The 2015 Refugio Beach Oil Spill: Oil Exposure and Potential Effects to Fish, Invertebrate Early Life Stages, and Kelp

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INTRODUCTION

On May 19, 2015, the underground Line 901 pipeline, owned and operated by Plains All American Pipeline, L.P., and Plains Pipeline, L.P., sustained a release of crude oil near Refugio State Beach in Santa Barbara County, California. Oil released from the pipeline pooled, then overflowed into a nearby culvert, across land and other drainage systems, and entered the Pacific Ocean in the nearshore environment. *Phyllospadix spp*. (surfgrass), *Zostera marina* (eelgrass) and *Macrocystis pyrifera* (giant kelp) beds were observed to be oiled. Additionally, dead fish and invertebrates associated with these habitat types were observed on beaches in the spill affected area. Surf water samples were collected by the Center for Toxicology and Environmental Health (CTEH), in support of the Unified Command, to assess potential exposure to members of the public and ecological receptors from chemical constituents related to the crude oil release. Additionally, the National Oceanic and Atmospheric Administration (NOAA) conducted overflights over the spill affected area to observe the presence of oil on the ocean surface. The purpose of this report is to summarize these water chemistry data and oil sheen observations in order to evaluate potential effects on fish and invertebrate early life stages and kelp in the nearshore environment.

METHODS

Field Sampling Procedures

Field sampling procedures were documented in the Emergency Response Environmental Sampling and Analysis Work Plan (CTEH, 2015). Surf water samples were collected from nine locations from 20 May 2015 to 20 July 2015 (Figure 1) by wading into the surf zone and filling a 1-L amber glass bottle for polycyclic aromatic hydrocarbon (PAH) analysis and a 1-L amber glass bottle for total petroleum hydrocarbon (TPH) analysis. Visual observations were denoted, and photographs were taken at each surface water sampling location. Daily overflights were conducted by NOAA from 21 May 2015 to 3 June 2015, and the GPS locations of oiling observations were recorded and mapped.

Chemical Analysis

CTEH water samples were shipped to Pace Analytical Laboratories and Gulf Coast Analytical Laboratories. Extracts were analyzed for PAHs by USEPA Method 8272SIM and for TPH (sum of gasoline, diesel and motor oil ranges; C5-C36) by USEPA Method 8015. Analytical data were not surrogate recovery corrected. Results for 37 individual PAHs and alkylated homologue groups were summed to estimate total PAHs ($TPAH_{37}$): naphthalene; 1-methylnaphthalene, 2-methylnapthalene; C2-naphthalenes; C3-naphthalenes; C4-naphthalenes; acenaphthylene; acenaphthene; fluorene; C1-fluorenes; C2-fluorenes; C3-fluorenes; phenanthrene; anthracene; C1-phenanthrene/anthracene; C2-phenanthrene/anthracene; C3-phenanthrene/anthracene; C4-phenanthrene/anthracene; pyrene; fluoranthene; C1-fluoranthene/pyrenes; C2-fluoranthene/pyrenes; C3-fluoranthene/pyrenes; benz[a]anthracene; chrysene; C1-chrysenes; C2-chrysenes; C3-chrysenes; C4-chrysenes; benzo(a)pyrene; perylene, benzo(e)pyrene; benzo(b)fluoranthene; benzo(k)fluoranthene; benzo(g,h,i)perylene;

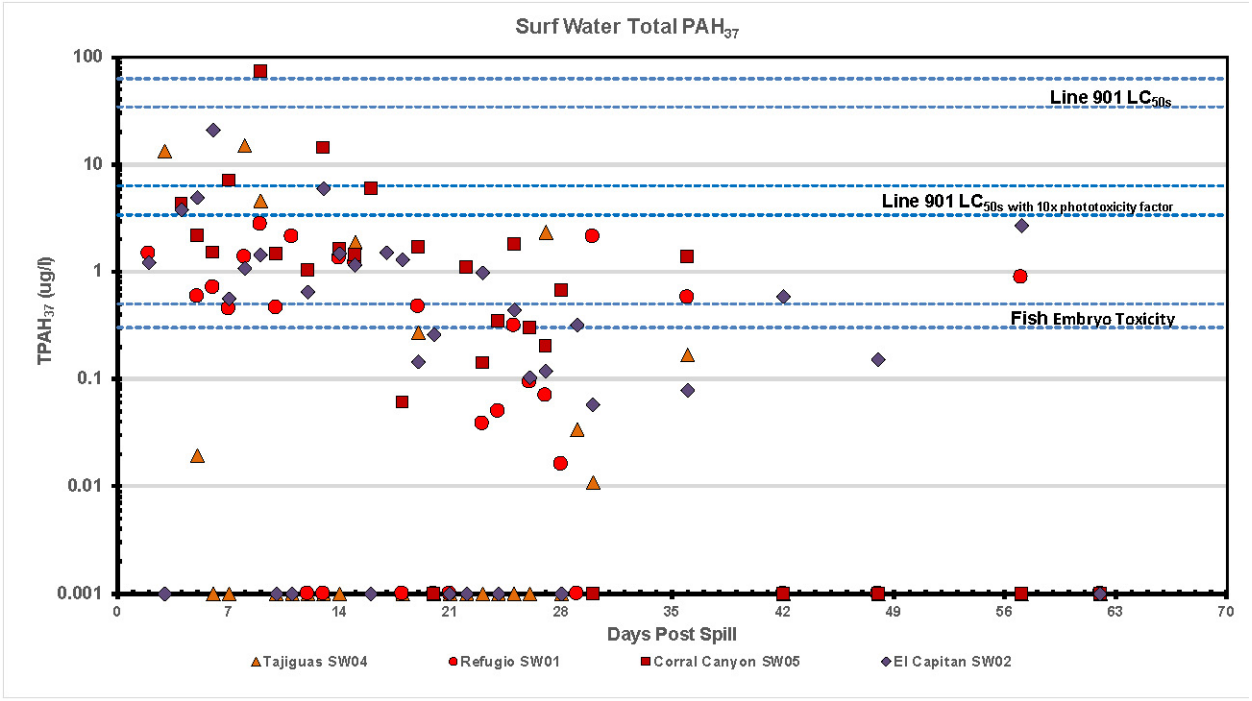
indeno(1,2,3-c,d)pyrene; and dibenz(a,h)anthracene. When calculating $TPAH_{37}$, non-detects (ND) were assumed to be zero.

