Marine Pollution Bulletin 62 (2011) 581–589

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Are sea otters being exposed to subsurface intertidal oil residues from the *Exxon Valdez* oil spill?

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ARTICLE INFO

Keywords:
Polycyclic aromatic hydrocarbons
Enhydra lutris
Sediment contamination
Exxon Valdez

ABSTRACT

Twenty years after the *Exxon Valdez* oil spill, scattered patches of subsurface oil residues (SSOR) can still be found in intertidal sediments at a small number of shoreline locations in Prince William Sound, Alaska. Some scientists hypothesize that sea otters continue to be exposed to SSOR by direct contact when otters dig pits in search of clams. This hypothesis is examined through site-specific examinations where SSOR and otter-dug pits co-occur. Surveys documented the exact sediment characteristics and locations on the shore at the only three subdivisions where both SSOR and otter pits were found after 2000. Shoreline characteristics and tidal heights where SSOR have persisted are not suitable habitat for sea otters to dig pits during foraging. There is clear separation between areas containing SSOR and otter foraging pits. The evidence allows us to reject the hypothesis that sea otters encounter and are being exposed by direct contact to SSOR.

1. Introduction

Two decades after the *Exxon Valdez* oil spill (EVOS) of March 24, 1989, patches of weathered subsurface oil residues (SSOR) persist along less than 0.1% of the shoreline of Prince William Sound (PWS), Alaska (Short et al., 2004, 2006; Michel et al., 2006, 2010; Page et al., 2008; Boehm et al., 2008). There have been no reports of EVOS residues persisting in shallow offshore sediments beyond 2000 (Integral Consulting Inc., 2006).

Between 1989 and 1992, several detailed shoreline surveys were performed by Shoreline Cleanup Assessment Teams (SCAT) consisting of trained State, Federal, and Exxon personnel to identify shorelines requiring cleanup (Neff et al., 1995; Page et al., 2008). SCAT surveys performed in 1990 through 1992 focused on quantifying the amount of SSOR on oiled shores. In these surveys SSOR, defined as oil found at a depth greater than 5 cm below the surface of sediments located beneath any surface armor of cobbles and boulders (Neff et al., 1995), were categorized visually as oil filled pores (OP), heavy oil residues (HOR), medium oil residues (MOR), light oil residues (LOR), oil film (OF), trace (TR), and no oil observed (NO). As the SSOR weathered on the shore by dispersion, dissolution, and biodegradation, the oiling levels became lighter. The hydrocarbons of greatest environmental concern in SSOR are polycyclic aromatic hydrocarbons (PAH) (Neff et al., 2010). Total PAH (TPAH) concentrations in sediments containing light oil residues (LOR or OF/TR) are currently considered to be too low and too highly weathered to present a health hazard to intertidal invertebrates and the wildlife that prey on them (Boehm et al., 2008; Neff et al., 2010). Thus, the major focus of the present study is on heavier oiling levels (OP, HOR, and MOR) of SSOR.

All the shores where heavier categories of SSOR were found after 2000 had been identified in the 1991 and 1992 SCAT surveys (Page et al., 2008). Eighteen of the 30 shoreline subdivisions where the May 1991 SCAT survey found heavier levels of SSOR still contained these categories of SSOR in 2001 (Page et al., 2008). The estimated area of heavier levels of SSOR declined by 88.5% from 24,514 m^2 in 1991 to 2820 m^2 in 2001.

Shoreline attributes required for long-term sequestration and persistence of SSOR have been documented following several marine oil spills and include anoxic peat deposits that sequester SSOR (e.g., *West Falmouth*: Reddy et al., 2002; *Exxon Valdez*: Page et al., 2008), mixed sand/gravel sediment layers overlain by a boulder/cobble surface armor and sometimes underlain by bedrock that protects SSOR (e.g., *Arrow*: Owens et al., 2006, 2008; *Exxon Valdez*: Owens et al., 2008; Taylor and Reimer, 2008; Li and Boufadel, 2010), large boulders that provide armoring for underlying surface oil and SSOR (e.g., *Exxon Valdez*: Irvine et al., 2006), and low water-permeability of oiled sediment layers, that slow dissolution and biodegradation (e.g., *Exxon Valdez*: Li and Boufadel, 2010). SSOR has persisted past 2000 on oiled shores in PWS as small, discontinuous patches, 4–21 cm thick and 12–19 cm beneath the underside of a protective boulder/cobble veneer, often in wave shadows

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0025-326X/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.marpolbul.2010.11.026

behind bedrock outcrops, and often underlain by bedrock or impermeable peat, in the middle and upper tide zones of low energy shores (Michel et al., 2006, 2010; Boehm et al., 2008; Page et al., 2008; Taylor and Reimer, 2008). Here, the majority of SSOR are sequestered in a fine-grained sediment matrix that fills the interstices between the subsurface boulders and cobbles. These shoreline sediment properties slow or prevent sediment erosion by storms or water washing by tidal water, rainwater, and surface runoff, or reduce water permeability through the sediments, causing sequestration and long-term persistence of SSOR. Although SSOR in the lower intertidal zone can be found at a few sites, its occurrence is well documented and rare (Short et al., 2006; Boehm et al., 2007a).

