Appendix E: Habitat Equivalency Analysis (HEA) Details for Marsh, Flats, and Sand/Gravel Beaches

Prepared by the *Cosco Busan* Oil Spill Natural Resource Trustees

This document describes the inputs used in the HEA for tidal marsh, tidal flat, and sand/gravel beaches oiled as a result of the *Cosco Busan* oil spill. Oiling designations are based on Shoreline Cleanup and Assessment Technique (SCAT) determinations of shoreline segment as well as supplemental information. SCAT oiling categories are based on a matrix of oil band width, percent oil cover, and oil thickness (reference). SCAT teams did not evaluate tidal flat oiling; therefore the shoreline oiling of the adjacent habitat was used to distinguish likely relative oiling of the tidal flats themselves

Table 1. Summary of the Trustees' Habitat Equivalency Analysis (HEA) inputs.

1A. Services Present for SALT MARSH

Heavy	Moderate	Light	Very Light
0 / 0%	0 / 50%	0 / 75%	0 / 85%
2 mo / 0%	2 mo / 50%	2 mo / 75%	2 mo / 85%
6 mo / 25%	6 mo / 65%	6 mo / 80%	6 mo / 90%
1 yr / 50%	1 yr / 75%	1 yr / 85%	1 yr / 100%
5 yr / 100%	3 yr / 100%	3 yr / 100%	
0.1 Acres	0.6 Acres	5 Acres	12 Acres

1B. Services Present for TIDAL FLATS

Adjacent to Heavy	Adjacent to Moderate	Adjacent to Light	Adjacent to Very Light
0 / 75%	0 / 85%	0 / 90%	0 / 98%
2 mo / 75%	2 mo / 85%	2 mo / 100%	2 mo / 100%
6 mo / 85%	6 mo / 100%		
1 yr / 100%			
4.2 Acres	255 Acres	289 Acres	1397 Acres

1C. Services Present for SAND/GRAVEL BEACHES

Heavy	Moderate	Light	Very Light
0 / 0%	0 / 40%	0 / 60%	0 / 80%
2 mo / 0%	2 mo / 40%	2 mo / 60%	2 mo / 80%
6 mo / 50%	6 mo / 80%	6 mo / 100%	6 mo / 100%
1 yr / 90%	1 yr / 90%		
3 yr / 100%	3 yr / 100%		
4.3 Acres	5.4 Acres	147 Acres	491 Acres

Table 2. Trustees HEA inputs and rationale for Heavy, Moderate, Light and Very Light Oiling in Salt Marsh, Tidal Flats and Sand Beach Habitats

Post-Spill Time; Services Present	Rationale for Services Present in Heavily Oiled Salt Marsh
T= 0; 0%	**Salt marshes in San Francisco Bay (SFB) are dominated by surface feeders (Neira et al., 2005), which are exposed to the oil on the vegetation and marsh surface during feeding.** **Heavy oiling smothered vegetation and fauna using the habitat, rendering it unsuitable for use by fish, invertebrates, and wildlife.** - Oiling occurred from the outer vegetation fringe to several meters towards the interior, affecting the predominant fauna utilizing the edges and channel borders of this habitat, as well as those crossing this interface to use different areas at different tidal levels for feeding and protection - Crustacea and gastropods are the dominant epifauna in salt marshes (Josselyn 1983). These species are motile and cross from marsh to tidal flat/channel to feed, increasing their exposure to the oiled marsh fringe as mentioned above **Marsh vegetation is also impacted by oil coating of leaf surfaces, resulting in reduced photosynthesis and tissue death.** - Laboratory and field studies of wetlands with 50-100% coating or oil application rate of 1.5-2 L/m^2 showed: o 100% reduction in *Spartina* photosynthesis for week one for Mexican crude oil (Pezeshki and DeLaune 1993) o Photosynthesis decreased by 63-80% of controls for 7-14 days after heavy oiling of *Spartina* with S. Louisiana crude (Smith et al. 1981) o *Spartina* dead biomass = 250% and live biomass = 70% of control at three weeks after oiling with No. 6 fuel oil (Alexander and Webb 1983) o All fish in the tidal creek of the field oiling experiment with weathered S. Louisiana crude died by day nine (Bender et al. 1977)

T= 2 mo; 0%	**End of active cleanup and associated disturbances in salt marsh areas** - Cleanup methods included cutting (at one location) and natural recovery; most areas remained coated with oil that was still tacky, thus continuing to be unsuitable for use **Oil in the salt marshes was bioavailable to fauna from initial spill, as well as 're-oiling' events through January 2008, that resulted in exposure and uptake.** - Bivalve invertebrates (mussels, clams, oysters) collected throughout the spill zone demonstrated accumulations of poly-aromatic hydrocarbons (PAHs) in concentrations that correlated well with the shoreline oiling category where it was collected - Tissue concentrations of PAHs in bivalves collected from oiled shorelines designated Heavy reached or exceeded concentrations found to have caused chronic and sub-chronic health endpoints (see Figure 1 and Table 3 below) o Mussels (*Geukensia*) collected from heavily oiled Stege marsh on 15-20 November 2007 (1-2 weeks post-spill) contained up to 61 ppm total PAHs; o Mussels collected on 30 January 2008 (12 weeks post-spill) contained 53 ppm total PAHs **Limited recovery of affected flora and fauna from oil exposure effects during winter non-reproductive period.** - Laboratory and field studies of wetlands with 50-100% coating showed: o Live aboveground biomass of *Spartina* plugs oiled with No. 6 fuel oil = 20% of control after 49 days (Pezeshki et al. 1995) o Heavily oiled fringing *Spartina* at the Chalk Point oil spill in the Patuxent River, MD had stem counts = 20% and stem height = 103% of unoiled reference sites 3 months post spill (Michel et al. 2002)
T= 6 mo; 25%	**Recovery of affected flora and fauna from oil exposure effects.** o Number of live stems/plot and live biomass = 30% of control at 15 weeks after heavy oiling of *Spartina* with S. Louisiana crude (Lindau et al. 1999) o Dead biomass of heavily oiled *Spartina* = 145% of control sites in field tests with No. 6 fuel oil after 5 months (Alexander and Webb 1983) o Amphipods = 30% of control and Chironomids = 8% of control at week 20 in field oiling experiment in *Spartina* marsh with weathered S. Louisiana crude oil (Bender et al. 1977)

