil development. The Terra Nova Field is located on the Grand Banks approximately 350 km southeast of Newfoundland (Canada). The amphipod (*Rhepoxynius abronius*) survival and solid phase luminescent bacteria (*Vibrio fischeri*, or Microtox) assays were conducted on sediment samples collected from approximately 50 stations per program year around Terra Nova during baseline (1997), prior to drilling, and in 2000, 2001, 2002, 2004, 2006, 2008 and 2010 after drilling began. The frequency of toxic responses in the amphipod toxicity test was low. Of the ten stations that were toxic in environmental effects monitoring (EEM) years, only one (station 30(FE)) was toxic in more than one year and could be directly attributed to Terra Nova project activities. In contrast, 65 (18%) of 364 EEM samples were toxic to Microtox. Microtox toxicity in EEM years was not related to distance from Terra Nova drill centres or concentrations of $>C_{10}$–C_{21} hydrocarbons or barium, the primary constituents of the synthetic-based drill muds used at Terra Nova. Of the variables tested, fines and strontium levels showed the strongest (positive) correlations with toxicity. Neither fines nor strontium levels were affected by drill cuttings discharge at Terra Nova, except at station 30(FE) (and that station was not toxic to Microtox). Benthic macro-invertebrate abundance, richness and diversity were greater in toxic than in non-toxic sediments. Therefore, Microtox responses indicating toxicity were associated with positive biological responses in the field. This result may have been an indirect function of the increased abundance of most invertebrate taxa in less sandy sediments with higher gravel content, where fines and strontium levels and, consequently, toxicity to Microtox were high; or chemical substances released by biodegradation of organic matter, where invertebrates are abundant, may be toxic to Microtox. Given the lack of association between Microtox results and discharge from Terra Nova, coupled with the confounding effects of other variables, the usefulness of Microtox toxicity tests within the context of environmental monitoring for the Terra Nova and, potentially, other offshore oil operations needs to be questioned. The amphipod toxicity tests showed that sediments in the vicinity of discharges of synthetic-based drilling mud cuttings are rarely toxic.

1. Introduction

The Terra Nova environmental effects monitoring (EEM) program is an extensive sampling program geared toward assessing effects of the Terra Nova offshore oil development on the marine environment. Five drill centres are active at Terra Nova: the Northeast (NE); Northwest (NW); Southeast (SE); Southwest (SW); and Far East (FE) drill centres. The NE, NW, SE and SW drill centres are located near the centre of the development within a Fisheries Exclusion Zone (FEZ). The FE drill centre is located approximately 5 km to the east of the centre of development (Fig. 1). Wells are drilled with both

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http://dx.doi.org/10.1016/j.dsr2.2014.10.014
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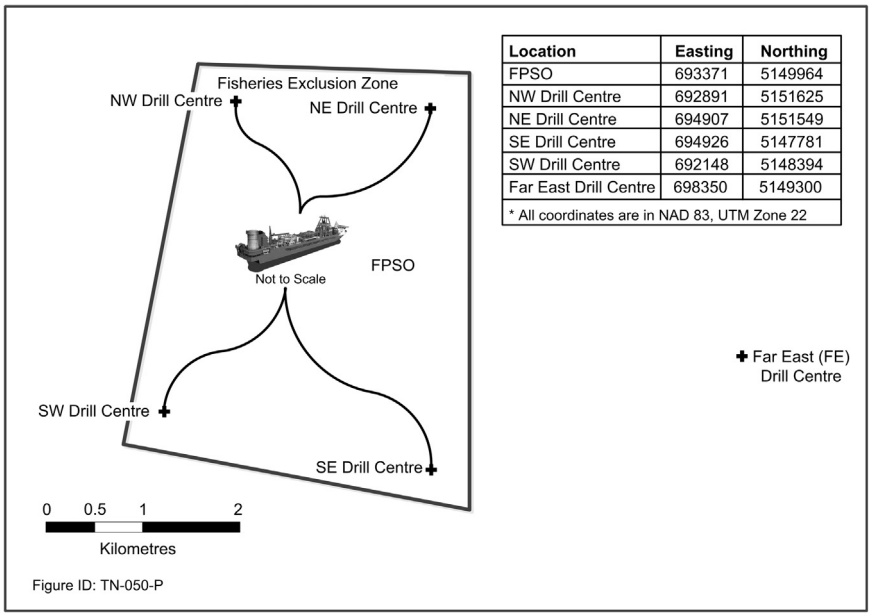

