Appendix H

Subtidal Injury Quantification and Habitat Equivalency Analysis

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Summary:

This document supports the Damage Assessment and Restoration Plan (DARP) by describing the injury quantification and scaling metrics used for subtidal habitats for the Refugio Beach Oil Spill (RBOS) Natural Resources Damage Assessment (NRDA).

Introduction:

On May 19, 2015, Plains Line 901 pipeline ruptured and oil flowed into the ocean, ocean water was observed to be fouled, and oiled marine animals died and washed up on local beaches coincident in time and space with the spill (see Appendix G-1 of the RBOS DARP). Subsequent assessment studies documented Line 901 crude oil on the surface of marine vegetation (see Appendix G-6 of the RBOS DARP), uptake of petroleum hydrocarbons in fish and invertebrates (see Appendices G-3, G-4, G-6, G-7 of the RBOS DARP)), oil constituents at levels known to cause death to fish embryos and other marine life (see Appendices E, G-4 of the RBOS DARP) and die-off of marine vegetation critical to the function of nearshore subtidal habitats within 3 months after the spill (see Appendix G-5 of the RBOS DARP). The Trustees found no plausible alternative explanations for these injuries to marine resources apart from the spill.

For the purpose of defining exposure zones for the shoreline and subtidal NRDA claims, the Trustees identified four oiling zones, A-D (Figure 1), with Zone B identified as the zone with the heaviest oiling, A and C (to the immediate east and west of zone B) being of medium oiling, and Zone D to approximately Long Beach, California, to the southeast, being the lightest oiling category (Figure 1). For subtidal injury determination and quantification, the Trustees focused on the area offshore of Zone B (Figure 1), coinciding with most Trustee subtidal data collections and observed subtidal injuries.