Large (~30–60 mm) clams, including butter clams (*Saxidomus giganteus*) and littleneck clams (*Prototheca staminea)*, represent nearly 80% of the diet of sea otters (*Enhydra lutris*) in PWS (Ballachey and Bodkin, 2006). These clams live in constantly wet, silty sand/gravel sediments between about +1.0 m above mean lower low water on the shore and a depth of about 40 m offshore (Neff et al., 2010). Sea otters gather clams by diving to the bottom in the lower intertidal zone offshore and digging pits up to 50 cm in diameter that are rarely more than about 15 cm deep (Boehm et al., 2007a). Because large clams do not occur in middle and upper intertidal sediments, sea otters do not dig foraging pits there.

Bodkin et al. (2002) and Bodkin and Ballachey (2003) reported that the sea otter subpopulation in the heavily oiled northern Knight Island (NKI) area has increased at a lower than expected rate since the 1989 spill and have hypothesized that sea otters are being injured by continuing exposure to EVOS residues while digging foraging pits in the intertidal zone. They have cited CYP1A biomarker data (Snyder et al., 2002) in sea otters to support this hypothesis, but Hook et al. (2008) have reported that those cited investigators did not actually measure sea otter CYP1A activity. Short et al. (2006) predicted that sea otters continue after 2000 to be exposed to SSOR while digging pits on the shore in search of clams. Recently, Harwell et al. (2010) conducted a risk assessment and concluded that, no plausible toxicological risk exists from SSOR to the sea otter subpopulation at NKI.

The objective of the present study is to use direct field observations and data to directly evaluate the hypothesis that sea otters are likely to encounter and be exposed to SSOR while digging foraging pits in the intertidal zone. We do this through site- and location-specific assessments of where SSOR are located on the shore and where sea otters dig foraging pits. This focused site-specific assessment provides additional verification of the results of a broader approach to the assessment of all possible exposure pathways of sea otters to SSOR (Neff et al., 2010).

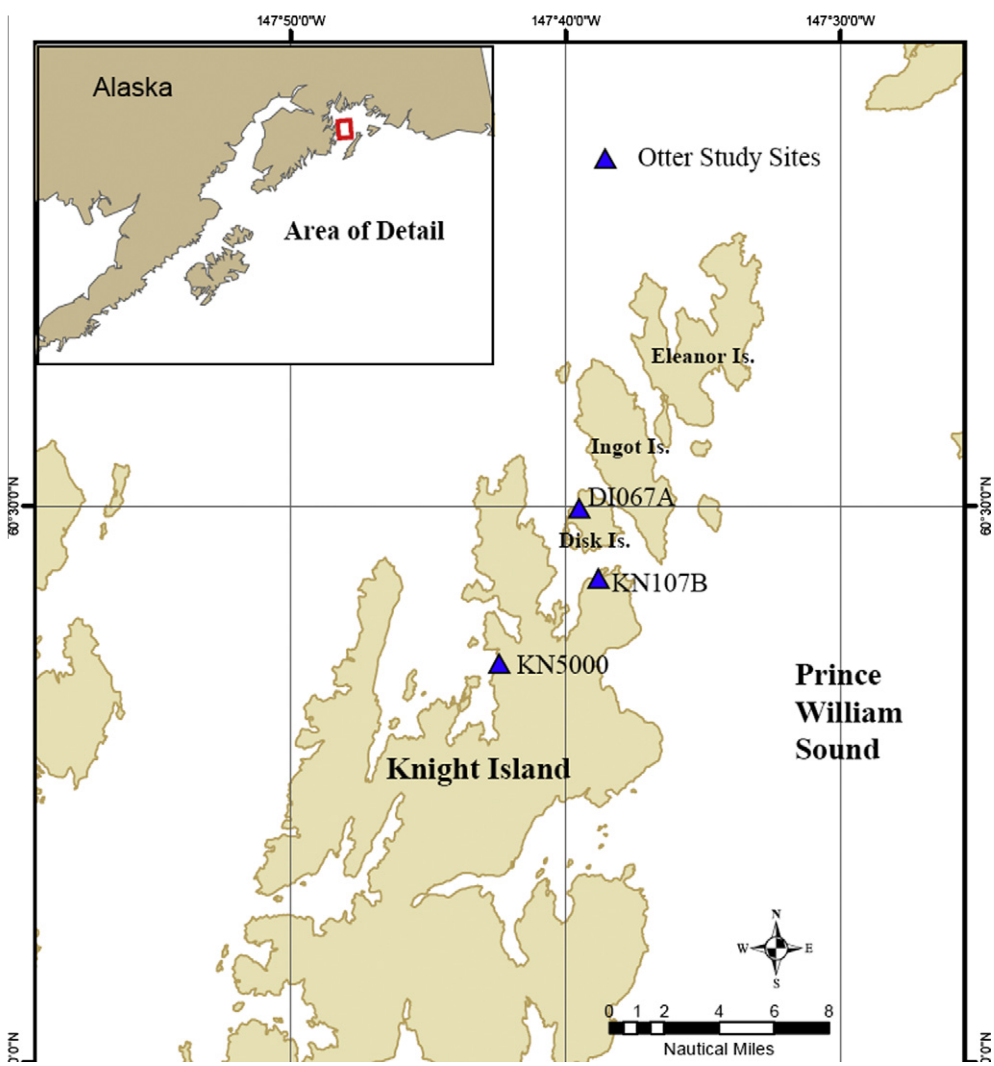

Fig. 1. Map of detailed survey locations discussed in text. Three subdivisions are indicated. KN107B and DI067A contain two sites in each.