Figure 1. *CTEH Surf Water Sample Locations within Exposure Zones A, B and C*.

RESULTS and DISCUSSION

Surf Water Chemistry

$TPAH_{37}$ surf water concentrations measured in Zone B, adjacent to the release site, ranged from not detected (ND) to 14.9 µg/l at Tajiguas (n=30), ND – 2.7 µg/l at Refugio (n= 29), ND – 73.2 µg/l at Corral Canyon (n=27), and ND – 21.1 µg/l at El Capitan (n=34; Figure 2). In the eastern portion of Zone B, $TPAH_{37}$ surf water concentrations ranged from ND – 9.1 µg/l at Haskells (n=32) and ND – 5.6 µg/l at Sands Beach (n=33), (Figure 3). $TPAH_{37}$ concentrations in Zones A and C ranged from ND – 11.9 µg/l at Gaviota (n=32), ND –5.3 µg/l at Goleta (n=27) and ND – 6.4 µg/l at Arroyo Burro (n=31; Figure 4). Samples were not consistently collected at Zone B locations until 5 days after the spill (23 May 2015). Hence, these concentrations do not represent the maximum concentrations that likely occurred in Zone B immediately after the spill. Highest $TPAH_{37}$ concentrations were measured at sampling locations near the release point in the first two weeks after the spill and then generally declined.