T= 1 yr; 50%	**Ongoing recovery reflects the time to restore to pre-spill age class distributions of these long-lived key species (by recruitment and immigration).** - Laboratory and field studies of wetlands with 50-100% coating showed impacts to vegetation and fauna after one year: o Number of live *Spartina* stems/plot = 75% and biomass = 80% of controls 1 year after oiling with S. Louisiana crude (Lindau et al. 1999) o *Spartina* standing crop = 40% of control after 1 year in field oiling experiment with weathered S. Louisiana crude oil (Bender et al. 1977) o No. 6 fuel oil spill in Galveston Bay resulted in mortality of aboveground vegetation with 100% oil cover; 7 months post-spill, live aboveground biomass = 44% of pre-spill; belowground biomass = 84% of pre-spill (Webb et al. 1981) o Percent cover for *Salicornia* that was heavily oiled and trampled was reduced compared to controls at 1 year (Hoff et al. 1993) o *Carex* heavily oiled by IFO 380 spill, with no cleanup or trampling, was the same as control after 1 year (Challenger et al. 2008) o 7 months after a spill of 250,000 gal No. 6 fuel oil in Chesapeake Bay, *Littorina* were 40% of control, with evidence of both redistribution and recruitment (skewed size class); also *Spartina* had reduced flowering (Hershner and Moore 1977) o Within 1 year after a No. 6 fuel oil spill in the Potomac River, heavily oiled *Spartina* marshes had greatly reduced populations of *Geukensia* (~20% of controls) and juvenile *Littorina* (~10% of controls). Age class distributions of *Littorina* remained altered for 2 years (Krebs and Tanner 1981) o Heavily oiled fringing *Spartina* at the Chalk Point oil spill in the Patuxent River, MD had stem counts = 72% and stem height = 120% of unoiled reference sites 1 year post spill (Michel et al. 2002)

T= 5 yr; 100%	**Recovery reflects the time to restore age class distributions (by recruitment and immigration).** - Shore crabs have life spans up to 4 years, and gastropods have life spans up to >10 years, and thus would have recovered to their pre-spill age class distributions o At the *Amoco Cadiz* spill in France, heavily oiled marshes with no cleanup disturbances recovered in less than 5 years (Baca et al. 1987) o Sell et al. (1995) summary of heavily oiled salt marshes found that initial colonization (i.e., the initial settlement or migration of macroscopic opportunists into the impacted site) of biota was observed to occur during the first year and that within 5 years of the contamination event; the marshes were within the recovery phase or were completely recovered o Mendelson et al. (1993) Heavy oiling in marsh vegetation. Total vegetation recovery within 4 years

Post-Spill Time; Services Present	Rationale for Services Present in Moderately Oiled Salt Marsh
T= 0; 50%	**Moderate oiling smothered vegetation and fauna using the habitat, rendering it unsuitable for use by fish, invertebrates, and wildlife.** **Salt marshes in San Francisco Bay are dominated by surface feeders (Neira et al. 2005), and therefore exposed to the oil on the vegetation and marsh surface during feeding.** - Crustacea and gastropods are the dominant epifauna in salt marshes (Josselyn 1983); these species are motile and cross from marsh to tidal flat/channel to feed, increasing their exposure to the oiled marsh fringe. - Oiling occurred from the outer vegetation fringe to several meters towards the interior, affecting the predominant fauna utilizing the edges and channel borders of this habitat, as well as those crossing this interface to use different areas at different tidal levels for feeding and protection **Marsh vegetation is also impacted by oil coating of leaf surfaces, resulting in reduced photosynthesis and tissue death.** - Laboratory and field studies of wetlands with moderate oiling showed: In lab tests with Mexican crude oil on *Spartina*, partial oil cover resulted in photosynthesis reduced to 53-71% of control, with recovery by week 4 (Pezeshki and DeLaune 1993), photosynthesis decreased by 63-80% of c*ontrols* for up to 2 weeks after both moderate and heavy oiling of *Spartina* with S. Louisiana crude (Smith et al. 1981)
T= 2 mo; 50%	**End of active cleanup and associated disturbances in salt marsh areas.** - Cleanup methods included natural *recovery*; most vegetation remained coated with oil that was still tacky and thus continued to present hazards to inhabitants. **Limited recovery of affected flora and fauna from oil exposure effects during winter non-reproductive period.** - Number of live biomass = 30% of control at 15 weeks after heavy oiling of *Spartina* with crude oil (Lindau et al. 1999)
T= 6 mo; 65%	**Recovery of affected flora and fauna from oil exposure effects.** o Dead biomass of moderately oiled *Spartina* = 130% of control sites in field tests with No. 6 fuel oil after 5 months (Alexander and Webb 1983)

