Appendix F. Shoreline Habitat Equivalency Analysis

The Refugio Beach Oil Spill began on 19 May 2015 near Refugio State Beach in Santa Barbara County, California. Oil travelled down coast to Ventura and Los Angeles Counties. The initial injury (i.e., the percentage injury representing the first month after the spill) to shoreline resources occurred as fresh oil deposited along the shorelines, fouling beaches, adhering to the rocky substrate, and smothering fauna. Impacts to the habitats continued for months, as oil remained adhered to rocks and was buried in sand throughout several locations. There were additional impacts in some areas along the shoreline due to clean-up efforts, which included driving on beach habitat to access remote locations, scouring and/or movement of cobble, and removing beach wrack. In some of the more heavily oiled areas, it was not possible to clean up buried oil, and the response relied on fall and winter swells to remove accreted sand that had buried oil deposits, delaying biological recovery.

This appendix describes a habitat equivalency analysis (HEA) for spill impacts to shoreline intertidal habitats. The intertidal zone is an area of transition that provides unique habitat for aquatic and terrestrial species. Dozens of bird and fish species utilize this zone to feed on macroinvertebrates in the lower and upper intertidal areas of the shoreline. When evaluated in terms of biomass, sand beaches are dominated by sand crab (*Emerita analoga*) communities in the lower intertidal zone, and by beach hoppers (talitrid amphipods, including *Megalorchestia spp.*) in the upper intertidal zone. The upper intertidal is inhabited by a wide variety of other invertebrates, but their biomass is significantly lower than that of beach hoppers. Sand crabs and beach hoppers dominate the invertebrate biomass on Southern California sandy beaches (Dugan et al., 2003). As a defining ecological characteristic of lower intertidal communities, sand crabs were used as a measure to estimate and describe injury to lower intertidal habitats as a whole. Beach hoppers were selected as a proxy for assessing impacts to the upper intertidal community, as they are an important part of the sandy beach ecosystem that: 1) process organic matter such as stranded kelp material, also known as wrack; 2) make up a significant portion of food items for several bird species; and, 3) are amenable to assessment of their populations through field sampling.

Shoreline habitat injury is quantified in terms of acres of exposed habitat within the entire intertidal zone and characterized by the intensity or degree of initial impacts. Given the wide geographic spread of the oil and the magnitude of exposed acreage, the injury estimate is split into four geographic exposure zones (A through D), which cover the affected areas from west (up-coast) to east (down-coast) (Figure 1).

Figure 1. Oil exposure zones, as determined from Shoreline Cleanup and Assessment Team (SCAT) data.

Calculations of the injury integrated over time account for acreage, intensity, and duration of injury. Recovery in Zone B is characterized in monthly time steps that capture the seasonality in the recruitment of the key indicator species (Table 1). Zones A and C (outside the main area of impact) are expected to be subject to the same recovery mechanism as Zone B, but the biological impacts in these areas are only a fraction of what was experienced in Zone B. Injuries in Zone D were significantly less and were approximated only where Line 901 tarball-oiling was observed (Figure 1).

The majority of the shoreline of the spill affected area is comprised of mixed sandy and rocky habitats. Sand covers and scours boulders and other rocky outcrops through seasonal movement, preventing typical rocky intertidal communities (i.e., barnacles, mussels, algae, and other sessile organisms) from populating many of these areas. A large proportion of the area quantified as shoreline habitat within the spill zone was comprised of this mixed sandy/rocky habitat. Since many of these locations are devoid of significant rocky intertidal fauna/floral communities, the Trustees considered these areas to function mostly as sand beach habitat ecologically. To facilitate injury quantification, mixed sandy/rocky habitat was assessed as sandy beach. Based on the Trustees' calculation of shoreline habitat acreages (Appendix D of the Damage Assessment and Restoration Plan), a total of 1488 acres of sandy beach within Zones A-D, and 5.4 acres of rocky intertidal habitat (all within Zone B) were injured. The determination of area and the severity of the injury within each habitat type and exposure zone is further described below.

