APPENDIX F

Service Losses and Recovery for Rocky Intertidal Habitat

October 2010

Rocky Intertidal Subgroup -Trustees
***Cosco Busan* Natural Resource Damage Assessment**

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A. Overview of Approach

The information in this document reflects the work of the trustees affiliated with the Rocky Intertidal Habitat subgroup. The trustees established this subgroup early in the NRDA process to provide guidance for assessing injury and evaluating recovery of rocky intertidal habitats in the incident area. Technical assistance was provided by consultants for the trustees, including Research Planning, Inc. (RPI) and researchers from University of California at Santa Cruz (UCSC) and Davis (UCD), and consultants associated with the Responsible Party, including Polaris.

The Rocky Intertidal Habitat subgroup relied upon an array of information to determine effects of the *Cosco Busan* spill on the shoreline habitats in this category. Similar to the other shoreline habitats, the degree of oiling is based on descriptors used by the Shoreline Cleanup and Assessment Technique (SCAT) Teams for response. Evaluated information included field data gathered during Tier I (sampling to document exposure and/or injury) and Tier II (sampling to document injury) assessment phases. The subgroup also obtained and analyzed field data from other monitoring programs [Multi-Agency Rocky Intertidal Network (MARINe) and National Park Service). In addition to studies conducted under the auspices of the *Cosco Busan* NRDA process, the Rocky Intertidal Habitat subgroup evaluated qualitative information such as pre- and post-spill photographs, field notes (*e.g.*, from Jepson Herbarium at UC Berkeley), and species data from other projects (*e.g.*, the Moss Landing Marine Laboratory Aquatic Invasives Study). In situations where field data were not available, the Rocky Intertidal Habitat subgroup used scientific literature to evaluate injury and expected recovery with a preference for studies done in nearby coastal locations and similar or same species assemblages.

B. Overview of Rocky Shoreline Habitats within the Incident Area

The rocky intertidal shoreline affected by this incident covers a broad range of rocky substrates from artificial to natural and an approximately 6-foot tidal range. The habitats covered by the rocky intertidal subgroup include bedrock, boulder, coarse gravel, cobble-pebble, riprap, and seawall. The habitat used by biota is three dimensional with organisms on the surfaces of rocks as well as along the sides, undersides, and between substrates. The biota present at these sites (excluding birds and marine mammals) varies depending upon tidal elevation. Many common taxa of these rocky shorelines and corresponding tidal elevation can be found in Hedgpeth (1971) and are summarized in Table 1 below.

Table 1. Common taxa found within rocky shoreline habitats within the *Cosco Busan* incident area

Zone	**Elevation** (ft, mean lower low water, MLLW)	**Common Taxa**
Supralittoral / Splash	+6 to +5	Rock louse (*Ligia* sp.), barnacle (*Chthamalus* spp.), periwinkle snail (*Littornia* spp.)
High	+5 to +3	Rockweeds (*Pelvetiopsis*/*Fucus*), Red algal “turf” (*Endocladia muricata*), *Mastocarpus papillatus*
Mid	+3 to 0	Rockweed (*Fucus gardneri*), Red algal “turf” (*Endocladia muricata/Gelidium* spp/*Cryptosiphonia woodii*), *Mastocarpus papillatus*, mussel (*Mytilus* spp.), purple shore crab (*Hemigrapsus nudus*)
Low	0 and slightly lower	Surfgrass (*Phyllospadix* spp.), kelp (*Laminaria* spp.)

C. Simplifying Assumptions

The following assumptions are based on an understanding of the literature and field observations by the Rocky Intertidal Habitat subgroup to describe how the habitats generally function, how the oiling and cleanup generally affected the rocky habitats, and how the affected habitat generally recovers. The subgroup used these assumptions to develop an “operational model” of rocky intertidal habitats within the spill zone and to generate the injury and recovery categories used for the Habitat Equivalency Analyses (HEAs).

1. *Rocky intertidal flora and fauna differ between the open coast and San Francisco Bay.* Dramatically different water currents, salinity, and wave energy affect the predominant flora and fauna occurring in the outer coast shorelines as compared with those found in the interior bay environs. However, some sites within San Francisco Bay are similar to some areas along the outer coasts of Marin, San Francisco, and San Mateo. Golden Gate Straits, the western shorelines of Angel Island and Alcatraz Island are exposed to westerly swells and have flora and fauna characteristic of the open coast (Silva 1979). Figure 1 illustrates these locations within San Francisco Bay.

Figure 1. Rocky outer coast shorelines for the *Cosco Busan* incident (shown in red)

2. *Oil exposure and resulting impacts differed between the open coast and the San Francisco Bay rocky shoreline.*

Wave exposure in the outer coast would result in a generally lower residence time of oil when compared to sites within San Francisco Bay. The Rocky Intertidal Habitat subgroup made a preliminary assumption that the reduced residence time of oil may result in lowered risk for exposure and injury at outer coast sites.