T= 6 mo; 65% Cont.	o Dead biomass of heavily oiled *Spartina* = 145% of control sites in field tests with No. 6 fuel oil after 5 months (Alexander and Webb 1983) Amphipods = 30% of control and Chironomids = 8% of control at week 20 in field oiling experiment in *Spartina* marsh with weathered S. Louisiana crude oil (Bender et al. 1977)
T= 1 yr; 75%	**Ongoing recovery of affected flora and fauna reflects duration to restore to pre-spill age class distributions of key species (by recruitment and immigration).** - Laboratory and field studies of wetlands with moderate oiling on the vegetation showed: o Number of live *Spartina* stems/plot = 75% of control and biomass = 80% of control 1 year after oiling with S. Louisiana crude (Lindau et al. 1999) o *Spartina* standing crop = 40% of control after 1 year in field oiling experiment with weathered S. Louisiana crude oil (Bender et al. 1977) o 7 months after a spill of 250,000 gal No. 6 fuel oil in Chesapeake Bay, *Littorina* were 40% of control, with evidence of both redistribution and recruitment (skewed size class); also *Spartina* had reduced flowering (Hershner and Moore 1977) o No. 6 fuel oil in Galveston Bay resulted in mortality of aboveground vegetation with 100% oil cover; 7 months post-spill, live aboveground biomass = 44% of pre-spill; belowground biomass = 84% of pre-spill (Webb et al. 1981) Moderately oiled fringing *Spartina* at Chalk Point oil spill (Patuxent River, MD) had stem counts = 33% and stem height = 82% of unoiled reference sites 1 year post-spill (Michel et al. 2002)
T= 3 yr; 100%	**Recovery reflects the time to restore age class distributions (by recruitment and immigration).** - Sell et al. (1995) summary of heavily oiled salt marshes found that initial colonization (i.e., the initial settlement or migration of macroscopic opportunists into the impacted site) of biota was occurred during the first year and that within 60 months the marshes were within the recovery phase or were completely recovered

Post-Spill Time; Services Present	Rationale for Services Present in Lightly Oiled in Salt Marsh
T= 0; 75%	**Light oiling predominantly adhered to vegetation and/or sediment surface.** - Crustacea and gastropods are the dominant epifauna in salt marshes (Josselyn 1983); These species are motile and cross from marsh to tidal flat/channel to feed, increasing their exposure to the oiled marsh fringe - Oiling occurred from the outer vegetation fringe to several meters towards the interior, affecting the predominant fauna utilizing the edges and channel borders of this habitat, as well as those crossing this interface to use different areas at different tidal levels for feeding and protection **Salt marshes in San Francisco Bay are dominated by surface feeders (Neira et al. 2005), exposed to the oil on the vegetation and marsh surface during feeding.** Given the presence of tacky oil interspersed throughout the vegetation at the edges and channel borders, impacts to fauna within the oil footprint and motile species that must cross the oiled marsh fringe (such as *Rallidae*) are expected to be common and widespread
T= 2 mo; 75%	**No cleanup methods were employed in lightly oiled marshes, thus removal and weathering of residual oil would be due to natural attenuation.** - Most impacted areas remained oiled, thus continued to be unsuitable for use. Residual oil remained "tacky" for several months following the spill and re-oiling events introduced less weathered oil into the marsh as well - In field experiment with application of 0.0375 L/m^2 of No. 5 fuel oil, many *Littorina* were killed initially; at 3 months oiled areas = 20% of control (3/m^2 in oiled versus 16/m^2) (Lee et al. 1981) **Limited recovery of affected flora and fauna from oil exposure effects during winter non-reproductive period.** Number of live biomass = 30% of control at 15 weeks after heavy oiling of *Spartina* with crude oil (Lindau et al. 1999)
T= 6 mo; 80% **T= 6 mo; 80% Cont.**	**Recovery of affected flora and fauna from oil exposure effects.** o Dead biomass of moderately oiled *Spartina* = 130% of control sites in field tests with No. 6 fuel oil after 5 months (Alexander and Webb 1983) o Dead biomass of heavily oiled *Spartina* = 145% of control sites in field tests with No. 6 fuel oil after 5 months (Alexander and Webb 1983) Amphipods = 30% of control and Chironomids = 8% of control at week 20 in field oiling experiment in *Spartina* marsh with weathered S. Louisiana crude oil (Bender et al. 1977)

T= 1 yr; 85%	**Recovery of affected flora and fauna from oil exposure effects.** o Dead biomass of moderately oiled *Spartina* = 130% of control sites in field tests with No. 6 fuel oil after 5 months (Alexander and Webb 1983) o Dead biomass of heavily oiled *Spartina* = 145% of control sites in field tests with No. 6 fuel oil after 5 months (Alexander and Webb 1983) Amphipods = 30% of control and Chironomids = 8% of control at week 20 in field oiling experiment in *Spartina* marsh with weathered S. Louisiana crude oil (Bender et al. 1977)
T= 3 yr; 100%	**Recovery reflects the time to restore age class distributions (by recruitment and immigration).** Shore crabs have life spans up to 4 years; gastropods have life spans up to >10 years

