INJURY ASSESSMENT FOR SALT MARSHES, SAND BEACHES, AND TIDAL FLATS AFFECTED BY THE M/V *COSCO BUSAN* OIL SPILL HABITAT EQUIVALENCY ANALYSIS (HEA) INPUTS

On 7 November 2007, the M/V *Cosco Busan* released approximately 53,000 gallons of intermediate fuel oil 380 into San Francisco Bay, California. The Natural Resource Trustees (Trustees) and representatives for the Responsible Party (RP) formed workgroups to conduct a Natural Resource Damage Assessment for the different resources affected by the spill. The Salt Marsh, Sand Beach, and Tidal Flat Habitats workgroup agreed to the three habitat types and four degrees of oiling (for a total of twelve injury categories), as follows:

Salt Marsh: Heavy, Moderate, Light, Very Light
Sand Beach: Heavy, Moderate, Light, Very Light
Tidal Flat: Adjacent to Heavy, Adjacent to Moderate, Adjacent to Light, Adjacent to Very Light

For each area/habitat covered by this document, the degree of oiling (with edits where agreed upon) and the habitat type were identified using the Shoreline Cleanup Assessment Team (SCAT) data. The SCAT data and other data sources (as described in the *CB_SCAT Data Process* file: *Part A - Access and GIS Database Reviews and Edits*) were then used to calculate the areas of each habitat/oiling injury category. The Trustees' methodologies for calculating the injured area are described more fully in *CB_SCAT Data Process* file: *Part B - Data Analysis And Area Calculations*. However, in summary, the Trustees conducted these calculations as follows: (1) The injury area for salt marsh habitats was the oil band; (2) the Trustees considered the entire intertidal zone of sand beach habitat as the area of injury; (3) the Trustees determined the oiling degree of tidal flat habitats (for which there was no SCAT data) based on the degree of oiling on the adjacent shorelines.

The injury to these areas was quantified using the Habitat Equivalency Analysis (HEA) approach, in which the injury is expressed in terms of the percent of ecological services provided subsequent to oiling (compared to pre-spill baseline levels for each habitat/oiling category), the rate at which the lost services are likely to recover over time, and the area of impact for each habitat and degree of oiling combination. The Trustees developed initial HEA inputs in 2008 for the twelve categories, based on review of the spill-related data available at that time. This included the maximum observed oiling (Max Oiling) distributions as identified by SCAT, polynuclear aromatic hydrocarbons (PAH) in tissues collected from biota (with preliminary determinations on whether the PAHs were a match to Cosco Busan oil), tarball counts over time at selected beaches, and initial review of the scientific literature and previous NRDA cases. The Trustees subsequently identified a need for the following: edits to the SCAT data (specifically changes to some Max Oiling designations based on Trustee observations or information), a compilation of information on wrack removal, approaches to estimate the widths of intertidal habitats, and additional literature review.

The Trustees and RP representatives met 24-25 September 2008 to review the edits to the Max Oiling distributions recommended by the Trustees, PAH in biota data, tarball counts and wrack summary data. The Trustees also presented the preliminary HEA service inputs described above for each habitat/oiling injury category (See Table 1). The RP representatives questioned the basis for the Trustees' preliminary HEA inputs, but did not offer alternative inputs at that time.

In addition, the RP requested more details on the scientific basis for the HEA inputs. The potential for follow-up or Tier II studies for these habitats was also discussed, but was not considered necessary for these habitats at that time. However, follow-up studies for rocky intertidal and eelgrass habitats have been or are currently being conducted.

As illustrated below in Table 1, the Trustees have revised the HEA inputs initially shared with RP representatives in September 2008, with inputs for quantification used by the Trustees in their revised estimates shown in Red. In revising these inputs, the Trustees carefully considered the recommendations made by the RP representatives. They also considered the revised data on Max Oiling distribution, PAH in tissue results (the interpretation of which have been significantly revised), and the results of the eelgrass monitoring studies (which were not previously available). In addition, the revised inputs reflect a more rigorous review of the scientific literature. These estimates may be revised again, based on any data obtained in future studies. Table 2 provides the HEA inputs and basis for the Trustees' estimates for calculating injury to the twelve salt marsh, sand beach, and tidal flat categories.

