



REPLY COMMENT

# Quantifying long-term risks to sea otters from the 1989 'Exxon Valdez' oil spill: Reply to Harwell & Gentile (2013)

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**ABSTRACT:** Recovery of sea otter populations in Prince William Sound (PWS), Alaska, has been delayed for more than 2 decades following the 1989 'Exxon Valdez' oil spill. Harwell & Gentile (2013; Mar Ecol Prog Ser 488:291–296) question our conclusions in Bodkin et al. (2012; Mar Ecol Prog Ser 447:273–287) regarding adverse effects that oil lingering in the environment may have on sea otters. They agree that exposure may continue, but disagree that it constitutes a significant risk to sea otters. In Bodkin et al. (2012), we suggested that subtle effects of chronic exposure were the most reasonable explanation for delayed recovery of the sea otter population in areas of western PWS, where shorelines were most heavily oiled. Here, we provide additional information on the ecology of sea otters that clarifies why the toxicological effects of oral ingestion of oil do not reflect all effects of chronic exposure. The full range of energetic, behavioral, and toxicological concerns must be considered to appraise how chronic exposure to residual oil may constrain recovery of sea otter populations.

**KEY WORDS:** Sea otter · 'Exxon Valdez' · Oil spill · *Enhydra lutris* · Ecological risk assessment

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## Introduction

In Bodkin et al. (2012), we presented data describing frequency of intertidal foraging of sea otters in the northern Knight Island Archipelago (NKIA), an area of Prince William Sound (PWS), Alaska, that was heavily oiled in 1989 and where oil persists in intertidal sediments (Short et al. 2004, 2006, 2007). We concluded that between 2003 and 2005, individual sea otters were exposed to oil from 2 to 24 times per year. Our exposure rate estimates explicitly accounted for the probability of otters encountering oil at the tidal levels and on the substrates where oil occurred. Estimated exposure varied considerably among individuals, and all otters increased frequency of intertidal foraging during late spring and

early summer, a time when most adult females were nursing pups, which may be more vulnerable to effects of exposure to crude oil (Bodkin et al. 2012).

Based on the estimated frequency of encountering intertidal oil (and the presence of oil in foraging pits), we concluded that chronic exposure to lingering oil was delaying sea otter recovery. It was not possible to quantify the exposure, and biological and ecological effects of long-term exposure are difficult to resolve and remain largely unknown (Bodkin et al. 2012).

Harwell & Gentile (2013) agree with our conclusion that a pathway of exposure to lingering 'Exxon Valdez' oil exists and generally agree with our estimates of rates of encountering oil. However, they disagree with our conclusion that this exposure constitutes a significant risk to sea otters. Harwell &

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Gentile (2013) reiterate results of their risk assessment model (Harwell et al. 2010), which accounted for exposure through ingestion of PAHs, and conclude that a toxicological response by sea otters to chronic oiling is implausible and therefore lack of recovery of sea otters at Knight Island cannot be attributed to lingering oil.

Assessment of risk for wild animals is complicated, however, as exposure to toxins is but one of many stressors faced by individuals, and these stressors may have synergistic interactions, resulting in cumulative effects that may extend well beyond those reflected by end points measured under controlled laboratory conditions with limited duration of exposure. Laboratory studies do not embody cumulative effects of lifetime toxin exposure, which in combination with other environmental stressors will elevate the ecological risk (see also Peterson et al. 2003). Furthermore, exposure to a combination of multiple PAHs and the unresolved complex mixture (UCM) fraction (Bodkin et al. 2012) may enhance toxicity, from interacting effects among compounds and with the natural environment (Laskowski et al. 2010, Silins & Högberg 2011) and from the many unidentified UCM compounds (Scarlett et al. 2007).

Here we describe adaptations and behaviors of wild sea otters that contribute to the risk of adverse effects from chronic exposure, with possible population level effects that may have contributed to the observed lack of full recovery over 2 decades (Bodkin et al. 2011). These additional risk factors are not included in the laboratory-based exposure models considered in Harwell et al. (2010) or Harwell & Gentile (2013).