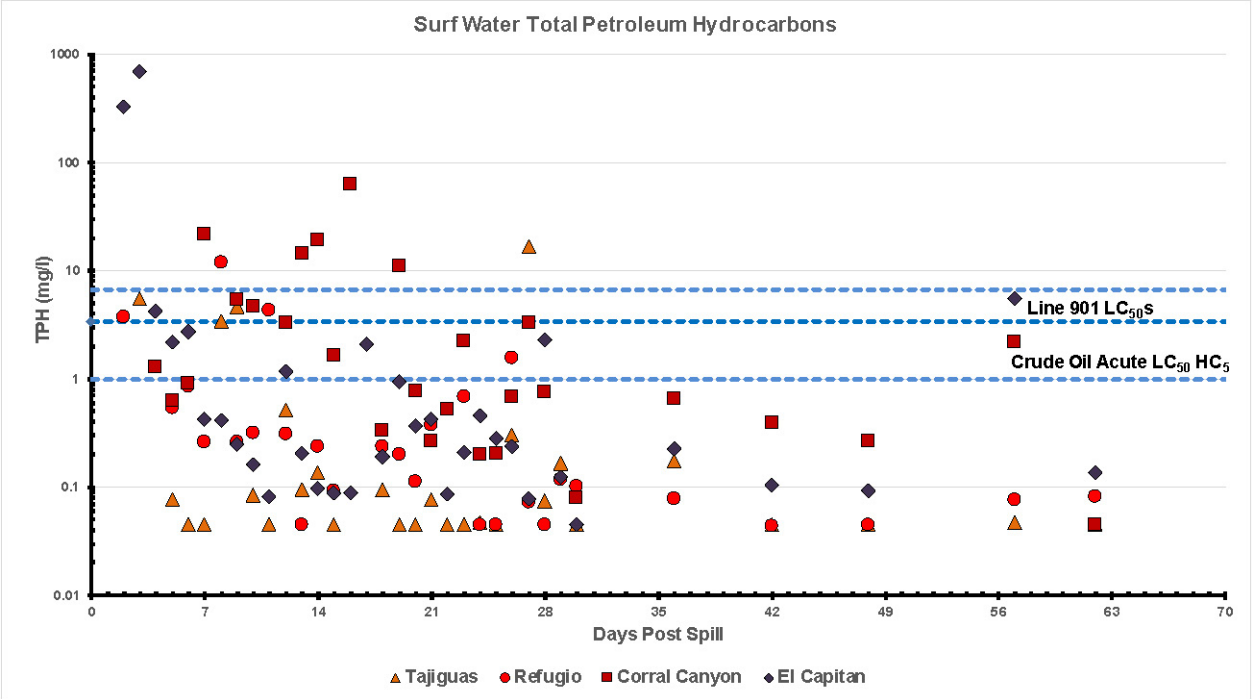
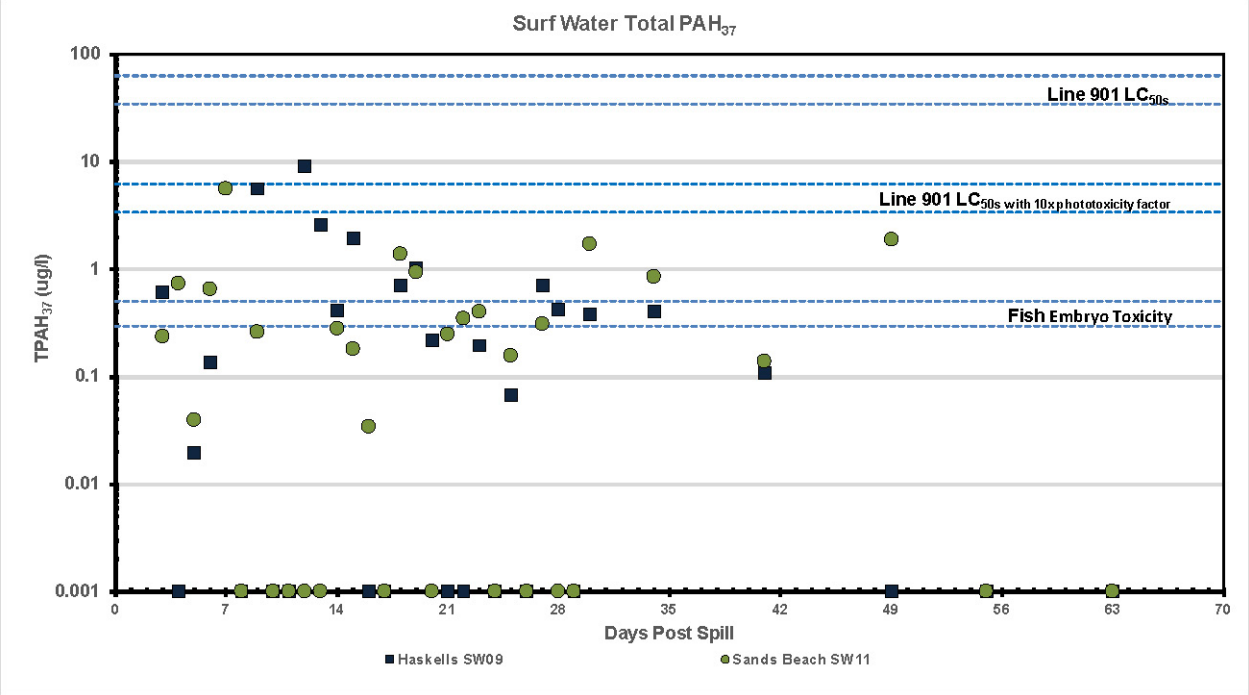


Figure 2. *Surf water $TPAH_{37}$ (ug/l; top; ND was zero but was set to 0.001 for graphing on a log scale) and TPH (mg/l; bottom) concentrations in Zone B, adjacent to the release point.*