Table 1. Trustee original HEA Inputs in BLACK. Revisions to HEA Inputs in RED

Services Present for SALT MARSH (no changes)

Very Light	**Light**	**Moderate**	**Heavy**
0 / 75%	0 / 50%	0 / 50%	0 / 0%
2 mo / 75%	2 mo / 50%	2 mo / 50%	2 mo / 0%
1 yr / 100%	1 yr / 75%	1 yr / 75%	1 yr / 50%
	3 yr / 100%	3 yr/ 100%	5 yr / 100%

Services Present for TIDAL FLATS (adjacent to..)

Very Light	**Light**	**Moderate**	**Heavy**
0 / 95%	0 / 85% 90%	0 / 75%	0 / 75%
2 mo / 95%	7 mo / 90% 95%	2 mo / 75% 85%	2 mo / 75%
7 mo / 100%	1 yr / 100%	7 mo / 85% 95%	7 mo / 85% 90%
		1 yr / 100%	1 yr / 100%

Services Present for SAND BEACHES

Very Light	**Light**	**Moderate**	**Heavy**
0 / 50% 75%	0 / 50%	0 / 0%	0 / 0%
2 mo / 50% 75%	2 mo / 50%	2 mo / 0%	2 mo / 0%
7 mo / 90% 95%	7 mo / 80% 90%	6 mo / 25% 75%	7 mo / 25% 50%
1 yr / 100%	1 yr / 100%	1 yr / 80%	1 yr / 75% 80%
		3 yr / 100%	3 yr / 100%

Table 2. HEA inputs and justifications for Salt Marsh, Sand Beach, and Tidal Flat service categories

Salt Marsh + Heavy Oiling

Post-Spill Time/Services Present	Summary of Basis for Assignment of Services Present

T= 0; 0%	Heavy oiling smothered vegetation and fauna using the habitat, rendering it unsuitable for use by fish, invertebrates, and wildlife
	
	- 60% of heavily oiled marsh lengths had >50% oil cover/coat; 40% had 11-50% (all in the oiled band)
	- 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.
	
	Salt marshes in San Francisco Bay (SFB) are dominated by surface feeders (Neira et al., 2005), exposed to the oil on the vegetation and marsh surface during feeding. 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:
	    - 100% reduction in *Spartina* photosynthesis for week 1 for Mexican crude oil (Pezeshki and DeLaune, 1993)
	    - Photosynthesis decreased by 63-80% of controls for 7-14 days after heavy oiling of *Spartina* with S. Louisiana crude (Smith et al., 1981)
	    - *Spartina* dead biomass = 250% and live biomass = 70% of control at 3 weeks after oiling with No. 6 fuel oil (Alexander and Webb, 1983)
	    - All fish in the tidal creek of the field oiling experiment with weathered S. Louisiana crude died by day 9 (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 continued to be unsuitable for use Oil in the salt marshes was bioavailable to fauna from initial spill, as well as due to apparent 're-oiling' event in early January 2008 that resulted in re-

	exposure of PAHs to fauna in East Bay fauna
	
	- *Geukensia* mussels collected from heavily oiled Stege marshes on 15-20 November 2007 contained up to 60.5 ppm total PAHs; Mussels collected 19 December 2007 contained 4.3 and 7.3 ppm total PAHs; collections on 30 January 2008 contained 53.3 ppm; All samples matched to *Cosco Busan* oil
	- PAHs in mussels exhibit a range of lipophilic affinities, thus elimination of the variety of PAHs in fuel oil are variable. Elimination constants for PAHs (summarized in Meador et al., 1995) range on the order of ~2 days for the lower MW compounds (phananthrene/anthracene) to up to ~30 days for the higher MW compounds (fluoranthene/benzo-a-pyrene). Further, depuration kinetics of PAHs generally indicate a biphasic component to elimination (rapid initial depuration with an asymptotic depuration of the residual), thus body burdens of impacted mussels directly after the spill likely were significantly higher than those determined in the subsequent sampling events.
	- Total PAHs in mussel tissues greatly exceeded 6 and 9 mg/kg, levels 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; embryo viability is predicted to be very low at these levels (Moore et al., 2004; 2006); bay 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), so the total PAH levels in tissues likely reduced spawn viability
	