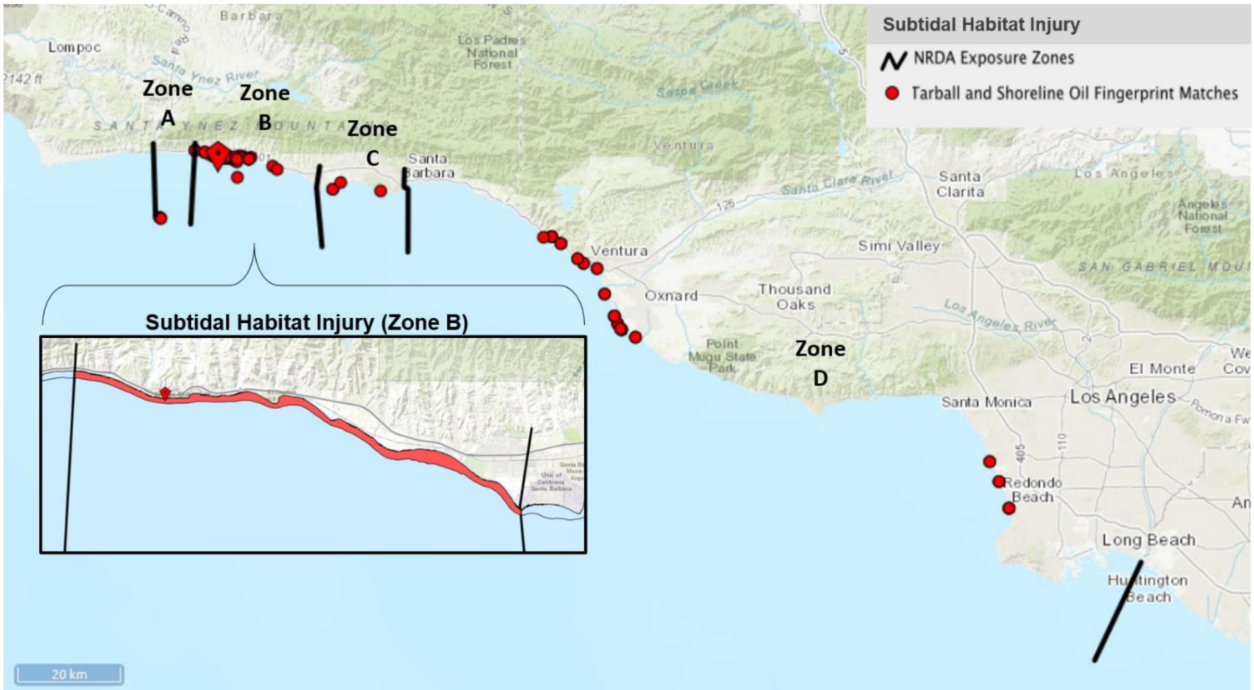

Figure 1 Habitat Exposure Zones (further described in the RBOS DARP) Defined for the Refugio Oil Spill NRDA showing beach tarball fingerprint matches. Zone B is the area of heaviest oiling. The Trustees quantified subtidal habitats injury from the shoreline to the 10 meter isobath offshore of Zone B.

Injury Determination

The Trustees calculated their subtidal injury claim from the shore to 10 m depth in Zone B. Although in Zone B, oil extended into the subtidal beyond the 10 m isobath, the 10 m isobath was selected because it approximates the offshore extent of the local kelp forest, an important foundational habitat. Ten meters is also the approximate depth to which the Trustees estimate oil mixed into the water column. Similarly, offshore surface and subtidal oil extended parallel to the shore east and west of Zone B, but the Trustees limited quantification to Zone B, where the majority of data collection occurred and where of observable subtidal impacts were located. The Trustee injury claims are based on a combination of empirical observations and consistency with an overall conceptual model that includes five main steps:

RELEASE & PATHWAYS: Spilled oil traveled from the ruptured pipeline across upland terrestrial areas, down a cliff face, across a beach, and into the ocean. Line 901 oil weathered to various degrees after it spilled and before it entered the ocean, but a substantial amount of the oil that flowed into the water was relatively unweathered and still contained lower molecular weight aromatic compounds. The inclusion of sediment and other debris into the oil as it traversed the terrain from the pipeline rupture to the ocean would have altered physical properties of the oil, which subsequently affected the buoyancy and distribution of oil in the nearshore environments.

MIXING & DILUTION: Spilled oil rapidly mixed in the ocean through physical forces of wind and waves in the turbulent surf zone. The oil-water mixture included relatively fresh crude oil, environmentally weathered oil, diluent (a mixture of lighter more volatile petroleum compounds), and other materials, such as oiled sediments and biological debris. Some of the oil dispersed in the water column re-surfaced, based on a lighter-than-water specific gravity, and aggregated into slicks that were moved by currents and winds to areas further away from the point of entry. Some of the oil containing debris lost buoyancy and sank to the bottom. Fractions of the oil that remained in the water column became dispersed or degraded. In general, the spilled oil became diluted and dispersed as it moved away from the initial point of entry to the ocean but maintained significantly elevated concentrations in the 0 – 3 m bathymetric zone throughout Zone B for more than a week after the spill based on the visible presence of oil droplets in the water.

EXPOSURE: Marine natural resources were exposed when oil flowed into and fouled various habitats, thereby affecting associated organisms. The Trustees treated the 0 – 3 m depth zone as a uniform exposure zone, weighted by habitat type. The Trustees determined injury separately in the offshore zone from 3 – 10 m bathymetric contours by habitat type: (1) water surface down to 2 m depth with variable short or extended exposures experiencing UV-enhanced phototoxicity; (2) mid-water column (from 2 to10 m depth) with fleeting exposures; and (3) benthic habitats (the seafloor communities) that extend roughly 1 m above the sea floor, with extended exposures to sunken oil due to entrapment or baffling of oil in 3 dimensional rock and vegetated habitat (Figure 2).

