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Examination of body burden and taint for Iceland scallop (*Chlamys islandica*) and American plaice (*Hippoglossoides platessoides*) near the Terra Nova offshore oil development over ten years of drilling on the Grand Banks of Newfoundland, Canada

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ABSTRACT

This paper presents results of analyses of body burdens of metals and hydrocarbons, and taste tests for taint, in Iceland scallop and American plaice performed as part of the Environmental Effects Monitoring (EEM) program for the Terra Nova offshore oil development (Grand Banks of Newfoundland, Canada). Scallop and plaice were collected in a Study Area located within approximately 1 km of drill centres at Terra Nova and in a Reference Area located approximately 20 km from the development. Samples were collected in 1997 to establish a baseline, and from 2000 to 2010, during drilling periods. Scallop adductor muscle tissue was contaminated with $> C_{10}-C_{21}$ aliphatic hydrocarbons resembling the drilling fluid in the synthetic drilling mud (SBM) used at Terra Nova in 2000, 2002 and 2004, but contamination of adductor muscle was not noted in 2006, 2008 and 2010. The maximum concentration in muscle was 28 mg/kg wet weight, noted in 2002. Scallop viscera was contaminated with hydrocarbons resembling drilling fluid in SBMs near drill centres in all EEM years except 2010. Viscera contamination with $> C_{10}-C_{21}$ hydrocarbons gradually decreased from a maximum of 150 mg/kg in 2000, to a maximum of 27 mg/kg in 2008; all values were below the laboratory reporting detection limit of 15 mg/kg in 2010. Therefore, evidence from both muscle and viscera indicates a decrease in tissue hydrocarbon contamination in recent years. Barium, another major constituent in drilling muds, has not been noted in scallop adductor muscles at concentrations above the reporting detection limit, but barium was detected in viscera in baseline and EEM years. The maximum concentration of barium in viscera during baseline sampling was 8 mg/kg. The maximum concentration in EEM years (29 mg/kg) was noted in 2000. The maximum concentration in 2010 was 25 mg/kg. The concentration of metals other than barium in scallop tissues was similar between the Terra Nova Study Area and the Reference Area. Hydrocarbons resembling the fluid in SBMs were noted in one American plaice liver sample collected near drill centres in 2000. Otherwise, there has been no evidence of project-related metals or hydrocarbon contamination in plaice liver or fillet samples. There has been no evidence of taint (off-taste) for scallop adductor muscle and plaice fillet tissue in baseline or EEM years. Combined with a parallel study on fish bioindicators at Terra Nova that showed that fish health at Terra Nova was similar to that at the Reference Area (Mathieu et al., 2011), these results indicate little to no detectable biological effects on Iceland scallop and American plaice as a result of Terra Nova activities.

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1. Introduction

This paper provides an examination of tissue contamination and taint for Iceland scallop (*Chlamys islandica*) and American plaice (*Hippoglossoides platessoides*) relative to drilling discharges at the Terra Nova offshore oil development. Monitoring of Iceland scallop and American plaice constitutes a portion of the Terra Nova Environmental Effects Monitoring (EEM) program. Published accounts of extensive effects monitoring programs are few, and results provided in this and accompanying papers are likely the first account of a 10-year monitoring program on effects of offshore drilling of multiple wells. Other published works include the Norwegian EEM program, geared toward regional monitoring rather than field-specific effects (Renaud et al., 2008); work described in a series of publications on effects in the Gulf of Mexico (Carr et al., 1996; Green and Montagna, 1996; Kennicutt et al., 1996; Montagna and Harper, 1996; Peterson et al., 1996), more recent work in the Gulf of Mexico described by Neff et al. (2005) and work described in a series of publications for the Brazilian offshore (Corrêa et al., 2009; Netto et al., 2009; Pozebon et al., 2009; Santos et al., 2009; Toldo and Ayup-Zouain, 2009).

The Terra Nova Field is located on the Grand Banks, 350 km southeast of Newfoundland (Canada), at a water depth of approximately 100 m (Fig. 1). Drilling started prior to the 2000 EEM program, with decreased drilling activity in 2007, prior to the 2008 and 2010 EEM programs (see DeBlois et al., 2014-a, for details on drilling statistics at Terra Nova). In general, drilling discharges include drill cuttings (crushed formation rock from well holes) and drilling muds used to facilitate the drilling process. Both water-based drilling muds (WBM) and synthetic-based drilling muds² (SBMs) have been used at Terra Nova. Drilling discharge solids predominantly settle to the seafloor. Contaminants in discharges include metals and, for SBMs, saturated hydrocarbons (see DeBlois et al., 2014-a, for details).