	No recovery of affected fauna during winter non-reproductive period
	
	- Laboratory and field studies of wetlands with 50-100% coating showed:
	  - Live aboveground biomass of *Spartina* plugs oiled with No. 6 fuel oil = 20% of control after 49 days (Pezeshki et al., 1995)
	  - 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)
	  - 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)
	  - 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= 1 yr; 50%	Laboratory and field studies of wetlands with 50-100% coating showed impacts to vegetation and fauna after one year: - Number of live *Spartina* stems/plot = 75% and biomass = 80% of

	controls 1 year after oiling with S. Louisiana crude (Lindau et al., 1999) - *Spartina* standing crop = 40% of control after 1 year in field oiling experiment with weathered S. Louisiana crude oil (Bender et al., 1977) - 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) - Percent cover for *Salicornia* that was heavily oiled and trampled was reduced compared to controls at 1 year (Hoff et al., 1993) - *Carex* heavily oiled by IFO 380 spill, with no cleanup or trampling, was the same as control after 1 year (Challenger et al., 2008) - 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) - 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) - 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) Shore crabs have life spans up to 4 years, and gastropods have life spans up to >10 years; Recovery reflects the time to restore to pre-spill age class distributions of these long-lived key species (by recruitment and immigration)
T= 5 yr; 100%	Full recovery is expected after 5 years - At the *Amoco Cadiz* spill in France, heavily oiled marshes with no cleanup disturbances recovered in less than 5 years (Baca et al., 1987) - Sell et al. (1995) summary of heavily oiled salt mashes 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. Shore crabs, gastropods, and amphipods would have recovered to their pre-spill age class distributions

<u>Salt Marsh + Moderate Oiling</u>

Post-Spill Time/Services Present	Summary of Basis for Assignment of Services Present

T= 0; 50%	Moderate oiling smothered vegetation and fauna using the habitat, rendering it unsuitable for use by fish, invertebrates, and wildlife
	
	- 25% of moderately oiled marsh lengths had 11-50% oil cover/coat; 75% had 1-10% (all in the oiled band)
	- 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 SFB are dominated by surface feeders (Neira et al., 2005), exposed to the oil on the vegetation and marsh surface during feeding. 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, but recovering by week 4 (Pezeshki and DeLaune, 1993)
	    - Photosynthesis decreased by 63-80% of controls for 7-14 days 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. - No recovery of affected fauna during winter non-reproductive period - Laboratory and field studies of wetlands with moderate oiling showed: - Dead biomass of moderately oiled *Spartina* = 130% of control sites in field tests with No. 6 fuel oil after 5 months; live biomass showed no differences (Alexander and Webb, 1983)
T= 1 yr; 75%	- Laboratory and field studies of wetlands with moderate oiling on the vegetation showed: - 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)

	- *Spartina* standing crop = 40% of control after 1 year in field oiling experiment with weathered S. Louisiana crude oil (Bender et al., 1977) - 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) - 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) - Moderately oiled fringing *Spartina* at the Chalk Point oil spill in the Patuxent River, MD had stem counts = 33% and stem height = 82% of unoiled reference sites 1 year post spill (Michel et al., 2002) -PAHs in mussels exhibit a range of lipophilic affinities, thus elimination of the variety of PAHs in fuel oil are variable. Elimination constants for PAHs (summarized in Meador et al., 1995) range on the order of ~2 days for the lower MW compounds (phananthrene/anthracene) to up to ~30 days for the higher MW compounds (fluoranthene/benzo-a-pyrene). Further, depuration kinetics of PAHs generally indicate a biphasic component to elimination (rapid initial depuration with an asymptotic depuration of the residual), thus body burdens of impacted mussels directly after the spill likely were significantly higher than those determined in the subsequent sampling events. - Total PAHs in mussel tissues greatly exceeded 6 and 9 mg/kg, levels 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; embryo viability is predicted to be very low at these levels (Moore et al., 2004; 2006); bay 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), so the total PAH levels in tissues likely reduced spawn viability
T= 3 yr; 100%	Full recovery is expected after 3 years because moderately oiled marshes and biota are expected to recover more quickly than heavily oiled marshes - At the *Amoco Cadiz* spill in France, heavily oiled marshes with no cleanup disturbances recovered in less than 5 years (Baca et al., 1987) - Sell et al. (1995) summary of heavily oiled salt mashes 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 60 months of the contamination event, the marshes were within the recovery phase or were completely recovered. Shore crabs have life spans up to 4 years; gastropods have life spans up to >10 years. Recovery reflects the time to restore age class distributions (by recruitment and immigration)