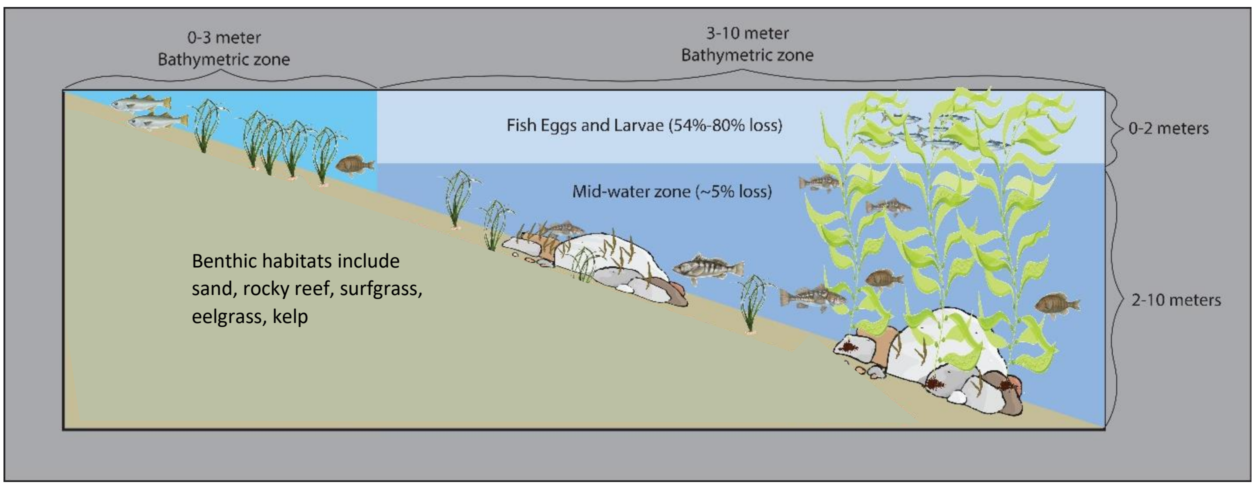

Figure 2 Description of subtidal habitats

INJURY DETERMINATION: Injuries to subtidal natural resources varied by the type, degree, and duration of exposure to spilled oil. Severity of an injury was based in part on the sensitivity of the life stage, as well as the species exposed. For example, fish early life stages, in general, have been shown through numerous published studies to be more sensitive than adult life stages to short-term, acute exposures of dissolved or dispersed oil (Pasparakis et al. 2019). However, all life stages may suffer mortality from short-term exposures if concentrations are high enough to cause physical fouling or various toxic responses. For the Line 901 oil spill, mortality was documented in mature fish and benthic invertebrates in the first few days of the spill, as well as to foundational habitat species such as surfgrass and kelps/algae over a period of 6 months. Trustees relied on the following evidence when determining the presence of injury:

1. Trustees observed an unusual and broad range of moribund and dead, oiled subtidal vertebrate and invertebrate animals washing ashore immediately after the spill (see Appendix G-1 of the

DARP). Acute mortality events like this have not been observed in past California oil spills in decades, setting a high level of concern for subtidal species.

2. Elevated PAH body burdens were measured in fish from areas closest to the release point; fishing closures occurred (even though this is a human loss, it underscores the fact that oil was in the water and contaminating fish) (Appendices G-3, G-6,G-7 of the DARP
3. Peer-reviewed studies from past oil spills support high mortality to ichthyoplankton (including early life stages of many fish species) in the upper 2 m surface water where slicks traverse (Appendix G-4 of the DARP).
4. Egg mortality and post-hatch mortality were observed in local fish species that spawn on the beach and occur in the shallow subtidal zone (see Appendix G-2 of the DARP).
5. Mortality to marine plant species (seagrasses and macroalgae) that comprise foundational subtidal habitat were documented up to three months after the spill (see Appendix G-5 of the DARP).