Quantification

The shoreline injury assessment (Appendix D of the Damage Assessment and Restoration Plan) involved studies that elucidated both exposure and injury to shoreline habitat species, including studies of representative fauna from different elevations of the shoreline (lower, middle, and upper intertidal), rather than attempting to study all species present on the shoreline. Sand crabs (*Emerita analoga*) were used to assess the lower intertidal habitat, bloodworms (*Thoracophelia mucronata,* formerly *Euzonus*) for the middle intertidal habitat (exposure only), beach hoppers (*Megalorchestia spp*.) for the upper intertidal habitat, and California mussels (*Mytilus californianus*) as a proxy for rocky intertidal species. Chemical analyses of body burdens of polycyclic aromatic hydrocarbons (PAHs) accumulated in these species, were used as indicators of oil exposure from the spill. Further, the first three species have different roles in the sandy beach food web, different levels of exposure to seawater and porewater (water table within the beach), different modes of respiration, and different pathways of exposure to buoyant material, such as oil and tarballs, that tend to strand in the upper beach. Exposure and injury studies concentrated on these and other representative taxa with the intention of using the information gathered to inform injury levels for the rest of the sandy beach community.

Rocky intertidal substrate surveys were conducted to monitor changes in abundances of sessile organisms, substrate, and “condition” (oil/tar presence, bleaching), along transects within fixed plots over time (post spill and six/twelve months post-spill), using a “RAPID assessment” protocol developed specifically for oil spills (Raimondi and Miner, 2009; Raimondi et al., 2012). Teams also surveyed permanent Long Term Monitoring sites within the approximate spill affected area that have been sampled over time using a similar protocol for comparison to historical data. In addition, biodiversity data gathered from Long Term Monitoring sites were used to examine patterns of community similarity among sites. Photos collected within each transect were scored and analyzed for substrate, condition (oiling/bleaching), species composition and proportion within the zone of view. Sites were re-visited in Fall 2015 and Spring 2016 to examine for community differences, presence/absence, or proportional changes to communities or substrate (Raimondi et al., 2019).

Shoreline injury estimates are based on multiple lines-of-evidence including abiotic data (e.g., chemistry), biotic data (e.g., biological surveys, toxicity bioassays) and information about the clean-up effort. See Appendix C of the Damage Assessment and Restoration Plan for a further explanation of HEA and Appendix D for more details on shoreline injury assessment methods.

Area

The Trustees identified four broad geographic zones based on documented shoreline oiling. For quantifying injuries to sandy beach habitat, the zone directly surrounding the release (Zone B) was further subdivided into nine “micro-zones”, centered on nine beach sampling locations (i.e., Arroyo Hondo, Arroyo Quemado, Tajiguas, Refugio, Venedito, El Capitan, Dos Pueblos, Haskell’s, and Coal Oil Point) with sufficient data to evaluate initial injuries. The area of shoreline habitat in each broad or micro-zone was calculated from the NOAA Geographical Information System (GIS) database displayed in the Environmental Response Management Application Southwest (ERMA Southwest, Appendix B of the Damage Assessment and Restoration Plan) and prepared by RPI (2018). Micro-zone acreages within Zone B were calculated by summing the acres of sand/mixed cobble beach habitat between the beach site sampled and the midway point between that site and the next site to the: 1) east, and 2) west. In cases for which the site was closest to the boundary of Zone B (Arroyo Hondo at the west end of Zone B, Coal Oil Point at the east end of Zone B), and all sandy beach acres between the site and the nearest boundary were included in the micro-zone area calculation. In total, Zone B contained 345.76 acres that were assessed for injury. All of the intertidal area in Zone A (63.18 acres) and C (191.29 acres) was evaluated for sandy beach injury, but only the SCAT confirmed tarball-oiled areas in Zone D (Figure 1) were evaluated for sandy beach injury (888 acres). For rocky intertidal habitat, 5.4 acres of habitat was assessed as injured.

Intensity of Oiling

The shoreline injury estimates relied on the Trustees' initial characterizations of oiling in the four geographic zones based on SCAT documented oiling levels [Figure 1 and RPI (2018)]. In some cases, Trustee photographs or field notes containing information about oil exposure were also considered, particularly within the individual micro-zones assessed in Zone B.