Salt Marsh + Light Oiling

Post-Spill Time/Services Present	Summary of Basis for Assignment of Services Present
T= 0; 50%	Light oiling predominantly adhered to vegetation and/or sediment surface - ~80% of the salt marsh length with light oiling had 1-10% oil cover/coat and ~20% had 11-50% cover/coat (all in the oiled band) - 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 SFB are dominated by surface feeders (Neira et al., 2005), exposed to the oil on the vegetation and marsh surface during feeding - There are very few laboratory and field studies of wetlands with light oiling. It is assumed that impacts to vegetation are limited and of short duration as described below at one year. - However, 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*s) are expected to be common and widespread
T= 2 mo; 50%	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) No recovery of affected fauna during winter non-reproductive period
T= 1 yr; 75%	Vegetation assumed fully recovered; however, biota are assumed to be still recovering: - *S. alterniflora* lightly oiled with IFO 180 from the *Julie N* spill had the same stem density and stem height as unoiled controls one year later (Michel et al., 1998)

	- In field experiment with application of 0.0375 L/m^2 of No. 5 fuel oil, at 6 months, *Littorina* in oiled areas = 3% of control (1/m^2 in oiled versus 33/m^2) (Lee et al., 1981)
T= 3 yr; 100%	Shore crabs have life spans up to 4 years; gastropods have life spans up to >10 years. Recovery reflects the time to restore age class distributions (by recruitment and immigration)

Salt Marsh + Very Light Oiling

Post-Spill Time/Services Present	Summary of Basis for Assignment of Services Present
T= 0; 75%	Very light oiling mostly occurred as tarballs or patches of oiled wrack both along the fringe and in the interior of the marsh - Most of the very lightly oiled marsh segments had <1% oil coat/cover or tarballs (all in the oiled band) - 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 - There are no laboratory and field studies of wetlands with very light oiling - 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.
T= 2 mo; 75%	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 fauna during winter non-reproductive period
T= 1 yr; 100%	Vegetation assumed fully recovered Fauna assumed fully recovered to their pre-spill abundance and age class distributions

Tidal Flats + Adjacent to Heavy Oiling

Post-Spill Time/Services Present	Summary of Basis for Assignment of Services Present
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 - Studies of the adjacent eelgrass in Keil Cove showed significant impacts to fauna, with observations of numerous slow-moving or dead caprellids in the field 2-10 days post spill (Kitting and Chen, 2009) - 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 rise and fall of the tide would significantly affect the microphytobenthos and benthic bacteria that secrete the mucilaginous matrix of biofilms

T= 2 mo; 75%	End of active cleanup and associated disturbances
	
	- Oil was still moving across tidal flats and affecting epifauna due to continued re-oiling events
	  - Studies of the adjacent eelgrass in Keil Cove showed ~97% loss of normally common caprellids by December 2007 (Kitting and Chen, 2009)
	  - Evidence of oil uptake by filter-feeding bivalves; *Mytilus* on adjacent shoreline in Keil Cove had 14.7 ppm total PAHs on 7 December 2007
	
	- PAHs in mussels exhibit a range of lipophilic affinities, thus elimination of the variety of PAHs in fuel oil are variable. Elimination constants for PAHs (summarized in Meador et al., 1995) range on the order of ~2 days for the lower MW compounds (phananthrene/anthracene) to up to ~30 days for the higher MW compounds (fluoranthene/benzo-a-pyrene). Further, depuration kinetics of PAHs generally indicate a biphasic component to elimination (rapid initial depuration with an asymptotic depuration of the residual), thus body burdens of impacted mussels directly after the spill likely were significantly higher than those determined in the subsequent sampling events.

T= 7 mo; 90%	Tarball stranding and re-oiling events continued into May 2007 - Recovery based on assumption that most of the affected species would have successfully reproduced; this is confirmed by the eelgrass studies that showed invertebrate densities increasing at oiled sites in April and May 2008 (Kitting and Chen, 2009)
T= 1 yr; 100%	Recovery based on assumption that most of the affected species have annual life histories and would have returned to pre-spill abundances

<u>Tidal Flats + Adjacent to Moderate Oiling</u>

Post-Spill Time/Services Present	Summary of Basis for Assignment of Services Present
T= 0; 75%	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 - Studies of eelgrass beds adjacent to moderately oiled shorelines (e.g., Keller Beach) showed ~90% loss of normally common caprellids by December 2007 (Kitting and Chen, 2009) - 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 rise and fall of the tide would significantly affect the microphytobenthos and benthic bacteria that secrete the mucilaginous matrix of biofilms