Injury Quantification

PERCENT SERVICE LOSS: One fundamental assumption in the Trustees' claim is that of a direct correlation between exposure levels and service loss. Since dose is a function of concentration and duration of exposure, decreasing either or both of these would likely lower the dose and reduce the toxic effect. Consequently, the service losses to subtidal benthic habitats claimed by the Trustees further offshore (i.e., 3-10 m bathymetric zone), except in the surface water zone, are lower than service losses claimed in the shallower nearshore zone (0-3 m bathymetric zone). The foundation of the Trustees' calculation of percent service loss to benthic habitats for the purposes of scaling was observed impacts to vegetation in the nearshore 0-3 m bathymetric zone. The Trustees conducted extensive surveys of the shallow subtidal surfgrass (*Phyllospadix torreyi*), and macroalgae (several species of both brown, green and red algae including *Egregia menziesii* and *Fucus distichus*) (see Appendix G-5 of the DARP). Observed injuries to these species were directly translated to a percent service loss for the entire associated benthic community. This direct relationship between injury and percent service loss is appropriate because this diverse community of surfgrass and algae is foundational to the ecological function of subtidal benthic habitat. It creates the habitat that supports a diverse community of benthic and demersal fish and invertebrates. Loss of foundational habitat is detrimental to every organism reliant upon it. Using this technique, the Trustees estimated a "base" percent service loss of 54% based on the area-weighted average across zone B of observed percent cover of impaired seagrass and algae (ranging from 35-88% loss) (see Appendix G-5 of the DARP). Percent service losses were calculated in different areas by adjusting for the type of habitat in that area (as described in "Exposure" above) and by distance from the shoreline.

The Trustees established percent service loss estimates for nearshore benthic, offshore surface layer, offshore mid-water layer, and offshore benthic habitats as follows (Figure 3):

> **NEARSHORE BENTHIC HABITATS:** The Trustees estimated 54% service loss to benthic habitats in the nearshore 0 – 3 m bathymetric zone, based on area-weighted averages of documented injuries to foundational species (see Appendix G-5 of the DARP). The injury is considered significant and persistent (i.e., > 1 year). For sand bottom habitats in this stratum the Trustees are claiming 10% of that loss, reflecting the lower productivity/services associated with sand

habitats compared to rocky reef, surfgrass or eelgrass habitats, resulting in a 5.4% loss for sand bottom habitats. Injury is estimated to decrease to 0 over five years post-spill.

OFFSHORE SURFACE LAYER: Published toxicity studies have shown high levels of mortality (>80%) to fish early life stages (typical of ichthyoplankton) exposed beneath crude oil surface slicks in the presence of environmentally relevant levels of UV light (i.e., photo-enhanced oil toxicity; Alloy et al. 2015; Alloy et al. 2016; Alloy et al. 2017; Morris et al. 2015). However, because of uncertainty across species and geographic areas the Trustees used a lower value of 54% loss, consistent with the loss calculated for the surf zone. This degree of loss would also apply to the kelp canopy community that occurs in the top 2 m of the water column. The injury is considered to be limited in duration.

OFFSHORE MID-WATER LAYER: The Trustees estimated 5% service loss to the mid-water column between the 3-10 m bathymetric contours to just above the bottom and the underlying foundational habitat. The injury percentage is based on an approximately 12 fold dilution of the total volume of water in the 0-3 m depth region mixing into the total volume of water in the adjacent 3-10 m depth region of Zone B. For purposes of simplification, the Trustees assume a direct inverse correlation between declining injury levels with increasing oil dilution. The Trustees used a volumetric approach to calculate loss in the midwater of the offshore areas (from 2m depth to just above the bottom from the outer edge of the "nearshore" zone to the 10 m isobath). In this method, the Trustees portray the water in the subtidal area of zone B in cross section as a triangle with side (a) representing the upper boundary of this layer at 2 m depth (horizontal) side (b) the water column (vertical), and side (c) representing the seafloor (hypotenuse)(Figure 3). The triangle representing the midwater area is divided up from the top black line of the triangle representing the top of the midwater layer, down to the side of the triangle representing the bottom of the seafloor. After dividing the water of the subtidal area into depth columns the Trustees then calculated the water column area for each depth interval down to a small triangle (red) representing the water column just above the seafloor. We then calculated the area of that triangle and added it to the water column area above it and multiplied it by the average distance of the contour interval to obtain the volume of the water for that total depth interval. The average distance of the contour interval was calculated by measuring the distance of 100 transects along each contour to the next sequential contour line and taking the average distance of those 100 transects. Lost services calculated for this area were 5% based on this method. Exposures in the mid-water layer are considered to be shorter term (i.e., days) but injuries to resources encountering this level of exposure could linger.