Mechanisms of Injury

Shoreline injury was estimated using three general mechanisms of injury: toxicity, fouling, and clean-up effort. Brief definitions for these are:

1. Toxicity. *The quality of being toxic or poisonous; the effects of oil or components of the oil (i.e., PAHs absorbed dermally or via ingestion) exerting a deleterious effect on organisms*.
2. Fouling. *Defined here as making foul or dirty with oil, in particular resulting from the contact between an organism(s) and the oil, and the organism(s) being directly oiled. As an example, fouling may result in coating and clogging of feeding appendages with oil, rendering them less able to perform their function.*
3. Clean-up Effort. *All methods used to clean up the oil, including hand removal, digging or excavation activity, raking, scraping, washing, blasting, trampling, driving, and crushing that occurred as part of that effort.*

Estimates of Injury

The initial impacts of the spill on sand beach habitat were calculated by aggregating estimates of the effects of fouling, toxicity, and clean-up effort during the first few months after the spill. Total injury captures these effects from the time of the spill until the resources are recovered and ecosystem services return to baseline. See Appendix D of the Damage Assessment and Restoration Plan for more details on shoreline injuries caused by the spill.

Full recovery from the spill requires having the entire suite of ecosystem services that were present before the spill fully restored and for pre-impact conditions to prevail, including the full complement of species and age classes that existed before the spill. Ecological services include those services related to secondary productivity or the ability to provide a full range of prey diversity, biomass and size structure to feed fish, birds and other predators; the production of propagules (eggs, larvae, juveniles); and functions such as nutrient recycling capacity. Representative fauna in upper and lower intertidal zones can live for several years and their population structures include multiple year classes (e.g., representative of larvae, juveniles, and adult life stages). Most beach invertebrates, excluding insects, continue to grow throughout their lives, producing more mass, processing more food, and providing more ecosystem services. Larger and older female invertebrates produce much greater numbers of offspring than small ones. For some species, larger individuals are more robust and better at surviving through harsh winter conditions.

Estimates of recovery time for oil disturbed sandy beach communities were based on monitoring data (beach hopper population data for upper beach), literature values for recovery from past spills/disturbances, and life history patterns of California sandy beach species. Because the representative sandy beach species assessed in Zone B lost substantial proportions of three age classes (first year, second year, and third year) during the spill, and recruitment is seasonal and episodic, full recovery to baseline would be three years at a minimum. Beach hoppers tend to occupy the upper beach elevations that were more heavily impacted by oil and clean-up during the spill. These and other beach-associated amphipods and other upper beach organisms rely exclusively on 'direct' development, whereby the dispersion of their propagules is highly constrained to a small area. For example, if a local population is extirpated or severely depressed, recovery will be protracted because few new individuals will be transported or recruit into the area (Hubbard et al., 2013). This contrasts with sand crabs, which reproduce by releasing planktonic larvae. Planktonic larvae may be transported many miles downcoast by longshore currents, allowing for greater dispersion of new recruits into areas that were reduced in population size. Unlike the beach hoppers, recovery of sand crabs (three years in this case) is faster as it is aided by the quick recolonization of the sandy beach by these new recruits, while the beach hoppers cannot quickly re-establish a large cohort on the beach due to their more constrained direct development method of reproduction.

As described above, Zone B was divided into specific "micro-zones". Within each micro-zone, the degree of injury resulting from fouling, toxicity and clean-up were added together within both the lower intertidal and upper intertidal habitats. Then, the upper and lower intertidal sums were averaged to get the "whole-beach injury" for the given micro-zone. The following is an example calculation:

		Mechanism	
Example:	Tajiguas (Lower Intertidal)	Fouling	0.55
		Toxicity	0.20
		Clean-up	0.10
	Total of 3 mechanisms		0.85
	Tajiguas (Upper Intertidal)	Fouling	0.58
		Toxicity	0.00
		Clean-up	0.05
	Total of 3 mechanisms		0.63

Whole-beach Injury (avg. upper & lower beach) = **0.74**. This is the initial injury in the Tajiguas micro-zone within Zone B.