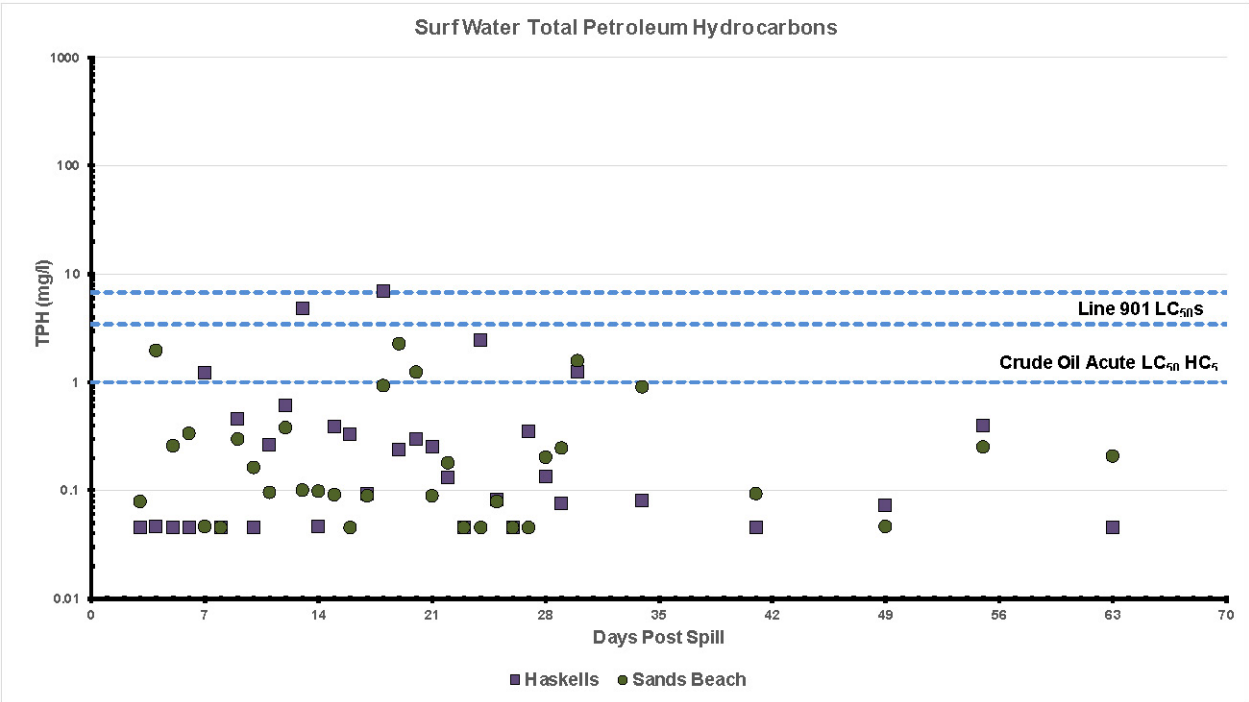


Figure 3. *Surf water TPAH$_{37}$ (ug/l; top; ND was zero but was set to 0.001 for graphing on a log scale) and TPH (mg/l; bottom) concentrations in Zone B, farther east of the release point.*