OFFSHORE BENTHIC HABITATS: The Trustees calculated losses to the offshore benthos based on areal dispersion of submerged oil across the benthic footprint of Zone B to the 10 m isobath. Sunken oil would not necessarily dilute out with the addition of more water but would persist for longer periods as small sediment-laden oil particles and droplets while spreading across the sea bottom by waves and currents. Sunken oil also has a high likelihood of being trapped or slowed in the bottom vegetation. The Trustees calculated losses using an area seafloor dispersion calculation. This method calculated the distance oil would travel along the seafloor from 0 to 3 m and 0 to 10 m by applying the Pythagorean Theorem. The seafloor distance is represented by the hypotenuse of a triangle that is created by the offshore distance and subsequent increase in depth associated with 1 m bathymetric contours (e.g., red triangle in

Figure 3). The two known sides of the triangle (distance offshore and change in depth) were used to complete the formula and calculate the distance along the bottom (calculated as a hypotenuse of a right triangle). The average distance from contour line to contour line ("a" in Figure 3) was calculated by measuring the distance of 100 transects along each contour to the next sequential contour line and taking the average distance of those 100 transects. The change in depth ("b" in Figure 3) was always one m as distance was between subsequent 1-m depth contours. In summary, these calculations resulted in an average seafloor distance of 76 m between the 0 and 3 m bathymetric contours, and 232 m between the 3 and 10m contours (Figure 2). Thus, seafloor dispersion would result in an approximately 4-fold decrease in exposure, so the 54% injury experienced in the 0-3 m zone would be reduced to an average of 13% in the 3-10 m zone. Injury to the benthic community, was similarly considered as decaying linearly with distance from the nearshore "baseline" injury of 54% to apply a 13% service loss across the 3-10 depth range for rocky reef, surfgrass, kelp and eelgrass habitats. For sand bottom habitats in this depth stratum the Trustees are claiming 10% of that loss, reflecting the lower productivity/services associated with sand habitats compared to rocky reef, surfgrass or eelgrass habitats, resulting in a 1.3% loss for sand bottom habitats. The injury is considered to decrease to 0 over 5 years post spill.