In Zone B, the initial injury percentage was an area-weighted average of the values of the calculations for the nine micro-zones. Then, monthly time steps were applied using monitoring data and life history characteristics to calculate the injury percentage over time until complete recovery from the injury was predicted. The sandy beach injury trajectory is detailed in Table

1. Zone B injury was assessed at 510.7 discounted service acre years (dSAYs). In Zones A and C, injury per acre was estimated as a fraction or fixed percent of the average per-acre injury in Zone B: 20% in Zone A (18.66 dSAYs) and 25% in Zone C (70.64 dSAYs). Those percentages were selected to approximate impacts associated with a lesser amount of oiling in Zones A and C when compared to Zone B. Zone D was estimated to be 5% injured in year one only, with no injury in subsequent years. Impacts in Zone D were lower because they were primarily based on removal of organisms by direct contact with tarballs, along with the removal of a subset of wrack material during cleanup activities (44.4 dSAYs).

Rocky intertidal habitat was modeled in the HEA as having a 29% service loss in year one, a 5% loss in year two, with no loss modeled in subsequent years. Initial injury was primarily due to direct smothering/fouling and subsequent tissue necrosis/bleaching of the sessile organisms populating this substrate. In addition, injury was caused by trampling (from spill assessment and clean-up activities), physical cleaning of rocky substrates, and sublethal effects from exposure to petroleum (e.g., impaired reproduction or growth). The degree of initial injury also relied on the assumption that the degree of impacts varied with the amount of oiling within Zone B, as more significant fouling was noted in locations adjacent to the release site (i.e., rocky outcrops adjacent to Refugio, Coral Canyon, and El Capitan). Recovery time was quantified based on the life histories of affected biota, and on notable increases of 'disturbance indicator' species (i.e., *Ulva sp.* and *Porphyra sp*.) identified during anniversary surveys at the highest impacted sites.

Using the standard economic discount rate of three-percent[1], total dSAYs lost for shoreline ecosystems, summed over all four zones (A-D) were 646.23: 644.4 dSAYs for sandy beach ecosystems, and 1.83 dSAYs for rocky intertidal ecosystems.

Restoration

The Trustees propose four projects to compensate for the injury described above; three projects for the sandy beach, and one project for the rocky intertidal habitat.

Ellwood Seawall Removal and Sandy Beach Restoration. The goal of this project is to restore lost sandy beach ecosystem services, allowing for more sand to accumulate on the beach and improving the quality of the existing habitat. The project site is Ellwood Beach in Goleta, CA. A creosote-treated wooden seawall currently constrains natural functioning of the ecosystem and lateral access along the shoreline at high tide. Removal of the seawall along 1600 meters of shoreline (approximately one mile) would improve ecological function on about 20 acres of intertidal shoreline seaward of and underneath the footprint of the structure. To quantify the benefits of the Ellwood Seawall Removal, the Trustees estimated that 20 acres of sand beach habitat would benefit from a 60% increase in ecosystem services over 6 years at a rate of 10% per year beginning in 2021. We also estimated that project benefits would end in May 2067 to account for long-term uncertainties in site condition, including those related to sea level rise. The total credit for this project is 232.3 dSAYs.

[1] This is an adjustment made to reflect the fact that services provided in the future are less valuable than services being provided now.

Santa Monica Sandy Beach and Dune Restoration. The goal of this project is to restore sandy beach and coastal dune habitat that has been degraded by intensive mechanical grooming. The project site is a public beach in Santa Monica Bay. The benefits of this project are estimated to be a 75% increase in ecological services over five acres that improves habitat in both the lower and upper intertidal zones. Invertebrate species richness in the lower intertidal zone is estimated to attain a 50% ecosystem services increase. In the upper intertidal zone, an increase from zero to four species of native plants in the dune and coastal strand zone will occur, which will help to initiate natural dune building processes. The Trustees estimate that this will lead to a 100% ecosystem services increase in the upper intertidal. So, adding both of those zone estimates together for purposes of the HEA, the Trustees expect a 10% ecosystem service increase each year over 7 years beginning in 2021, followed by 5% increase in the eighth year, with a 46-year project life ending in May 2067. This represents a 75% increase in ecosystem services overall by averaging benefits provided to the lower and upper intertidal zones. The total credit for the five-acre project is 70.4 dSAYs.