Post-Spill Time; Services Present	**Rationale for Services Present in Very Lightly Oiled Salt Marsh**
T= 0; 85%	**Very light oiling mostly occurred as tarballs or patches of oiled wrack both along the fringe and in the interior of the marsh.** - Crustacea and gastropods are the dominant epifauna in salt marshes (Josselyn 1983); These species are motile and cross from marsh to tidal flat/channel to feed, increasing their exposure to the oiled marsh fringe - Salt marshes in SFB are dominated by surface feeders (Neira et al. 2005), exposed to the oil on the vegetation and marsh surface during feeding **It is assumed that impacts to vegetation are limited and of short duration; however, significant but intermittent impacts to motile fauna are anticipated due to distribution of tarballs and wrack.** - Total PAHs in bivalves collected from Very Lightly oiled shorelines were within levels (6 and 9 mg/kg) at which 100% lysosomal destabilization is predicted to occur, based on data from Hwang et al. (2002, 2008) for field and laboratory studies of oysters, respectively *Mytilus* mussels have a single massive spawn in late fall and/or winter (Shaw et al. 1988) and *Geukensia* spawns from early summer to early fall (Cohen 2005)
T= 2 mo; 85%	**No cleanup methods were employed in very lightly oiled marshes, thus removal and weathering of residual oil was due to natural attenuation.** - The impacted areas remained oiled, thus continued to present a hazard to resident fauna No recovery of affected flora during winter non-reproductive period
T= 6 mo; 90%	**Ongoing recovery of affected flora and fauna from oil exposure effects.**
T= 1 yr; 100%	**Recovery reflects the time to restore age class distributions (by recruitment and immigration).**

Post-Spill Time; Services Present	Rationale for Services Present in Tidal Flats Adjacent to Heavy Oiling
T= 0; 75%	**Oil moving across intertidal flats would foul fauna and reduce the use of the flats habitat by fish, invertebrates, and wildlife.** - The only tidal flat adjacent to heavily oiled shorelines was in Keil Cove where the adjacent beach had a band of oil 237 m long and 3-m wide with 80% cover; cleanup included removal of oiled gravel using a barge for support - Dominant species on tidal flats include mollusks (*Gemma, Nutricola, Venerupis, Cryptomya)*, oligachaetes, amphipods, harpacticoid copepods, and polychaetes (Brusati 2004, Neira et al. 2005) - Many of these species are suspension feeders and surface deposit feeders, making them susceptible to exposure to oil films on the surface and oil suspended in the water column o Biofilms on tidal flats accounts for 45-59% of the total diet of western sandpipers (Kuwae et al. 2008) and likely for similar sandpipers, who winter in SFB in large numbers; oil moving across the tidal flats with the tide would significantly affect the phytobenthos and bacteria that secrete the matrix of biofilms
T= 2 mo; 75%	**Oil was still moving across tidal flats and potentially affecting epifauna due to continued re-oiling events.** - Evidence of oil uptake by filter-feeding bivalves; Mussels on adjacent shoreline in Keil Cove had 15 ppm total PAHs (*Cosco Busan* Match)on 7 December 2007
T= 6 mo; 85%	**Tarball stranding and re-oiling events continued into May 2007.**
T= 1 yr; 100%	**Recovery based on assumption that most of the affected species would have returned to pre-spill abundances.**

Post-Spill Time; Services Present	Rationale for Services Present in Tidal Flats Adjacent to Moderate Oiling
T= 0; 85%	**Oil moving across intertidal flats would foul fauna and reduce the use of the flats habitat by fish, invertebrates, and wildlife.** - Most of the tidal flats adjacent to moderately oiled shorelines were located on the south side of Brooks Island and along the Albany shoreline along Richland Inner Harbor from Ford Channel to Point Isabel - Dominant species on tidal flats include mollusks (*Gemma, Nutricola, Venerupis, Cryptomya)*, oligachaetes, amphipods, harpacticoid copepods, and polychaetes (Brusati 2004, Neira et al. 2005) - Many of these species are suspension feeders and surface deposit feeders, making them susceptible to exposure to oil films on the surface and oil suspended in the water column Biofilms on tidal flats accounts for 45-59% of the total diet of western sandpipers (Kuwae et al. 2008) and likely for similar sandpipers, who winter in SFB in large numbers; oil moving across the tidal flats with the tide would significantly affect the phytobenthos and bacteria that secrete the matrix of biofilms
T= 2 mo; 85%	**End of active cleanup and associated disturbances.** **Tissue samples indicate ongoing oil exposure** - *Cryptomya* clam samples collected 19 December 2007 from tidal flat locations on south Brooks Island contained total PAHs of 7.5 and 12 ppm *Cosco Busan* Match); on 30-31 January 2008, values were 9.4 and 13 ppm, by March 2008, the concentration had dropped to 1.6 ppm, all matching *Cosco Busan* source oil, indicating whole oil exposure to infauna Two *Mytilus* samples from the south shore of Brooks Island in December 2007 contained 17 ppm total PAHs; in January 2008, two samples contained 11 and 129 ppm
T= 6 mo; 100%	**Recovery based on assumption that most of the affected species would have returned to pre-spill abundances.**