Concerns associated with effects of drilling discharges on fisheries resources include potential tainting of human-use resources from hydrocarbons present in SBMs (e.g., APPEA (Australian Petroleum Producers and Exploration Association), 1998; Gerrard et al., 1999; OGP (International Association of Oil and Gas Producers), 2003; Hurley and Ellis, 2004; Challenger and Mauseth, 2011). Bioaccumulation of contaminants in fish tissue (e.g., Rushing et al., 1991; Neff et al., 2000), with associated effects on fish health (Mathieu et al., 2011) could also occur; along with interference with feeding for filter feeders caused by fine drill particles, with associated sub-lethal effects on growth and reproduction (e.g., Cranford and Gordon, 1992; Barlow and Kingston, 2001; Armsworthy et al., 2005; Cranford, 2006).

Iceland scallop and American plaice were selected for the Terra Nova monitoring program because both are closely associated with bottom sediments and are therefore vulnerable to localized contamination via ingestion of sediments or food.³ Iceland scallop are caught commercially in the Terra Nova area. In general, these sedentary filter feeding bivalves are found on hard bottoms consisting largely of sand, gravel, shell fragments and stone. American plaice have been under moratorium for directed fishing on the Grand Banks, but were once the most important flatfish fishery in the area. This bottom-dwelling fish is often considered to be sedentary, with limited feeding and spawning migrations (Bigelow and Schroeder, 1953; Pitt, 1967). However, there is some evidence of a seasonal migration off the Grand Banks in the winter to warmer water along the shelf edge (Morgan and Brodie, 1991). Diet varies with size but, in general, polychaetes, echinoderms,

mollusks, crustaceans and fish are important components of plaice diet (Scott and Scott, 1988).

To examine potential effects of the Terra Nova development on body burden of drilling discharge-related chemicals and taint, scallop and plaice were collected in 1997 prior to development (baseline), and in 2000, 2001, 2002, 2004, 2006, 2008 and 2010 (EEM years). In all years, samples were collected near Terra Nova and at a reference site following a Control-Impact (CI) design (Green, 1979; also see Green (2005) for details on CI designs specifically for offshore oil and gas developments). Test results on body burden and taint are discussed in this paper. A parallel study, conducted as part of the EEM program and reported in Mathieu et al. (2011), monitored change in fish health bioindicators in response to drilling waste and produced water discharges from Terra Nova. Results on plaice bioindicators are briefly discussed here for completeness, with details in Mathieu et al. (2011).

2. Methods

2.1. Field sampling

Iceland scallop and American plaice were collected within approximately 1 km from drill centres at Terra Nova (referred to here as the Study Area). Scallop and plaice were also collected in a Reference Area located approximately 20 km to the southeast of the development, in an area with similar substrate and water depth characteristics. Scallop and plaice transects in the Study Area were located outside of a Fisheries Exclusion Zone (FEZ) established to protect subsea infrastructure around drill centres and the Terra Nova Floating, Production, Storage and Offloading (FPSO) facility. Fig. 2, provided as an example of the distribution of transects in the Study Area, shows the location of transects for scallop and plaice in the Terra Nova Study Area in 2010.

Collection surveys were performed onboard a Fisheries and Oceans Canada research survey vessel (1997–2008) or a commercial fishing vessel (2010). Since 2000, surveys have been carried out in May, June or July. Catch rates during the November 1997 baseline program were low, which led to Spring or Summer sampling in subsequent years. Scallop were collected by towing an 8-foot dredge at 3 knots for 15 min/transect. Plaice were collected using a Campellan 1800 trawl or a commercial otter trawl towed at 3 knots for 15 min/transect.

Approximately 50 plaice and 500 scallop were collected in each area in each sample year for analysis of metals and hydrocarbon body burden and for taint tests. Only those plaice larger than 250 mm in length were retained for analysis.

Dissection of tissues was done at sea. Scallop and plaice that had suffered obvious dredge or trawl damage were discarded. Adductor muscle for scallop and top fillet for plaice were frozen at –20 °C for subsequent taste analysis. Adductor muscle and viscera for scallop and bottom fillets and liver for plaice were frozen separately at –20 °C for body burden analysis.

To ensure sample integrity and prevent onboard contamination, the fishing deck of the survey vessel was washed with degreaser, scrubbed with a deck broom, and then flushed with seawater before the survey. The fishing deck and chute leading to the processing facilities were flushed with seawater between transects. Sampling personnel wore new latex gloves and all sampling and measuring instruments were washed with mild soap and water then rinsed with distilled water between transects.

2.2. Tissue composites and laboratory analysis

Since 2001, batches of 20 scallop viscera and matching adductor muscle were randomly selected from each of approximately

² The synthetic drilling fluid in the SBM used at Terra Nova is a low-toxicity hydroisomerized and hydrogenated iso-alkane (iso-paraffin) mixture.

³ Species selection benefited from guidance from regulatory agencies, nationally and internationally recognized experts and the fishing industry.

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