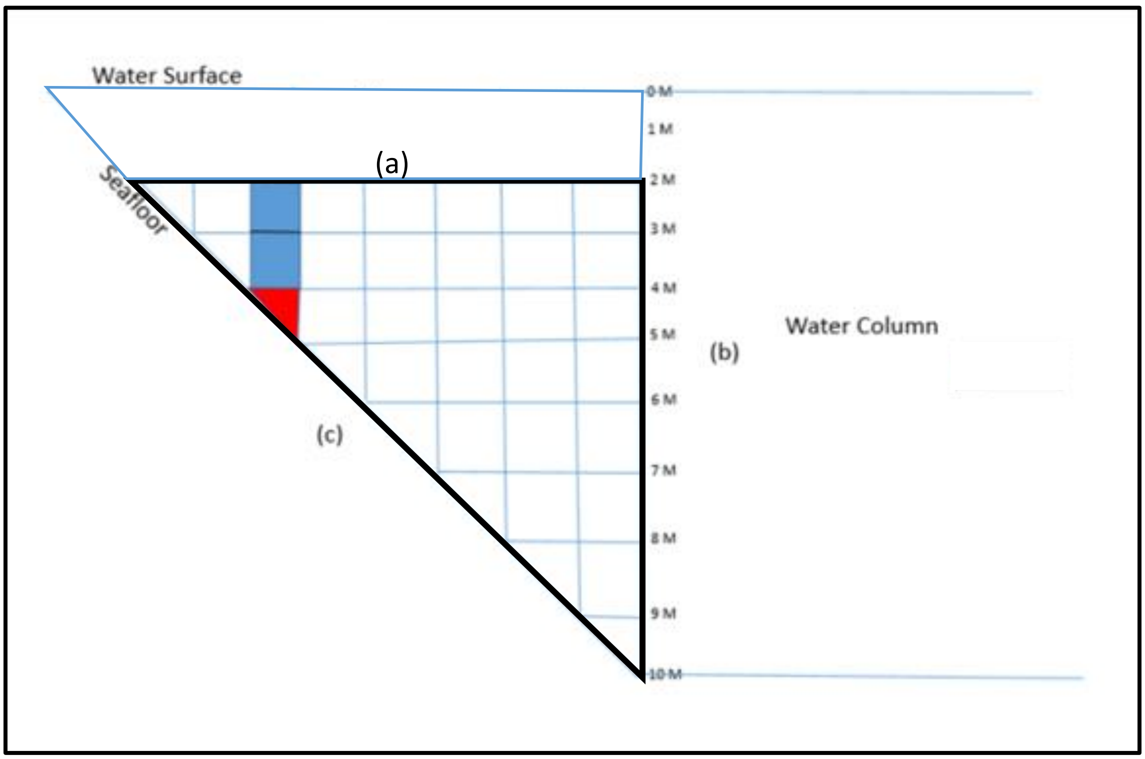

Figure 3 Subtidal quantification schematic diagram used to calculate volumetric dilution and areal dispersion factors. The red triangle shows the elements used to calculate the seafloor spreading distance with the Pythagorean Theorem.

Scaling Restoration Actions

The Trustees used Habitat Equivalency Analysis (HEA) to calculate injury Discount Service Acre years (DSAYs) for scaling compensatory restoration for the subtidal injury in the nearshore benthic habitats and the offshore benthic habitats. DSAYs were calculated based on the percent service loss for subtidal habitats based on the documented injury to vegetated habitat in surfgrass studies. In summary, the HEA calculations characterize a rapid initial loss that occurs in the first 6 months of the spill, followed by a relatively rapid recovery (88% recovered after a year, 94% after two years, and 100% after 5 years). Percent injury in the 0-3 m bathymetric zone was set at 54%, but adjusted for the relative productivity of different habitat types, thus a 5.4% injury was applied to open sand habitats, 54% was applied to rocky reef, kelp canopy, eelgrass or surfgrass habitats. The same approach was used for benthic habitats in the 3-10 m bathymetric zone, but a baseline injury of 13% was used, based on quantification discussed in the last section. This analysis resulted in a loss of 178.5 DSAYs in the 0-3 m bathymetric zone and 117.4 DSAYs in the 3-10 m bathymetric zone (Table 1). The Trustees did not identify specific, separate projects to benefit the offshore surface or midwater habitats because there are substantial benefits to water column species from restoration projects discussed below, which primarily restore benthic vegetated habitat.

Table 1. Summary of injury scaling for subtidal benthic habitats.

Depths	Habitat type	Base injury (%Loss)	Habitat factor	Final injury (% Loss)	Habitat acres	Discount Service Acre years (DSAY) for compensation
Nearshore Benthic Habitats (0-3 m isobath)	Rocky reef with kelp	54%	1.0	54%	3	1.6
	Rocky reef no kelp canopy	54%	1.0	54.%	208	124.7
	Eelgrass/Surfgrass	54%	1.0	54%	63	37.8
	Sand	54%	0.1	5.4%	240	14.4
Total (0-3 m)					**514**	**178.5**
Offshore Benthic Habitats (3-10 m isobath)	Rocky reef (kelp canopy	13%	1.0	13%	24	3.5
	Rocky reef (no canopy)	13%	1.0	13%	595	86.2
	Eelgrass/Surfgrass	13%	1.0	13%	98	14.1
	Sand	13%	0.1	1.3%	940	13.6
Total (3-10 m)					**1657**	**117.4**

The Trustees identified four categories of restoration activities (abalone restoration, eelgrass restoration, kelp restoration, and seawall removal) that would collectively compensate for approximately 47% of the losses to subtidal habitats caused by the release of Line 901 oil. These projects were selected and prioritized by their ability to enhance and restore subtidal habitats in the region affected by the spill. Projects within Zone B were heavily prioritized over projects that were in the region but outside Zone B. These projects are discussed below in order of priority.

ABALONE RESTORATION

In order to be successful, abalone restoration requires applying multiple approaches when possible (e.g., adult translocation and juvenile captive propagation and outplanting) and requires a multi-year program with repeated outplanting events. In addition, restoration in the marine environment requires the use of boats and divers, which elevates the cost above costs associated with implementing land-based restoration work. The Trustees proposed a 10-acre restoration project (5 acres within each of the Marine Reserves) that will be implemented over a 5-year period and subsequently monitored for an additional 5 years. To scale this project, the Trustees assumed a 50% service increase that would be realized at the end of the 5-year implementation period. This credit would be maintained for 20 years, at which point the credit would diminish due to uncertainties about how the population may fare beyond that timeframe. The project (including post-implementation monitoring) has an estimated DSAY value of 73.6.