T= 2 mo; 85%	End of active cleanup and associated disturbances
	
	- Tissue samples indicate ongoing oil exposure
	  - *Cryptomya* clam tissues collected 19 December 2007 from two tidal flat locations on south Brooks Island contained total PAHs of 7.5 and 12.2 ppm; on 30-31 January 2008, values were 9.4 and 13.0 ppm, by March 2008, the concentration had dropped to 1.6 ppm, all matching *Cosco Busan* source oil, indicating oil exposure to infauna
	  - Two *Mytilus* samples from the south shore of Brooks Island in December 2007 contained 16.6 ppm total PAHs (Match); in January 2008, two samples contained 11.4 and 128.7 ppm (Match); by March, two samples contained 1.0 (Probable Match/Mix) and 20.3 ppm (Match)

T= 7 mo; 95%	Tarball stranding and re-oiling events continued into May 2007 - Tissue samples indicate decreasing oil exposure - One *Mytilus* sample from the south shore of Brooks Island collected on 24 June 2008 contained 1.0 ppm total PAHs which fingerprinted as Probable Match/Mix, indicating a very low level of oil from the *Cosco Busan* remained - Recovery based on assumption that most of the affected species would

	have successfully reproduced; this is confirmed by the eelgrass studies that showed invertebrate densities increasing at oiled sites in April and May 2008 (Kitting and Chen, 2009)
T= 1 yr; 100%	Recovery based on assumption that most of the affected species have annual life histories and would have returned to pre-spill abundances

Tidal Flats + Adjacent to Light Oiling

Post-Spill Time/Services Present	Summary of Basis for Assignment of Services Present
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 - Studies of eelgrass beds adjacent to lightly oiled shorelines (e.g., Emeryville) reported observations of numerous slow-moving or dead caprellids in the field 2-10 days post spill (Kitting and Chen, 2009) - 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 rise and fall of the tide would significantly affect the microphytobenthos and benthic bacteria that secrete the mucilaginous matrix of biofilms

T= 7 mo; 95%	Tarball stranding and re-oiling events continued into May 2007
	
	- Tissue samples indicate decreasing oil exposure
	  - In Albany Bay, *Geukensia* mussels contained 25.9 ppm total PAHs on 30 January 2008 (Match) and 4.6 ppm (No Match) on 26 March 2008
	  - In Emeryville, Mytilus mussels contained 20.6 ppm total PAHs on 20 December (Match), 11.6 ppm on 30 January 2008 (Match), and 1.5 ppm (No Match) on 26 March 2008
	- Recovery based on assumption that most of the affected species would have successfully reproduced; this is confirmed by the eelgrass studies that showed invertebrate densities increasing at oiled sites in April and May 2008 (Kitting and Chen, 2009)

T= 1 yr; 100%	Recovery based on assumption that most of the affected species have annual life histories and would have returned to pre-spill abundances

Tidal Flats + Adjacent to Very Light Oiling

Post-Spill Time/Services Present	Summary of Basis for Assignment of Services Present
T= 0; 95%	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 - Studies of eelgrass beds adjacent to very lightly oiled shorelines (e.g., Crown Beach) reported high abundances of caprellids before and during the spill, then a 47% drop 19 days post spill (Kitting and Chen, 2009) - 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 rise and fall of the tide would significantly affect the microphytobenthos and benthic bacteria that secrete the mucilaginous matrix of biofilms
T= 2 mo; 95%	End of active cleanup and associated disturbances - Assume end of oil remobilization in very lightly oiled areas - *Cryptomya* clam tissues collected in Bolinas Lagoon on 11 December 2007 contained 4.7 ppm total PAHs (Match), indicating exposure to infauna on the tidal flats - *Mytilus* mussel tissues collected from the shoreline in Bolinas Lagoon on 28 November 2007 contained 2.1 ppm total PAHs (No Match); samples collected 30 January 2008 contained 0.4 and 0.6 ppm (No Match)
T= 7 mo; 100%	Recovery based on assumption that affected species have would have returned to pre-spill abundances

<u>Sand Beach + Heavy Oiling</u>

Post-Spill Time/Services Present	Summary of Basis for Assignment of Services Present
T= 0; 0%	Heavy oiling smothered/fouled fauna using the habitat, rendering it unsuitable for use by fish, invertebrates, and wildlife - Most of the heavily oiled sand beaches had 11-50% oil cover; 7% had >90% oil cover (all in the oiled band) 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 - Sand lance avoided low levels of oil contaminated sand (113-116 ppm) compared to clean sand (Pinto et al., 1984) All 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) - 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; 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); - In a study of the Ixtoc I spill on Texas beaches, the heaviest oiled transect showed a statistically significant reduction (86%) in total intertidal benthic invertebrate population densities between pre-spill and 1 month post-spill sampling periods (Thebeau et al., 1981)