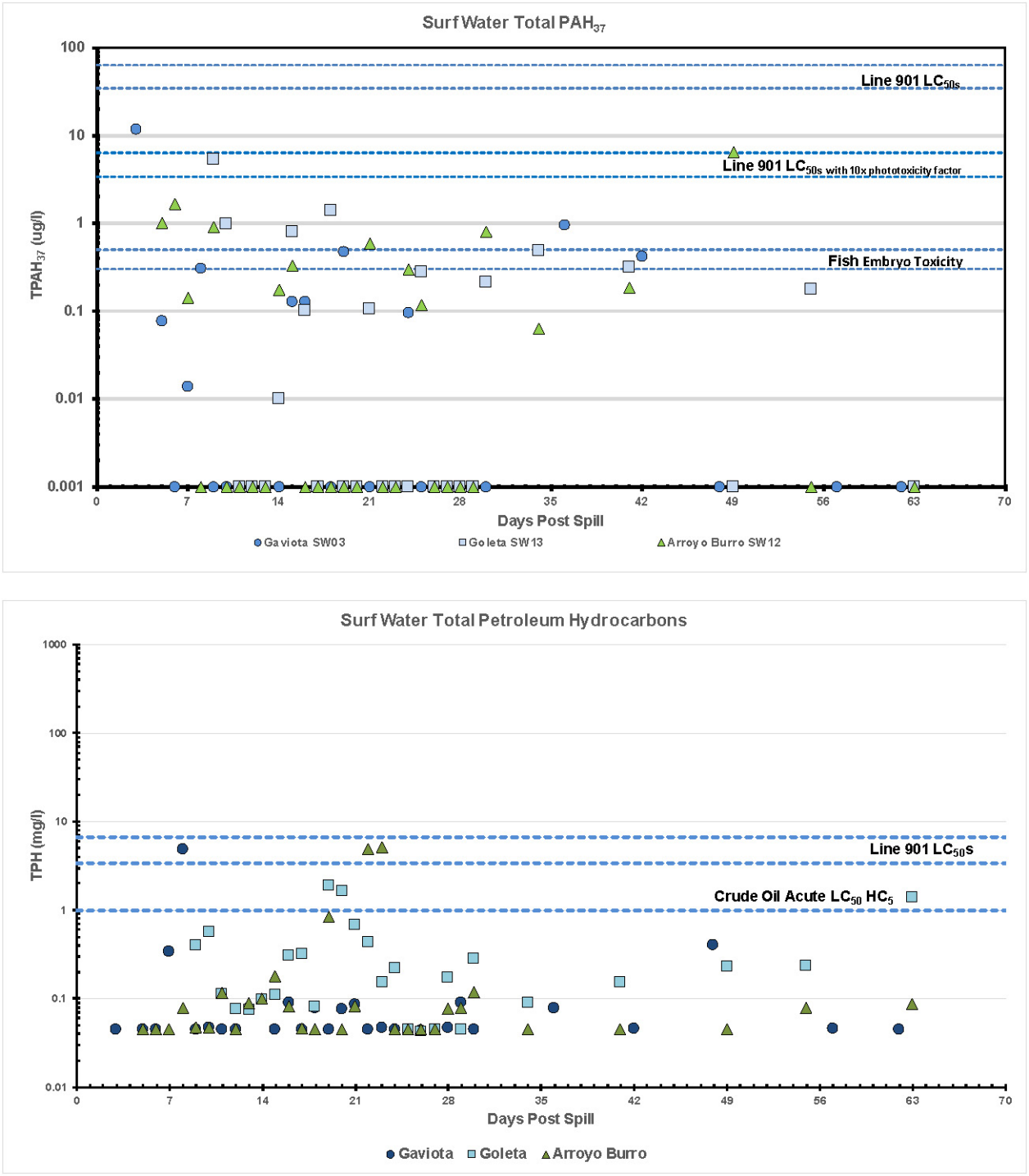


Figure 4. *Surf water $TPAH_{37}$ (ug/l; top; ND was zero but was set to 0.001 for graphing on a log scale) and TPH (mg/l; bottom) concentrations in Zone A and C.*

TPH concentrations were not directly correlated to $TPAH_{37}$ concentrations because they were collected as separate samples, and surf water was likely heterogeneous due to the presence of oil droplets and particulates. Field samplers noted the presence of tarballs and sheen during sampling, and the highest frequency of reported sheen observations was in Zone B (Figure 5).

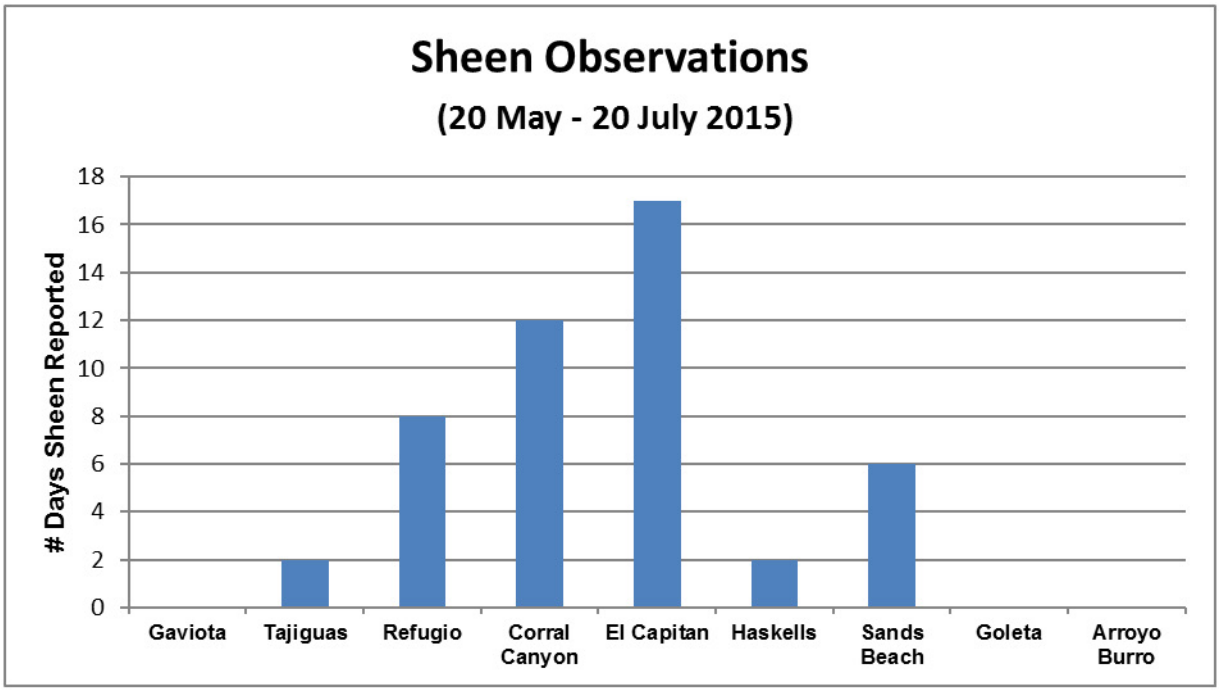


Figure 5. *Number of Days Field Samplers Observed and Recorded Sheen from 20 May to 20 July 2015.*

TPH surf water concentrations measured in Zone B, adjacent to the release site, ranged from 0.04 – 16.6 mg/l at Tajiguas (n=30), 0.04 – 11.9 mg/l at Refugio (n= 29), 0.04 – 63.1 mg/l at Corral Canyon (n=28), and 0.04 – 697 mg/l at El Capitan (n=34; Figure 2). In the eastern portion of Zone B, further from the spill site, TPH surf water concentrations ranged from 0.04 – 6.9 mg/l at Haskells (n=33) and 0.04 – 2.3 mg/l at Sands Beach (n=33; Figure 3). TPH concentrations in Zones A and C ranged from 0.04 – 4.9 mg/l at Gaviota (n=32), 0.04 – 1.9 mg/l at Goleta (n=27), and 0.04 -5.1 mg/l at Arroyo Burro (n=31; Figure 4). These concentrations do not represent the maximum concentrations that likely occurred in Zone B immediately after the spill for the reasons mentioned above.