Post-Spill Time; Services Present	Rationale for Services Present in Tidal Flats Adjacent to Light Oiling
T= 0; 90%	**Oil moving across intertidal flats would foul fauna and reduce the use of the flats habitat by fish, invertebrates, and wildlife.** - Most of the tidal flats adjacent to lightly oiled shorelines were located in Albany Bay between Point Isabel and Golden Gate Fields, smaller flats on either side of the Berkeley Marina, and the western end of Emeryville Crescent - Dominant species on tidal flats include mollusks (*Gemma, Nutricola, Venerupis, Cryptomya)*, oligachaetes, amphipods, harpacticoid copepods, and polychaetes (Brusati 2004; Neira et al. 2005) - Many of these species are suspension feeders and surface deposit feeders, making them susceptible to exposure to oil films on the surface and oil suspended in the water column o Biofilms on tidal flats accounts for 45-59% of the total diet of western sandpipers (Kuwae et al. 2008) and likely for similar sandpipers, who winter in SFB in large numbers; oil moving across the tidal flats with the tide would significantly affect the phytobenthos and bacteria that secrete the matrix of biofilms **Tissue samples indicate oil exposure** At Radio Beach in Emeryville, *Mytilus* mussels contained 21 ppm total PAHs on 20 December (*Cosco Busan* Match), 12 ppm on 30 January 2008 (Match)
T= 2 mo; 100%	**Recovery based on assumption that most of the affected species would have returned to pre-spill abundances.** - In Emeryville, *Venerupis* clams collected 6 weeks post-spill, and over 250-meters from the adjacent shoreline, still contained low levels of PAHs matching *Cosco Busan*

Post-Spill Time; Services Present	Rationale for Services Present in Tidal Flats Adjacent to Very Light Oiling
T= 0; 98%	**Oil moving across intertidal flats would foul fauna and reduce the use of the flats habitat by fish, invertebrates, and wildlife.** - Most of the tidal flats adjacent to very lightly oiled shorelines were located on the north side of Brooks Island, between Berkeley Marina and Emeryville Crescent, in South Bay near Alameda, and most of Bolinas Lagoon - Dominant species on tidal flats include mollusks (*Gemma, Nutricola, Venerupis, Cryptomya)*, oligachaetes, amphipods, harpacticoid copepods, and polychaetes (Brusati 2004, Neira et al. 2005) - Many of these species are suspension feeders and surface deposit feeders, making them susceptible to exposure to oil films on the surface and oil suspended in the water column o Biofilms on tidal flats accounts for 45-59% of the total diet of western sandpipers (Kuwae et al. 2008) and likely for similar sandpipers, who winter in SFB in large numbers; oil moving across the tidal flats with the tide would significantly affect the phytobenthos and bacteria that secrete the matrix of biofilms *Cryptomya* clam tissues collected in Bolinas Lagoon on 11 December 2007 contained 4.7 ppm total PAHs (*Cosco Busan* Match), indicating exposure to infauna on the tidal flats
T= 2 mo; 100%	**Recovery based on assumption that most of the affected species would have returned to pre-spill abundances.**

Post-Spill Time; Services Present	Rationale for Services Present on Heavily Oiled Sand/Gravel Beaches
T= 0; 0%	**Heavy oiling smothered/fouled fauna using the habitat, rendering it unsuitable for use by fish, invertebrates, and wildlife.** **The entire intertidal zone on sand beaches is exposed to the oil.** - Entire intertidal zone up to the oiled band at the high-tide line was impacted as the oil washed across the entire zone; Oil was mixed into the surf zone by wave action, and stranded on the beach face during falling tides o De la Huz et al. (2005) found significant reductions in numbers of species at all 4 tidal zones (from swash to dry) on sand beaches 8 months after the *Prestige* heavy fuel oil spill o Sand lance avoided low levels of oil contaminated sand (113-116 ppm) compared to clean sand (Pinto et al. 1984) **Interstitial invertebrate species in spill area severely affected because of heavily oiled wrack and removal of wrack during cleanup.** - Beach wrack is inhabited by a wide variety of insect and other arthropod species. Coleopteran beetles and flies (Diptera) are the most abundant, with 35 and 11 species respectively being found in one study. Other groups include mites, spiders, pseudoscorpions, centipedes, isopod crustaceans, hymenopterids (wasps), and orthopterids (Lavoie 1984) o Chan (1977) reported no organisms in oiled beach wrack nor in the oil-soaked sand 9 days after a 1,500-3,000 barrel spill of emulsified crude oil in the Florida Keys
T= 2 mo; 0%	**End of active cleanup, associated disturbances, and wrack removal.** - Cleanup methods included predominantly manual removal of oiled sand and wrack removal, as well as trenching and sediment relocation at Rodeo Beach - Dominant species on sand beaches include amphipods and flies (<1 year life span), Coleopteran beetles (2 year life span), isopods (2-3 year life span), *Emerita* (<1 year life span) o In a study of the Ixtoc I spill on Texas beaches, the heaviest oiled transect showed 86% reduction in total intertidal benthic invertebrate population densities between pre-spill and 1 month post-spill sampling periods (Thebeau et al. 1981)
T= 6 mo; 50%	**Tarball stranding and re-oiling events continued into May 2007.** - PAH concentrations in mussels samples from adjacent to interior beaches indicated a return to ambient levels by March-June 2008, depending on location