### External oiling

Deleterious physiological effects of external oiling on sea otters are well documented (Costa & Kooyman 1982, Siniff et al. 1982, Davis et al. 1988, Williams et al. 1988, 1995). Oil contamination of sea otter pelage will vitiate its water repellence and impair its thermoregulatory function; this results in hypothermia, which is physiologically costly in cold aquatic habitats.

In experimental oiling of 11 to 25% of a sea otter's pelage with 35 to 60 ml of crude oil, Costa & Kooyman (1982) documented an average decline in subcutaneous body temperature of 8.8°C and a 40 to 120% elevation in oxygen consumption. One animal in 5 died 11 d after 1 experimental oiling and washing (Costa & Kooyman 1982). Results of these experi-

ments are conservative, as otters were washed following experimental oiling and provided with plentiful food.

Based on studies of lingering oil in intertidal sediments at NKIA, wild sea otters occasionally will have encountered volumes of oil similar to experimental levels (Short et al. 2004). Additionally, animals in the wild will not be washed, must acquire their own food, and ambient air and water temperatures are lower in Alaska than they were in California, where the experiments were conducted. Even with lesser levels of contamination, there would be a metabolic cost.

Harwell et al. (2010) recognize the potential for external oiling of pelage, and include it in their model as a source of ingested PAHs, via grooming, but do not consider associated energetic costs. As demonstrated by Costa & Kooyman (1982) and supported by observations after the 'Exxon Valdez' spill (Williams et al. 1995), however, relatively minor external oiling, left untreated, contributes to morbidity and mortality in sea otters.

### Energetic costs of altered activity

Sea otters live on a strict energy budget with little plasticity for unanticipated energetic costs (Yeates et al. 2007), especially at northern latitudes where thermal conditions are most challenging. In Alaska, sea otters spend 9 to 12 h d<sup>-1</sup> foraging, 11 to 12 h d<sup>-1</sup> resting, and 2 to 3 h d<sup>-1</sup> in other behaviors such as traveling and grooming (Garshelis et al. 1986, Bodkin et al. 2007, Esslinger et al. 2011). Experimental studies demonstrated increased grooming and elevated basal metabolic rates in otters exposed to relatively small amounts of external oil (Costa & Kooyman 1982, Siniff et al. 1982, Davis et al. 1988).

Chronic exposure to oil will require increased grooming, as it is essential to maintain insulative properties of the pelage. This will affect the overall activity budget, with a reduction in either resting or foraging time. The energetic burden of restoring contaminated fur is unknown but will be costly, because grooming ranks with surface swimming as the most energetically demanding of sea otter behaviors (Yeates et al. 2007).

### Behavioral and demographic responses

Sea otters display dietary specialization (Tinker et al. 2007, 2008) and occupy small home ranges, on the order of a few km to a few tens of km of shoreline

(Garshelis et al. 1984, Jameson 1989, Ralls et al. 1996, Estes et al. 2003). Lingering 'Exxon Valdez' oil in PWS is aggregated in intertidal habitats that were heavily oiled in 1989 (Short et al. 2004, 2006, 2007), and coincides with the area where sea otter recovery has been delayed (Bodkin et al. 2011).

The extent to which sea otters avoid oiled habitats is unknown. Otter foraging pits were equally frequent on oiled and unoled beaches in western PWS, suggesting avoidance may be minimal (Bodkin et al. 2012). However, if otters avoid oil, then longer-term behavioral modifications may include social disruption, permanent relocation away from oiled shorelines, and utilization of alternative foraging habitats or prey species, as availability of the species and habitats they prefer is restricted by contamination. Females with small pups may be affected disproportionately, as levels of intertidal foraging are high during the post-parturition period (Bodkin et al. 2012). Thus while avoidance would reduce exposure potential, it also could be associated with increased energetic costs that may adversely affect survival and ultimately population growth.