EELGRASS RESTORATION: There are limited opportunities for coastal eelgrass restoration within Zone B. The Trustees propose restoration at a roughly 3-acre site where the habitat is likely to support eelgrass but is far enough from existing beds that natural recruitment is unlikely (Altstatt, personal communication). This work will create productive habitat services within Zone B. Previous restoration work with the species of eelgrass that frequents the coastal ocean (*Zostera pacifica*) suggests that full recovery of the eelgrass bed after project implementation is a relatively slow process that can take 7-10 years (Altstatt et al. 2014), so the Trustees propose a slow increase in credit over the course of approximately 15 years to a maximum of 70%, which will be realized for up to 20 years post-implementation and then decline for the same reasons that the credit of the abalone project declines after the same timeframe. This project has an estimated DSAY value of 27.

SAND-DWELLING KELP RESTORATION: While there are no opportunities for direct kelp forest restoration within Zone B, there are limited opportunities for kelp restoration offshore of Goleta Beach, which lies outside the southeastern border of Zone B. This project was initiated by a small group of dedicated citizen scientists who are attempting to restore the kelp forest that once existed in Goleta Bay. While there is no rocky reef habitat in the bay that typically supports kelp forests, it has been speculated that the kelp had once established itself on tube-forming worm colonies that frequent open sand habitats (e.g., colonies of the tube worms belonging to the genus *Diopatra*). The project aims to restore these “sand-dwelling” kelp plants by inserting small granite columns into the sediment, exposing the top 10-20 cm of the column to kelp recruitment. The ultimate goal of this project is that kelp holdfasts will spread beyond the area occupied by the granite column and form a kelp forest of sufficient density to support kelp canopy. This is currently a one-acre project that has shown some short-term success (i.e., kelp plants have recruited to a number of the granite columns), but the approach is still experimental in nature, and it is difficult for the Trustees to evaluate how the project will fare during storm events that could pull out the columns and associated kelp. The scope of this project is to expand the permits associated with the current one-acre project and to implement a systematic monitoring program. The Trustees are reluctant to propose a larger scale buildout of this project because the results are still preliminary, and the longer-term viability of the approach is unknown. This project has an estimated DSAY value of 6.8.

ELLWOOD SEAWALL: If the Ellwood Seawall removal project is selected as a shoreline project, the Trustees estimate that the removal of the seawall will have benefits to subtidal marine habitats that go beyond the benefits for sandy beach habitat (the primary goal of this project). These benefits include a presumed reduction in turbidity and scour in the offshore habitats resulting from the reduction in reflective wave energy that will occur after the seawall has been removed. These benefits have not been quantified in similar projects so the Trustees consider this project to have uncertainties regarding its benefits for subtidal habitat. In order to help quantify these benefits, the Trustees proposed that the current project budget be expanded to include long-term monitoring of subtidal habitats adjacent to the seawall removal site. The Trustees will require pre- and post-removal monitoring. The Trustees estimated a maximum credit of 30% applied to 20 acres of habitat that will be realized 5 years after the removal of the seawall, will persist for approximately 20 years, and will then decline due to uncertainties similar to those outlined above. The Trustees adjusted the habitat benefits based on acres of habitat type (e.g., 1/10 credit for open sand), so the project scaling is closely aligned with the injury scaling. The benefits to acreage of sandy habitat (Figure 2) within the project impact area were therefor scaled at 3%. The estimated DSAY value of this project is 35.