	Invertebrate community structures are altered following wrack removal more than 6 months after removal (Dugan et al. 2009) o Studies of the large crude oil spill from the *Sea Empress* in Wales showed that Crustacea on sand beaches were severely depleted 3 to 6 months post-spill (Moore 1998) o Abundance of macrofauna dominated by amphipods, isopods, and polychaetes were reduced (often by 20-50%) 6 months after the *Prestige* spill of a heavy fuel oil off Spain (Junoy et al. 2005); the number of species on heavily oiled beaches before the spill was 15-20 versus 10-16 after the spill o A common nemertean was present on only 22% of the beaches affected by the *Prestige* oil spill 6 months after the spill, and present on only 61% of the beaches after 18 months (Herrara-Bachiller et al. 2008)
T= 1 yr; 90%	**Based on life histories of dominant species (1-3 years), recovery is estimated at 90% after 1 year.** o Meiofauna on sandy shorelines showed no impacts 9 months after the *Sea Empress* spill in Wales (Moore et al. 1997) o Macroinfauna abundance in sand beaches affected by the *Prestige* spill showed evidence of recovery 18 months post-spill, with isopods and polychaetes mostly recovered; species richness also increased (Castellanos et al. 2007)
T= 3 yr; 100%	**Recovery reflects the time to restore age class distributions (by recruitment and immigration).** o Full recovery of sand beach fauna was predicted to take 31 months in experimental oiled-sediment field studies in the Strait of Juan de Fuca, WA (Vanderhorst et al. 1981) o Macrofauna at the heavily oiled beaches at the *Prestige* spill site were not fully recovered after 3 years (Castellanos et al. 2007)

Post-Spill Time; Services Present	Rationale for Services Present on Moderately Oiled Sand/Gravel Beaches
T= 0; 40%	**Moderate oiling smothered/fouled fauna using the habitat, rendering it unsuitable for use by fish, invertebrates, and wildlife.** **The entire intertidal zone on sand beaches was affected by the oil.** - Entire intertidal zone up to the oiled band at the high-tide line was impacted as the oil washed across the entire zone; Oil was mixed into the surf zone by wave action, and stranded on the beach face during falling tides o De la Huz et al. (2005) found significant reductions in numbers of species at all 4 tidal zones (from swash to dry) on sand beaches 8 months after the *Prestige* heavy fuel oil spill o Sand lance avoided low levels of oil contaminated sand (113-116 ppm) compared to clean sand (Pinto et al. 1984) **Interstitial invertebrate species in spill area or cleanup zone severely affected because of heavily oiled wrack and removal of wrack during cleanup.** - Beach wrack is inhabited by a wide variety of insect and other arthropod species. Coleopteran beetles and flies (Diptera) are the most abundant, with 35 and 11 species respectively being found in one study. Other groups include mites, spiders, pseudoscorpions, centipedes, isopod crustaceans, hymenopterids (wasps), and orthopterids (Lavoie 1984) - Interstitial detritus as a major food source for these species results in chronic exposure to oil due to unremoved oil permeation. - Chan (1977) reported no organisms in oiled beach wrack nor in the oil-soaked sand 9 days after a 1,500-3,000 barrel spill of emulsified crude oil in the Florida Keys
T= 2 mo; 40% **T= 2 mo; 40%**	**End of active cleanup, associated disturbances, and wrack removal.** - Cleanup methods included predominantly manual removal of oiled sand and wrack; however, there was extensive trenching and sediment relocation at Rodeo Beach - Dominant species on sand beaches include amphipods and flies (<1 year life span), Coleopteran beetles (2 year life span), isopods (*Excirolana* with a 2-3 year life span), *Emerita* (<1 year life span); chronic exposure to oil would have continuing effects because of their feeding behaviors and association with beach wrack where oil also tends to accumulate o In a study of the Ixtoc I spill in Texas, four out of seven transects showed a decrease of at least 50% in

Cont.	total benthic invertebrate population densities between pre-spill and 1 month post-spill sampling periods for intertidal and shallow subtidal habitats (Thebeau et al. 1981) - January 2008 storm resulted in significant re-oiling event across much of East Bay resulting in re-exposure of PAHs to fauna. Several *Mytilus* samples collected from Stege, Emeryville, Albany and Brooks Island in 30-31 January 2008 had PAH concentrations approximately equal, and in several instances up to an order of magnitude higher, than samples collected at the same sites in 20-21 December 2007
T= 6 mo; 80%	**Invertebrate community structures are altered following wrack removal more than 6 months after removal (Dugan et al., 2009)** - Tarball stranding and re-oiling events along the outer coast sand beaches continued into April 2007 - Mussel and clam samples showed that PAH concentrations in tissues had returned to background levels by March-June 2008 - Studies of the large crude oil spill from the *Sea Empress* in Wales showed that amphipods and Crustacea on sand beaches were severely depleted 3 to 6 months post-spill (Moore 1998) The number of species on "lightly" oiled beaches (similar to moderate for the *Cosco Busan*) before the *Prestige* spill of a heavy fuel oil off Spain was 15-20 versus 11-16 (6 months after the spill); abundances at 6 months were also reduced by up to 75% (Junoy et al. 2005)
T= 1 yr; 90%	**Based on life histories of dominant species (1-3 years), recovery is estimated at 90% after 1 year.** Meiofauna on sandy shorelines showed no impacts 9 months after the *Sea Empress* spill in Wales (Moore et al. 1997)
T= 3 yr; 100%	**Recovery reflects the time to restore age class distributions (by recruitment and immigration).**