Location	Easting	Northing
FPSO	693371	5149964
NW Drill Centre	692891	5151625
NE Drill Centre	694907	5151549
SE Drill Centre	694926	5147781
SW Drill Centre	692148	5148394
Far East Drill Centre	698350	5149300

* All coordinates are in NAD 83, UTM Zone 22

Fig. 1. Drill centre location.

water-based drill muds (WBMs) and synthetic-based drill muds (SBMs). $>C_{10}$–C_{21} hydrocarbons and barium are the main contaminants from discharge of SBM-on-drill cuttings, and barium is the main contaminant of WBM-on-drill cuttings. Contamination with metals other than barium and alterations in sediment particle size may also occur to some degree, although this has been minor at Terra Nova (see DeBlois et al., 2014-a, 2014-b, for additional details on project discharges and an examination of sediment contamination). Biodegradation of hydrocarbons in SBMs as well as mortality and decomposition of benthic organisms may also lead to localized increases in sulphide and ammonia levels and lower sediment oxidation/reduction (redox) potential.

Environmental impacts of discharge of drilling wastes from oil and gas platforms on the benthos of the adjacent sea floor have been documented (e.g., Olsgård and Gray, 1995; also see Paine et al., 2014 and references therein) and laboratory toxicity tests on sediments are extensively used to assess potential effects of contamination (e.g., Ingersoll et al., 1997; Newman and Unger, 2003; Chapman, 2006). These tests are integral components of numerous national programs to assess sediment quality in coastal areas (Swartz et al., 1986; Bay, 1992; Fairey et al., 1996; Bay et al., 1998; Long, 2000). The Terra Nova EEM program includes measurement of sediment toxicity, as well as measurement of sediment chemistry and assessment of benthic community structure. Sediments surrounding the Terra Nova development were collected predevelopment, in 1997, and then over seven EEM cycles (2000, 2001, 2002, 2004, 2006, 2008 and 2010). Sediment toxicity for the program was measured by the reduction of microbial luminescence of a marine bacterium (*Vibrio fischeri)* in a Microtox Solid-Phase Test (SPT) and by percent survival of an amphipod (*Rhepoxynius abronius*) exposed to the sediments.

Toxicity to amphipods was limited. Toxicity to Microtox was encountered more frequently. The purpose of this paper is to explore the associations between amphipod and Microtox responses and sediment physical, chemical and biological attributes. The sensitivity of the toxicity tests used in the Terra Nova EEM program was evaluated to determine the usefulness of each test to the program.

2. Materials and methods

2.1. Field collections

Sediment collection for the Terra Nova EEM program is performed in late summer/early autumn from sampling facilities installed on an offshore supply vessel. Sediment stations for the baseline and EEM programs were established based on a radial design, with a higher density of stations near drill centres where contamination was expected to be highest (Fig. 2). A total of 49 to 54 stations were sampled in each program year. Some stations sampled during baseline (1997) could not be sampled in EEM years because of construction activity or proximity to subsea infrastructure.

Sediment samples were collected using a large-volume corer (mouth diameter=35.6 cm; depth=61 cm) designed to mechanically take an undisturbed sediment sample over approximately 0.1 m^2 of seabed. Three core samples were collected at each station. The top 7.5 cm of one core was used for toxicity testing. Sediments from all three cores were used for particle size and chemistry analysis and sediments from two cores were used to assess benthic community structure (see DeBlois et al., 2014-b; Paine et al., 2014, for details on methods for collections of chemistry and benthic community samples, respectively). Sediments collected for toxicity were stored in the dark at 4 °C in high-density food-grade polyethylene buckets (amphipod toxicity), or in sterile 200-mL Whirl-Paks (Microtox).

2.2. Laboratory analysis

All toxicity tests were conducted at an ISO/IEC 17025 accredited laboratory, in accordance with published Environment Canada Standard Methods.

2.2.1. Amphipod toxicity test

The amphipod toxicity test is a ten-day static, whole sediment toxicity test during which overlying water is not renewed. The amphipod test protocol followed Environment Canada (1998), which includes guidance on test organism selection, species-