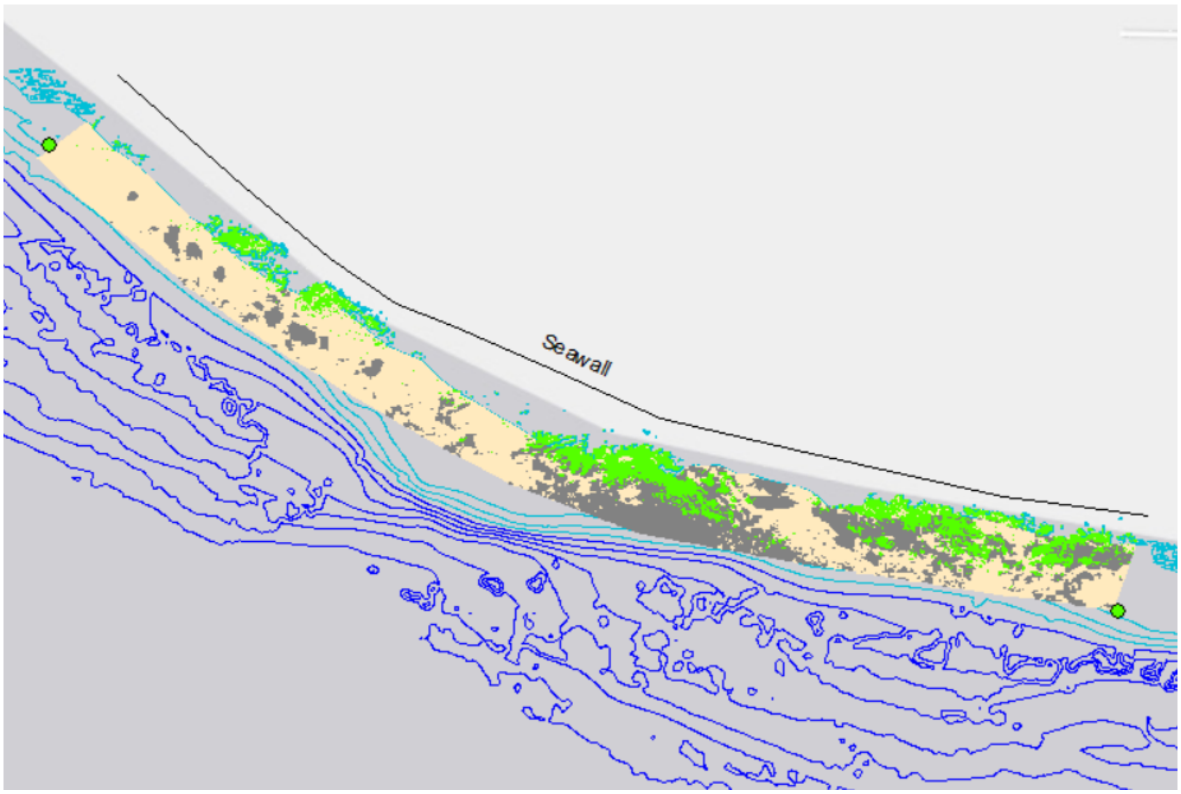

Figure 2. Map of habitats within the 20 acres of subtidal habitat adjacent to the seawall removal project. Rocky habitat (5.6 acres) indicated in grey, sand habitat (11.3 acres) indicated in beige, and seagrass habitat (3.6 acres) indicated in bright green.

REMAINING DSAYs: For remaining DSAYs, the Trustees will use remaining subtidal funds for projects as follows. The first option will be to scale up one or several of the restoration projects described above in the event that a larger scale project is feasible; the second option would be to fund projects that have strong nexus to the Line 901 oil spill that may come to light in the future; and the third option will be to provide funding for marine debris removal.

Marine Debris removal, particularly derelict fishing gear, can have limited benefits to marine habitats and can also reduce mortality of marine fish, birds, invertebrates and mammals along the Gaviota Coast. Marine debris removal is identified as a lower priority for a number of reasons. The degree of benefit that fishing gear removal has to each of these resources depends greatly on the location and habitat from which the gear is removed, and the nature of the items removed. While there are some opportunities to remove fishing gear from the greater southern California Bight, opportunities to remove gear from Zone B or along the Gaviota Coast have proven to be limited. Thus, direct benefits of gear removal to the benthic marine habitats that were injured by the spill are also limited. Benefits to the affected habitat of gear removal from other areas within Southern California are impossible to quantify, as they will vary greatly depending on the variables mentioned above.

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