T= 7 mo; 50%	BeachWatch wrack monitoring data indicates no lag in wrack accumulations; however, invertebrate community structures remain altered following wrack removal more than 6 months following removal (J. Dugan, Pers. Comm.) 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 - 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) - 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 - A common nemertean was present on 22% of the beaches affected by the *Prestige* oil spill 6 months after the spill, whereas it was present on 61% of the beaches after 18 months (Herrara-Bachiller et al., 2008)
T= 1 yr; 80%	Based on life histories of dominant species (1-3 years), recovery is estimated at 80% after 1 year - Meiofauna on sandy shorelines showed no impacts 9 months after the *Sea Empress* spill in Wales (Moore et al., 1997) - 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%	Based on life histories of dominant species (1-3 years), recovery is estimated at 100% in 3 years - 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) - Macrofauna at the heavily oiled beaches at the *Prestige* spill site were not fully recovered after 3 years (Castellanos et al., 2007)

<u>Sand Beach + Moderate Oiling</u>

Post-Spill Time/Services Present	Summary of Basis for Assignment of Services Present
T= 0; 0%	Moderate oiling smothered/fouled fauna using the habitat, rendering it unsuitable for use by fish, invertebrates, and wildlife - 57% of the moderately oiled sand beaches had 1-10% oil cover; 43% had 11-50% oil cover (all in the oiled band) 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 - Sand lance avoided low levels of oil contaminated sand (113-116 ppm) compared to clean sand (Pinto et al., 1984) All 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; 0%	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 - In a study of the Ixtoc I spill in Texas, four out of seven transects showed a decrease of at least 50% in 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; 75%	BeachWatch wrack monitoring data indicates no lag in wrack accumulations; however, invertebrate community structures remain altered following wrack removal more than 6 months following removal (J. Dugan, Pers. Comm.) 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; 80%	Based on life histories of dominant species (1-3 years), recovery is estimated at 80% 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%	Based on life histories of dominant species (1-3 years), recovery is estimated at 100%

Sand Beach + Light Oiling

Post-Spill Time/Services Present	Summary of Basis for Assignment of Services Present
T= 0; 50%	Light oiling would foul fauna and reduce the use of the beach habitat by fish, invertebrates, and wildlife - 71% of the lightly oiled sand beaches had <1% oil cover; 18% had 1-10% oil cover; 11% had 10-50% oil cover (all in the oiled band) - 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; 50%	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 16.1 ppm total PAHs; mussels adjacent to lightly oiled beaches in the Emeryville Crescent on 30 January 2008 contained 11.5 ppm and adjacent to lightly oiled beaches on Brooks Island contained 11.4 ppm (all matched to *Cosco Busan* oil), 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. - In experiments sand lance avoided low levels of oil contaminated sand (113-116 ppm) compared to clean sand (Pinto et al., 1984)
T= 7 mo; 90%	BeachWatch wrack monitoring data indicates no lag in wrack accumulations; however, invertebrate community structures remain altered following wrack removal more than 6 months following removal (J. Dugan, Pers. Comm.) 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 - Meiofauna on sandy shorelines showed no impacts 9 months after the Sea Empress spill in Wales (Moore et al., 1997) Recovery based on assumption that most species would have recovered except for the longer-lived isopods and beetles
T= 1 yr; 100%	Based on life histories of dominant species (1 year), recovery is estimated at 100% after 1 year

Sand Beach + Very Light Oiling

Post-Spill Time/Services Present	Summary of Basis for Assignment of Services Present
T= 0; 75%	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 - ~75% of the lightly oiled sand beaches had <1% oil cover; 25% had 1-10% oil cover (all in the oiled band) 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; 75%	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= 7 mo; 95%	Tarball stranding and re-oiling events continued into May 2007 - Recovery based on assumption that most species would have recovered except for the longer-lived isopods and beetles - Meiofauna on sandy shorelines showed no impacts 9 months after the *Sea Empress* spill in Wales (Moore et al., 1997)
T= 1 yr; 100%	Based on life histories of dominant species (1 year), recovery is estimated at 100% after 1 year

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