Long-term Fate and Persistence of Oil from the *Exxon Valdez* Oil Spill: Lessons Learned or History Repeated

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Abstract

As a continuation of the extensive shoreline studies undertaken since 1989, we conducted systematic surveys in 2007 and 2008 to evaluate the form, chemical composition, accessibility, and location of remaining subsurface oil (SSO) residues of *Exxon Valdez* oil on shorelines in Prince William Sound. We found SSO residues only in isolated patches, buried in low-permeability sediments protected from water-washing and erosion by surface boulder and cobble armoring. These SSO residues are sequestered and largely isolated from natural weathering processes that would result in their complete and rapid removal. SSO residues are not accessible or bioavailable to wildlife that forage on the shore. These findings confirm the lessons learned from all previous crude oil spills:

1) SSO residues can be sequestered for decades in intertidal sediments at locations where the subsurface water flow required for erosion, dissolution, and biodegradation of the oil is low.
2) Sequestration limits the exposure of biota to potentially harmful fractions of the SSO.

Introduction

For over 20 years, scientists have been studying the shorelines of Prince William Sound (PWS) to understand the distribution, fate, persistence, and bioavailability of *Exxon Valdez* oil residues that stranded on the shore in 1989. Grounding of the tanker resulted in the release of 258,000 barrels of Alaska North Slope crude oil into PWS. Shoreline surveys in 1989 found that approximately 783 km (16%) of the 4,800 km of PWS, Alaska, and another 1,300 km (13%) of the roughly 10,000 km of shoreline in the western Gulf of Alaska were oiled to varying degrees. Subsequent surveys were undertaken by the joint State, Federal, and Exxon Shoreline Cleanup Assessment Team (SCAT) from 1990 to 1992. In 1991–1992, surface oil was found along 96 km while subsurface oil (SSO) was present on approximately 10 linear km in PWS. Subsequent shoreline surveys in 1990 through 1992 documented the rapid decline of shoreline oiling in PWS from 420 km in 1990 to 10 km in 1992. About one-third of the subdivisions where surface oil was found in 1991 also contained SSO. In more recent PWS studies (2001–2009) by Exxon and National Oceanic and Atmospheric Administration (NOAA) supported scientists, SSO has been observed as small, discontinuous,~3 cm thick patches, located under a 5–10 cm layer of surface sediment and/or boulder/cobble armor cover in the middle and upper tide zones of a small fraction of the shores where it was documented in 1991. Currently, few locations remain that have any significant SSO, but the presence of these SSO residues continues to support the hypothesis of continuing harm to wildlife. This poster summarizes what is known about the persistence and bioavailability of SSO residues and how our current understanding relates to observations from other well-studied oil spills.

Comprehensive Surveys Are Essential

Comprehensive shoreline surveys in 1989–1992 provided the basis for assessing oil distribution and persistence, allowing us to predict current conditions. The 2001 NOAA survey was based on results of the 1991 survey. The surveys showed that:

- Surface oil was removed rapidly; persistent residues weathered to inert asphalt
- SSO declined at rates from ~80%/year in 1989–1992 to ~4%/year after 2001.
- By 2001, most SSO was light oil residues. Only heavy and medium oil residues (HOR and MOR) may pose an ecological risk.

Joint Shoreline Surveys Sought to Identify SSO Deposits

Beginning in 1990, SSO deposits became an issue of concern and resulted in the following specific shoreline surveys:

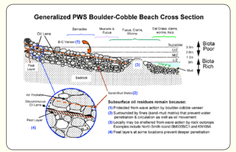
- SSAT 1990 documented intertidal SSO deposits, defined as oil >5 cm below surface boulder/cobble armor.
- MAYSAP (1991) and FINSAP (1992) surveyed sites where SSO was found by earlier surveys
- The number of shoreline subdivisions surveyed decreased from year to year as subdivisions with no SSO were dropped.

Joint Survey	Year	Total PWS Length	Subdivisions Surveyed	Number of Pits Dug
SSAT	1990	1,109 km	711	3,534
MAYSAP	1991	386 km	434	2,990
FINSAP	1992	32 km	81	712

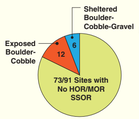
Oil Persistence is Related to Substrate and Environmental Exposure

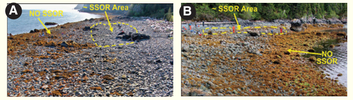
The amount and distribution of the remaining oil on the shoreline is a function of beach geomorphology and exposure. Most remaining SSO residues (SSOR) occur as sequestered deposits in low permeability sediment in boulder/cobble/gravel beaches that are protected by a surface boulder veneer.

Why do boulder/cobble shorelines promote SSO persistence?



Subsurface oil sequestered in fine sediment beneath boulder/cobble "armor"

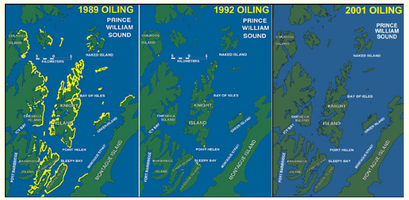




Example is based on NOAA 2001 data

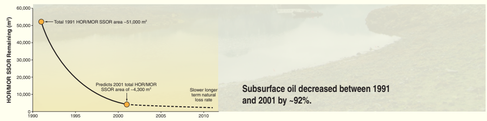
Most Shoreline Oil is Removed Rapidly by Natural Processes

As a result of extensive cleanup and natural processes, the vast majority of oil on the shoreline was removed by 1992.