Comparison of Surf Water Chemistry to Fish and Invertebrate Toxicity Benchmarks

An acute (6-day) survival and growth bioassay with sand crab (*Emerita analoga*) megalopae and 7-day survival and growth bioassay with inland silverside (*Menidia beryllina*) juveniles were conducted with a high energy water accommodated fraction of Line 901 source oil (Appendix E). The lethal concentration to 50% of the test animals (Line 901 LC_{50}s) at the end of the bioassays ranged from 34.4 – 63.5 µg/l $TPAH_{37}$. On a TPH basis, the Line 901 LC_{50}s ranged from 3.4 – 6.7 mg/l. These values are similar

to LC_{50} values generated for crude oils with other species. For example, the acute (2-4 day) TPH lethal (LC_{50}) hazardous concentration affecting 5% of the species in the community (HC_5) was 1 mg/l (Barron et al., 2013). This TPH HC_5 (1 mg/l) addressed acute toxicity via the narcosis mode of action without the presence of ultraviolet light (UV). Studies have shown that UV light can enhance the toxicity of PAHs by a factor from 2 – 1000 (Barron, 2017). For the purpose of this evaluation, Line 901 LC_{50} values were adjusted with a 10x factor (3.4 – 6.3 µg/l $TPAH_{37}$) to estimate phototoxicity. In a recent literature review, Lee et al (2015) reported that the EC_{50} – LC_{50} for sublethal or chronic exposures ranged from 0.3-60 µg/l for TPAH and from 0.03-11 mg/l for TPH. Oil induced fish embryotoxicity, such as pericardial and yolk sac edemas, and craniofacial, spinal and cardiac deformities have been reported to occur at the lower end of the range (0.3 µg/l TPAH; Incardona et al., 2015) and Hodson (2017) concluded that concentrations greater than 0.1 µg/l TPAH following oil spills should be considered hazardous. In a series of toxicity tests conducted following the Deepwater Horizon oil spill, the EC_{20} for fish embryo cardiotoxicity for TPAH was reported at be as low as 0.5 µg/l, and UV exposure produced lethality (LC_{50}) as low as 0.1 µg/l for TPAH (Deepwater Horizon Natural Resource Damage Assessment Trustees, 2016). The percentages of surf water samples at each location (Figures 2-4) exceeding the lowest $TPAH_{37}$ Line 901 LC_{50} (34.4 µg/l), the lowest $TPAH_{37}$ Line 901 LC_{50} adjusted for phototoxicity (3.4 µg/l), the TPAH fish embryo toxicity benchmark (0.3 µg/l; Lee et al., 2015), and the TPH Acute LC_{50} HC5 (1 mg/l; Barron et al., 2013) were calculated (Figure 6). These benchmark exceedances indicate surf water concentrations were potentially lethal to fish and invertebrate early life stages.