Post-Spill Time; Services Present	Rationale for Services Present on Lightly Oiled Sand/Gravel Beaches
T= 0; 60%	**Light oiling fouls fauna and reduces the use of the beach habitat by fish, invertebrates, and wildlife.** - Beach wrack is inhabited by a wide variety of insect and other arthropod species. Coleopteran beetles and flies (Diptera) are the most abundant, with 35 and 11 species respectively being found in one study. Other groups include mites, spiders, pseudoscorpions, centipedes, isopod crustaceans, hymenopterids (wasps), and orthopterids (Lavoie 1984); all of these fauna would be affected by even light oiling of the wrack - Mole crabs collected from the south end of Rodeo Beach 10 days post-spill contained elevated PAHs matched to *Cosco Busan* source oil **The entire intertidal zone on sand beaches was affected by the oil.** - Entire intertidal zone up to the oiled band at the high-tide line was impacted as the oil washed across the entire zone; Oil was mixed into the surf zone by wave action, and stranded on the beach face during falling tides De la Huz et al. (2005) found significant reductions in numbers of species at all 4 tidal zones (from swash to dry) on sand beaches 8 months after the *Prestige* heavy fuel oil spill, even on lightly oiled beaches
T= 2 mo; 60% **T= 2 mo; 60%** Cont.	**End of active cleanup, associated disturbances, and wrack removal.** - Cleanup methods included manual removal of tarballs and oiled wrack - Dominant species on sand beaches include amphipods and flies (<1 year life span), Coleopteran beetles (2 year life span), isopods (*Excirolana* with a 2-3 year life span), *Emerita* (<1 year life span); chronic exposure to oil would have continuing effects because of their feeding behaviors and association with beach wrack where oil also tends to accumulate Bay mussel tissues collected adjacent to lightly oiled Muir Beach on 20 November 2007 contained 16 ppm total PAHs; mussels adjacent to lightly oiled beaches in the Emeryville Crescent on 30 January 2008 contained 12 ppm and adjacent to lightly oiled beaches on Brooks Island contained 11.4 ppm (*Cosco Busan* Match), indicating on-going exposure to oil. - January 2008 storm resulted in significant re-oiling event across much of East Bay resulting in re-exposure of PAHs to fauna. Several *Mytilus* samples collected from Stege, Emeryville, Albany and Brooks Island in 30-31 January 2008 had PAH concentrations approximately equal, and in several instances up to an order of magnitude higher, than samples collected in the same vicinities in 20-21 December 2007. o In experiments sand lance avoided low levels of oil contaminated sand (113-116 ppm) compared to clean sand (Pinto et al. 1984)

	BeachWatch wrack monitoring data indicates no lag in wrack accumulations; however, invertebrate communities are altered following wrack removal (Dugan et al. 2009) - Tarball stranding and re-oiling events continued into May 2008 - Studies of lightly oiled and low intensity-cleaned sand beaches 8 months after the Prestige heavy fuel oil spill in Spain showed 40-47% reductions in number of species and large reductions in macrofauna abundance in the upper intertidal zone (De la Huz et al. 2005) - Bay mussel tissues collected adjacent to lightly oiled beaches in March 2008 contained low levels of PAHs that did not match Cosco Busan oil o Meiofauna on sandy shorelines showed no impacts 9 months after the Sea Empress spill in Wales (Moore et al. 1997)
T= 6 mo; 100%	**Recovery based on assumption that affected species have would have returned to pre-spill abundances.**

Post-Spill Time; Services Present	Rationale for Services Present with Very Light Oiling in Sand/Gravel Beaches
T= 0; 80%	**Very light oiling would foul fauna and reduce the use of the beach habitat by fish, invertebrates, and wildlife.** - Many of the very lightly oiled beaches are important habitat for wintering western snowy plover, federally listed as threatened **The entire intertidal zone on sand beaches was affected by the oil.** Entire intertidal zone up to the oiled band at the high-tide line was impacted as the oil washed across the entire zone; Oil was mixed into the surf zone by wave action, and stranded on the beach face during falling tides
T= 2 mo; 80%	**End of active cleanup, associated disturbances, and wrack removal.** - Cleanup methods included mostly manual removal of tarballs and oiled wrack Dominant species on sand beaches include amphipods and flies (<1 year life span), Coleopteran beetles (2 year life span), isopods (*Excirolana* with a 2-3 year life span), *Emerita* (<1 year life span); chronic exposure to oil would have continuing effects because of their feeding behaviors and association with beach wrack where oil also tends to accumulate
T= 6 mo; 100%	**Recovery based on assumption that affected species have would have returned to pre-spill abundances.**