Oiling is patchy within the spill zone and at a given location—becomes more so as time goes on.

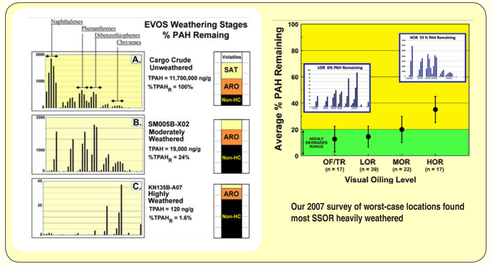
Note: In 2001 patches are not visible at scale of map.



Subsurface oil decreased between 1991 and 2001 by ~92%.

Oil Weathering Removes Toxic Components

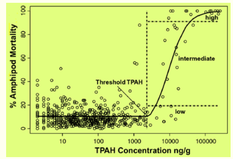
The oil weathered rapidly, even before it hit the shoreline in 1989. Thereafter, a steady progression of weathering served to remove most of the oil's more toxic components.



Our 2007 survey of worst-case locations found most SSOR heavily weathered

Oil Toxicity Decreases As It Weathers

Because chemical weathering reduced total polycyclic aromatic hydrocarbon (PAH) concentrations, the toxicity of oil, as measured in standard amphipod bioassays done on sediment samples collected in 1990–1993, diminished after 1989.



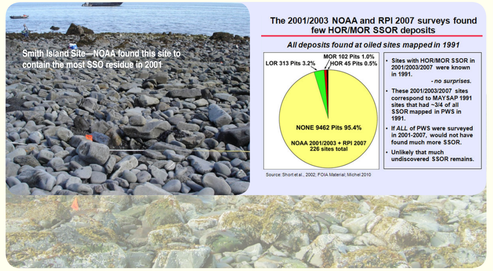
TPAH Threshold = 2600 ppb

LC10 = 4100 ppb TPAH (similar to ER-L)

After 20 Years, Some Oil Remains

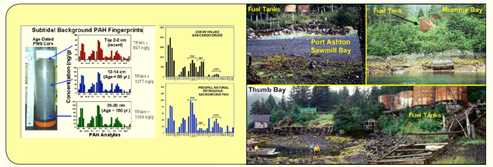
As seen with other spills, oil remains in a few isolated localities. We know why and where. The locations of MOR/HOR identified by SCAT 1990–1992 closely correlate with SSOR identified by NOAA in 2001 and 2003, and the RPI surveys of 2007 and 2008.

Boehm et al. (1995), stated that "Localized residues of weathered oil will no doubt exist beyond 1994 at certain locations, but their environmental significance will be negligible compared with other stresses ongoing in the sound."



Other Sources of PAHs Are Present in Prince William Sound

PWS is not chemically pristine. Sophisticated forensic analysis identified background levels of PAHs from hydrocarbon-rich natural deposits southeast of PWS and PAHs from commercial operations in sediments throughout PWS. These levels represent the baseline conditions against which the fate of inputs from the spill can be measured.



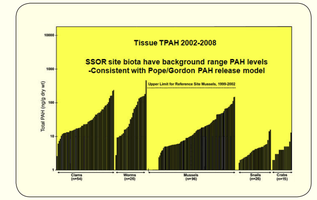
Fingerprinting differentiates the regional petrogenic hydrocarbon background in PWS from spill oil.

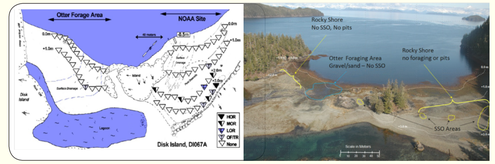
Past fuel use at former fish processing facilities and mines adds bioavailable baseline PAH.

No Risk of Exposure or Injury from Remaining Oil

Direct measurements and observations confirm that the remaining SSOR exist as scattered sequestered deposits at specific well-known locations and are not readily bioavailable or bioaccessible. The SSOR are degrading naturally and pose no risk to the environment.

Sea otters do not dig for prey where SSOR are present





Conclusion

The fate and persistence of subsurface *Exxon Valdez* oil, as sequestered in isolated localities and biologically unavailable, was predictable based on results of previous oil spill studies (Arrow, Amoco Cadiz, others) and confirmed from field studies continuing from 1989 to 2008.

Key Citations

Boehm, P.D., D.S Page, E.S. Gilfillan, W.A. Stubblefield, and E.J. Harner. 1995. Shoreline ecology program for Prince William Sound, Alaska, following the Exxon Valdez oil spill: Part 2—Chemistry and toxicology. In: Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters. P.G. Wells, J.N. Butler, and J.S. Hughes (eds). American Society for Testing and Materials, Philadelphia, PA.

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