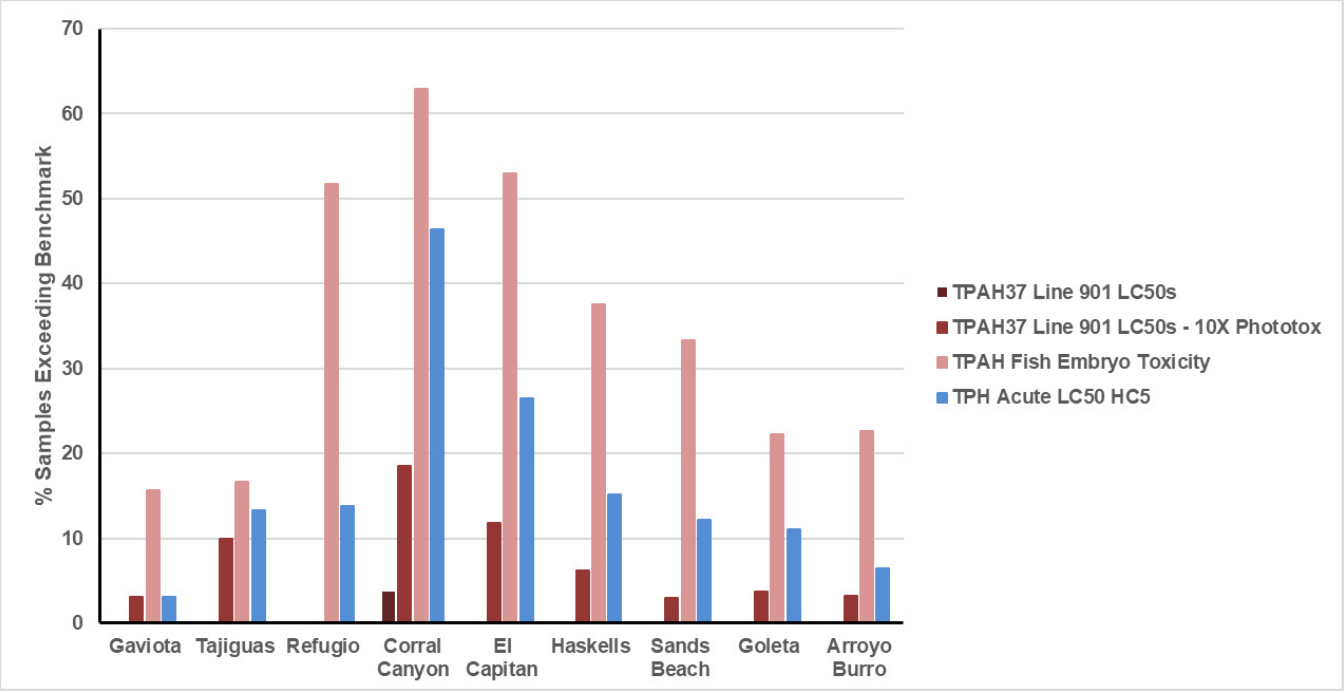


Figure 6. *Percent of surf water samples collected 20 May to 20 July 2015 at each location that exceeded fish and invertebrate early life stage toxicity benchmarks.*

Surface Oil Observations from Overflights and SCAT Data

The first overflight occurred on the third day of the spill (May 21, 2015), and oil was observed on the surface of the ocean throughout Zones A and B and beyond the 10m bathymetric line (Figure 7). Surface oiling continued to be observed during the first week as the oil moved eastward within Zone B and southward (May 25, 2015; Figure 7). Surface oil continued to be observed until the last overflight on June 3, 2014. During the overflights, oil was observed in the kelp canopy in Zone B, as depicted in Figure 8. A composite of the surface oil observations, with a 0.5 km buffer around each observation, made from May 21 – June 3, 2015, is depicted in Figure 9. Surface oil was observed throughout Zone B, both within the 0-10 m bathymetric zone where kelp occurs and farther offshore (> 10 m bathymetric zone).