Coastal Dune Enhancement Projects. The goal of these projects is to reduce invasive plant abundance and restore native plants, dune forms and processes. Restoration costs per acre of dune habitat will vary by site, but the following parameters represent an average benefit to shoreline environments estimated from three proposed dune restoration project locations within Ventura County: Ormond Beach, San Buenaventura, and McGrath. To quantify restoration benefits, the Trustees estimated a 60% increase in ecosystem services over 6 years at a rate of 10% per year beginning in 2020. The Trustees estimate a 23-year project life, with benefits tapering off after 18 years at a rate of 10% per year to account for uncertainties related to maintenance of the dune vegetation. Under these assumptions, 50.1 acres of dune restoration would compensate for the sand beach injuries not addressed by the Ellwood Seawall Removal and Santa Monica Sandy Beach and Dune Restoration projects described above. The project would yield an estimated 341.7 dSAYs of credit.

Black Abalone Transplantation and Restoration. The goal of this proposal is to restore black abalone populations in areas affected by the spill and enhance the function of rocky intertidal habitat. The proposal is based on four tasks: 1) characterization of the genetic structure of the donor and recipient black abalone populations, 2) restoration to make habitat suitable for transplanted post-emergent (50-75 mm) black abalone and settlement of larval and subsequent growth of juvenile black abalone, 3) transplantation of post-emergent black abalone from a donor population, and 4) assessment of transplantation efficacy through monitoring population and habitat maintenance and local recruitment success. Based on the target density of abalone, the Trustees would transplant approximately 100 individuals (within a total of 0.4 acres), with subsequent intensive recruitment monitoring. For scaling, the Trustees estimated a 50% increase in ecosystem services over 17 years at a rate of 4% per year beginning in 2020 with a 23-year project life to account for uncertainties, including sea level rise. The Trustees estimate 0.4 acres will be restored, yielding 1.83 dSAYs.

Table 1. Injury trajectory used for sandy beach habitats in Zone B.

Month Interval No.	Start Month	Start Date	End Month	End Date	Zone B Injury Percentage (as decimal)
1	May	19	June	18	0.8000
2	June	19	July	18	0.8167
3	July	19	Aug	18	0.8333
4	Aug	19	Sept	18	0.8500
5	Sept	19	Oct	18	0.8500
6	Oct	19	Nov	18	0.8500
7	Nov	19	Dec	18	0.8500
8	Dec	19	Jan	18	0.8500
9	Jan	19	Feb	18	0.8500
10	Feb	19	Mar	18	0.8150
11	Mar	19	Apr	18	0.7550
12	Apr	19	May	18	0.6700
13	May	19	June	18	0.5850
14	June	19	July	18	0.5000
15	July	19	Aug	18	0.4750
16	Aug	19	Sept	18	0.4750
17	Sept	19	Oct	18	0.4750
18	Oct	19	Nov	18	0.4750
19	Nov	19	Dec	18	0.4750
20	Dec	19	Jan	18	0.4750
21	Jan	19	Feb	18	0.4750
22	Feb	19	Mar	18	0.4450
23	Mar	19	Apr	18	0.3900
24	Apr	19	May	18	0.3350
25	May	19	June	18	0.2800
26	June	19	July	18	0.2250
27	July	19	Aug	18	0.2000
28	Aug	19	Sept	18	0.2000
29	Sept	19	Oct	18	0.2000
30	Oct	19	Nov	18	0.2000
31	Nov	19	Dec	18	0.2000

32	Dec	19	Jan	18	0.2000
33	Jan	19	Feb	18	0.2000
34	Feb	19	Mar	18	0.1850
35	Mar	19	Apr	18	0.1500
36	Apr	19	May	18	0.1150
37	May	19	June	18	0.0800
38	June	19	July	18	0.0450
39	July	19	Aug	18	0.0250
40	Aug	19	Sept	18	0.0250
41	Sept	19	Oct	18	0.0250
42	Oct	19	Nov	18	0.0250
43	Nov	19	Dec	18	0.0250
44	Dec	19	Jan	18	0.0250
45	Jan	19	Feb	18	0.0250
46	Feb	19	Mar	18	0.0250
47	Mar	19	Apr	18	0.0000
48	Apr	19	May	18	0.0000

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