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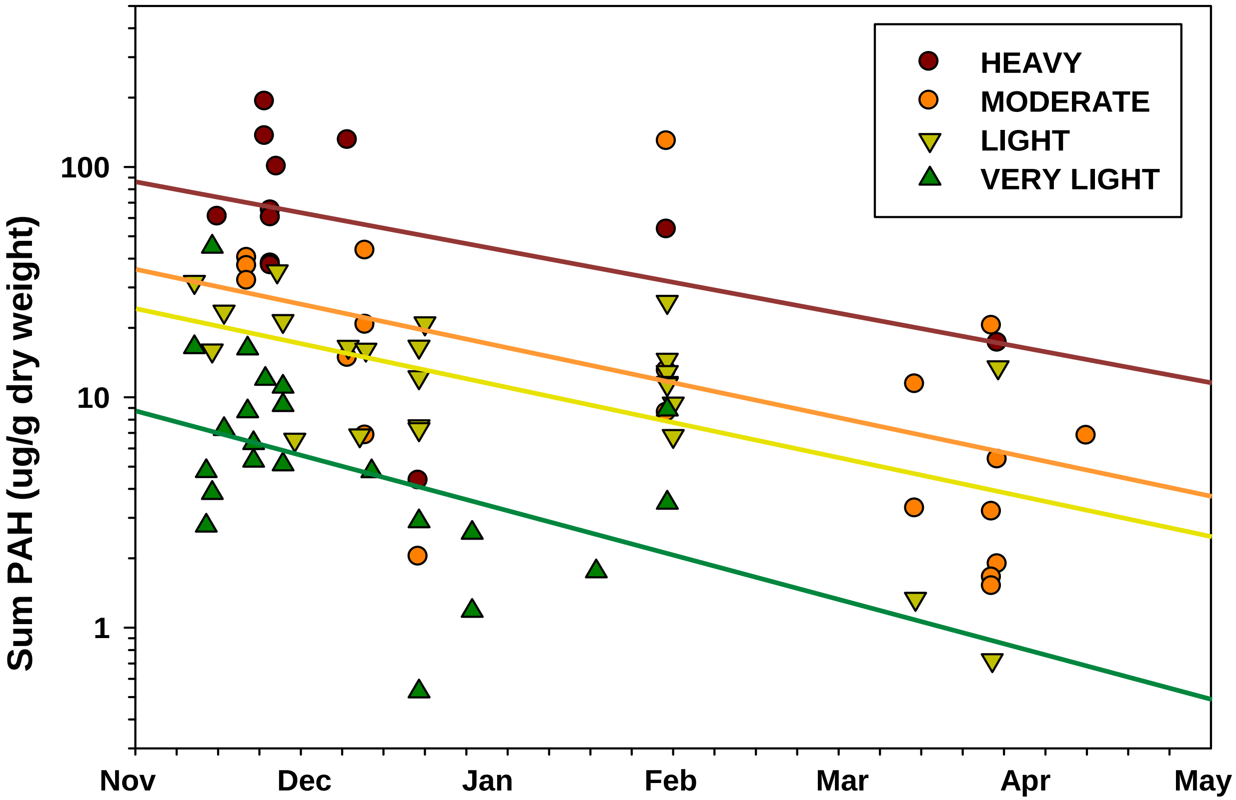
Figure 1. Total PAH (ug/g dry weight) concentrations from bivalve samples collected up to 6 months post-spill. Samples are identified by oiling designation assigned during spill response.



DEGREE	AVG. (1ST MONTH)	MIN. (1ST MONTH)	MAX. (1ST MONTH)
HEAVY	85.8	37.2	191.0
MODERATE	36.4	31.9	40.1
LIGHT	22.4	6.5	35.3
VERY LIGHT	11.0	2.8	45.0

Table 3. Bivalve PAH exposure studies showing chronic effects linked to PAH critical body burdens at relevant concentrations. (Reported as dry weight (d.w.) or wet weight (w.w.))

Species	Exposure Conditions	General response	Specific Response	Critical Body Residue
Blue mussel (*Mytilus edulis*) [1]	Field collected 132 days after the Sea Empress spill	Cellular breakdown	73 – 83% lysosomal stability relative to controls	105 - 150 µg/g w.w. (PAH mixture)
Bay Mussel (*Mytilus galloprovincialis*) [2]	12 day laboratory exposure to the *Prestige* oil	DNA damage	Significant DNA strand breakages	17 µg/g d.w. (Sum of 36 PAHs)
Eastern oyster *(C. virginica*) [3]	Field collected from a contaminated site	Cellular breakdown	74 % lysosomal stability relative to controls	12.4 µg/g d.w. (Sum of 37 PAHs)
Arctic Scallop (*Chlamys islandica*) [4]	15 day laboratory exposure to Ekofisk crude oil	Impaired immune function	152% haemocytes; 40% lysosomal stability; 48% phagocytes compared to controls	5.7 µg/g d.w. (Sum of 19 PAHSs)
Eastern oyster (*Crassostrea virginica*) [5]	25 day feeding exposure to a PAH mixture	Cellular breakdown	50% lysosomal stability relative to controls	2.1 µg/g d.w. (PAH mixture)
Blue mussel (*M. edulis*) [6]	Samples across a contamination gradient	Cellular breakdown	50% lysosomal stability relative to controls	1.0 µg/g d.w. (Sum of 16 PAHs)
Giant mussel (*Choromytilus chorus*) [7]	Field collected samples	Metabolic stress	Scope for growth below 0 J/g/h	1.0 µg/g d.w. (PAH mixture)
Eastern oyster (*C. virginica*) [8]	Field collected from a contaminated site	Cellular breakdown	81% lysosomal stability relative to controls	0.7 µg/g d.w. (Sum of 19 PAHs)

Species	Exposure Conditions	General response	Specific Response	Critical Body Residue
European Clam (*Ruditapes decussates*) [9]	28 day exposure to a PAH contaminated site	Cellular breakdown	Significant increase in lipid peroxidation	0.3 µg/g w.w. (PAH mixture)
Brown mussel (*Perna perna*) [10]	15 day exposure to an oil refinery site	Cellular breakdown	38 – 50% lysosomal stability relative to controls	0.3 µg/g d.w. (Sum of 37 PAHs)

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