Furthermore, it is important to consider how sea otters recover from large-scale reductions in population abundance. At NKIA, where mortality approached 90% (Bodkin & Udevitz 1994), recovery presumably included recruitment of juveniles from adjacent areas, consistent with normal juvenile dispersal (Jameson 1989, Ralls et al. 1996). Juvenile sea otters rely heavily on intertidal forage species (Doroff & Bodkin 1994), elevating their exposure risk and contributing to low survival rates (Monson et al. 2000, 2011), in this case until sometime after 2003, when sea otter abundance began to recover (Bodkin et al. 2011).

### Individual variation in exposure

Chronic exposure to lingering oil will not necessarily affect all individuals equally. Recently weaned sea otters forage in the intertidal more than adults, leading to greater oil exposure than we calculated based on our time-depth recorder data (Bodkin et al. 2012), which included adults and sub-adults (Age 3). Moreover, individual foraging strategies modify site-specific exposure (e.g. Johnson et al. 2009, Miller et al. 2010). Thus, there may be a bimodal distribution of exposure and of subsequent toxicological effects.

Temporal variation in exposure also contributes to differences among individuals. We found a higher frequency of foraging in the intertidal in late spring and early summer, possibly in response to greater

energetic content of intertidal prey (Esslinger et al. 2011). This coincides with a spring peak in pupping in PWS (Garshelis et al. 1984). Further, regardless of season, female sea otters with newborn pups forage to a greater extent in intertidal areas (USGS unpubl. data), increasing exposure to risk. Neonate sea otters stay with their mother and are entirely dependent on her for nourishment and grooming, so both will thus be more susceptible to adverse effects of external and internal oil exposure than independent individuals.

### Conclusions

Harwell et al. (2010) concluded that there is no plausible risk of toxicological effects from oil exposure, but we find no plausible alternative to the conclusion that presence of lingering oil has been a constraint to recovery of species inhabiting nearshore areas that were heavily oiled in 1989 (Monson et al. 2000, 2011, Bodkin et al. 2002, Ballachey et al. 2003, 2011, 2012, Miles et al. 2012; see also Esler et al. 2002, 2010, 2011, Golet et al. 2002, Jewett et al. 2002, Thomas et al. 2007, Springman et al. 2008, Esler & Iverson 2010, Iverson & Esler 2010). Other explanations for population depression described by Harwell & Gentile (2013) do not adequately explain the spatial distribution of the observed effects.

We attribute the difference between Harwell et al. (2010) and our conclusions, at least in part, to the fact that they limited their assessment to oral ingestion of oil. We argue that toxicological effects and energetic costs of chronic exposure represent stressors that act synergistically with natural stressors in the environment to produce cumulative effects that cannot be duplicated in laboratory studies on which Harwell et al. (2010) based their model, whereas studies of sea otters and other species have provided ample evidence of demographic and biochemical differences between individuals in oiled versus unoled areas since 1989.

Exposure has extended throughout the lifetime of individuals at risk, may have occurred through inhalation and transdermal absorption in addition to ingestion during foraging and grooming, and may have led to metabolic costs and behavioral alterations that reduced survival. Furthermore, the rates of ingestion modeled by Harwell et al. (2010) were based largely on data from 2002 and later, when exposure was diminishing and adverse effects of oil appeared to be moderating, which is consistent with the population recovery underway in sea otters (Bod-

kin et al. 2011) and sea ducks (Esler & Iverson 2010, Iverson & Esler 2010, Esler et al. 2010, 2011).

Finally, we reiterate the conclusions of Peterson et al. (2003) that, given delayed effects on multiple species following the 'Exxon Valdez' spill and continuing release of hydrocarbon pollutants into marine environments, (1) risk assessment modeling and estimation of natural resource injury need to be reconsidered, and (2) development of ecosystem-based toxicology is required to understand and ultimately predict chronic, delayed, and indirect long-term risks and effects.

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