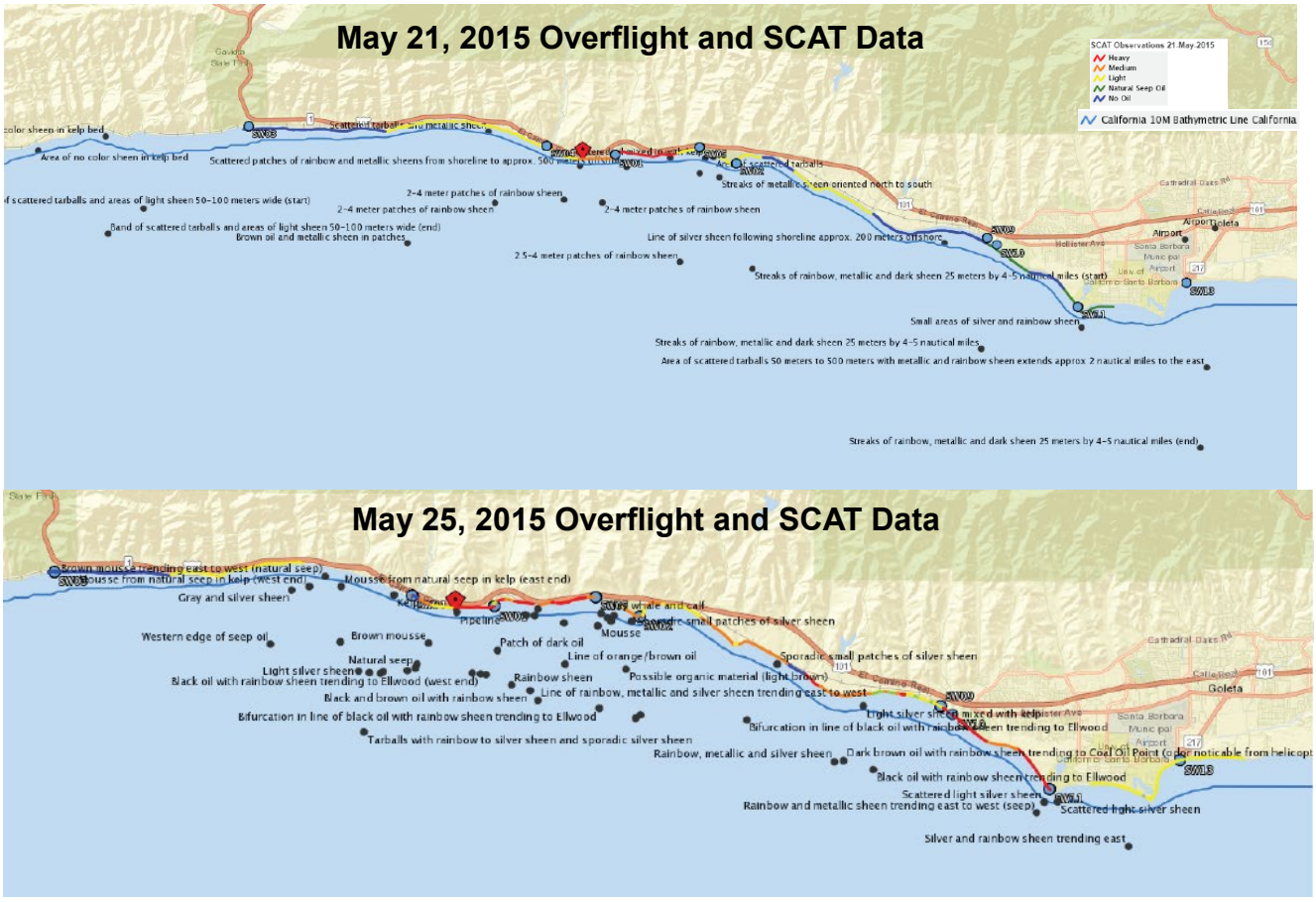


Figure 7. *Surface oil observations from overflights and SCAT data from May 21, 2015, (top) and May 25, 2015 (bottom).*

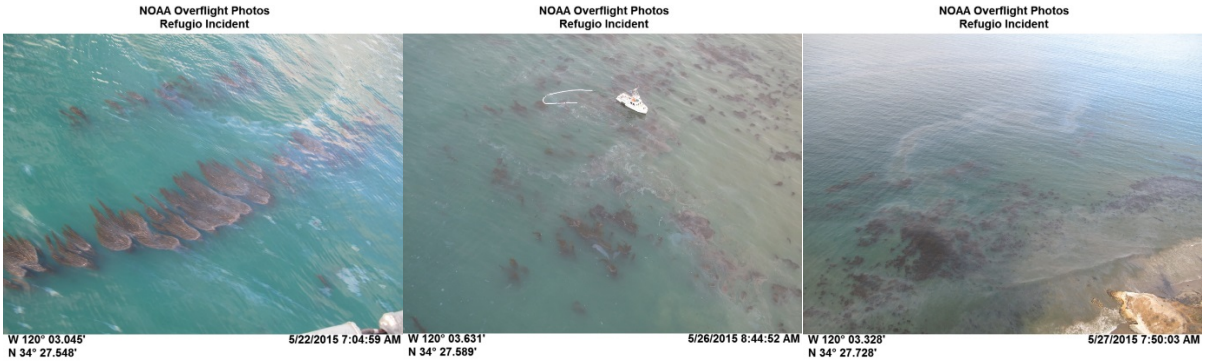


Figure 8. *Aerial photographs of oil in kelp canopy in Zone B from May 22 – 27, 2015.*

Figure 9. *Composite map of Zone B surface oil observations (May 21 – June 3, 2015) with a 0.5km buffer around each observation point*

In Santa Barbara, the giant kelp (*Macrocystis pyrifera*) is the foundational species of the subtidal rocky reef ecosystem (Miller et al. 2015). Attached to the rocks by holdfasts, the kelp fronds grow to the water surface, creating a forest that provides vertical habitat for one of the richest communities on earth (Foster and Schiel 1985, Schiel and Foster 2015). Hundreds of invertebrate and fish species use the fronds and holdfasts of giant kelp as a place to live, a refuge from predators, and an enhanced food supply in the form of plankton and small epiphytes that live on the fronds. Early life stages of many fish and invertebrate species live in the kelp canopy near the water surface as the fronds dampen currents and provide protection. At the Arroyo Quemado kelp forest, a Santa Barbara Coastal Long-Term Ecological Research site, common species include polychaetes, sea urchins, sea stars, spiny lobsters, kelp bass, rockfish, California sheephead and several other algal species (Schiel and Foster 2015). Additionally, seabirds and marine mammals frequently forage in the kelp forest.

During the January 1969 spill of over 70,000 barrels of crude oil into the Santa Barbara Channel from Platform A (Foster et al. 1971, Foster and Holmes 1977), offshore kelp beds received the first dose of incoming oil, and the kelp beds' floating fronds held large quantities of oil (Mitchell et al. 1970). The oil did not appear to stick to healthy fronds because of the species' mucus production but was seen adhering to patches of damaged tissue (Mitchell et al. 1970, Foster et al. 1971). A quantitative evaluation of the effects of the oil on the kelp canopy was not conducted for the 1969 spill.

However, laboratory studies have shown that kelp fronds exposed to crude oil become bleached (Antrim et al.1995). When significantly bleached, portions of the plant decayed in 3-4 days and then broke off. Plants with color loss were less slippery, indicating a loss of the mucus coating. Disruption of the mucus layer and subsequent drying lead to splitting and microbial decay of the tissue. Reduced photosynthesis accompanied the loss of photosynthetic pigments and disruption of cellular metabolism (Antrim et al. 1995). Thus, direct contact of the kelp canopy with oil may have reduced primary productivity. Since the kelp canopy can trap the oil, this may have increased the exposure duration for kelp and the fish and invertebrates associated with the canopy. This also may have resulted in increased mortality for the exposed organisms, including the more sensitive fish and invertebrate early life stages. Recent studies have shown that exposure to thin floating oil sheens are lethal to fish and invertebrate early life stages, and effects are potentiated with exposure to UV light (Morris et al., 2015).

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