3. *In San Francisco Bay, riprap sites retained oil longer than other rocky shoreline types due to residual oil in interstitial spaces.*

SCAT data and observations from Tier I rocky intertidal surveys indicated the presence of oil within the crevices of riprap. These locations are protected from wave action. Oil persisted longer there than did surficial deposits of oil that could be removed naturally or by cleaning activities.

4. *Most of the oil was deposited in the mid, high and splash intertidal zones such that the degree of impacts and recovery differ between the stranded zone in the rocky intertidal and the non-stranded, lower intertidal zone.*

The oiled band, as described by SCAT surveys, had the highest degree of oil exposure and impact. However, the lower intertidal zone below the oiled band was also exposed to intermittent oiling during rising and falling tides and was impacted further by trampling and exposure to oil released during cleanup efforts.

5. *Sites with HOTSIE (hot water, high pressure cleaning) and rock removal and replacement, had different impacts and recovery than sites without "heavy" cleaning.*

For sites with HOTSIE or rock removal and replacement, we assumed that the predominant impacts were a result of response activities, although initial and residual oil also contributed as well. We assumed that at sites without HOTSIE or rock replacement (but including those with other treatments), the impacts were primarily associated with their level of oiling and manual clean-up. Other types of treatment included treatment with cold water at low pressure and high volume at Horseshoe Cove (Marin Co.) and treatment with the chemical dispersant Cytosol at Berkeley Marina (Alameda Co.). Table 2 lists these locations.

Table 2. HOTSIE and rock replacement sites [1]

Location[2]	Treatment	SCAT sub-segment ID
Middle Harbor Shoreline Park	HOTSIE	ALB03-04
Aquatic Park	HOTSIE	SFH013
Treasure Island near Incident Command	HOTSIE	SFF03, SFF04
Berkeley Marina - Adventure Park	HOTSIE	ALA011A, ALA011C_1, ALA011C, ALA011C2
Belvedere	HOTSIE	MRQ001A
Pt. Isabel Dog Park	HOTSIE	CCZ023
Pt. Isabel	HOTSIE	CCZ25-1, CCZ25-2, CCZ25-3, CCZ26
South Albany Bulb	HOTSIE	ALA05
Shimada Park	HOTSIE	CCZ015
Keil Cove	Rock replace	MRR020

[1] Information from Response incident action plans, Polaris, and East Bay Regional Park District.
[2] Locations were predominately within rip-rap and sea-wall habitats. Keil Cove is a cobble-pebble habitat.

6. *The degree of impacts associated with manual cleaning varied according with the amount of oiling (e.g., sites with "moderate" oiling have more cleaning related impacts than "lightly" oiled)*

We assume that sites with heavier oiling had more personnel deployed for cleaning activities for longer periods of time than less oiled sites. We assume that both the amount of oiled biota removed and trampling impacts (particularly in the high intertidal) were related to the number of personnel in an area. The following photos from Pt. Blunt indicate the level of clean-up activity (Figure 2), typical clean-up actions (Figure 3) and oiled algae (*Fucus gardneri*) removed during clean-up (Figure 4).

Figure 2: Manual clean-up actions at Pt. Blunt, Angel Island. Photo: Dan Richards, November 21, 2007.

Figure 3. Manual rock cleaning with *Fucus gardneri* (above hand) at Pt. Blunt, Angel Island. Photo: Dan Richards, November 21, 2007.

Figure 4. Bag of oiled *Fucus gardneri* (including holdfasts) from cleaning activities at Pt. Blunt, Angel Island. Photo: Dan Richards, November 21, 2007.

7. *Recovery times from the UCSC study of artificially disturbed rocky intertidal communities in Central California are representative of likely recovery times from impacts of the Cosco Busan spill to in-bay and outer coast rocky intertidal habitats.*

Data on the recovery of rocky intertidal assemblages along Central California coast from the UCSC study of artificially disturbed rocky intertidal communities with different sized disturbances (clearing) within an intact habitat (Conway-Cranos 2009) were considered representative of recovery times for those assemblages following *Cosco Busan* spill impacts.

8**.** *Working Definition of Recovery*

The Rocky Intertidal subgroup defined recovery as the attainment of 100% of the ecological services that would have been present but for the *Cosco Busan* spill. This definition may include some services that are hard or expensive to quantify (*e.g.*, reproductive output, age class distribution). Note that this definition of recovery along and the previously stated simplifying assumptions has been explicitly used to separate out the various injury and recovery categories (Figure 5).

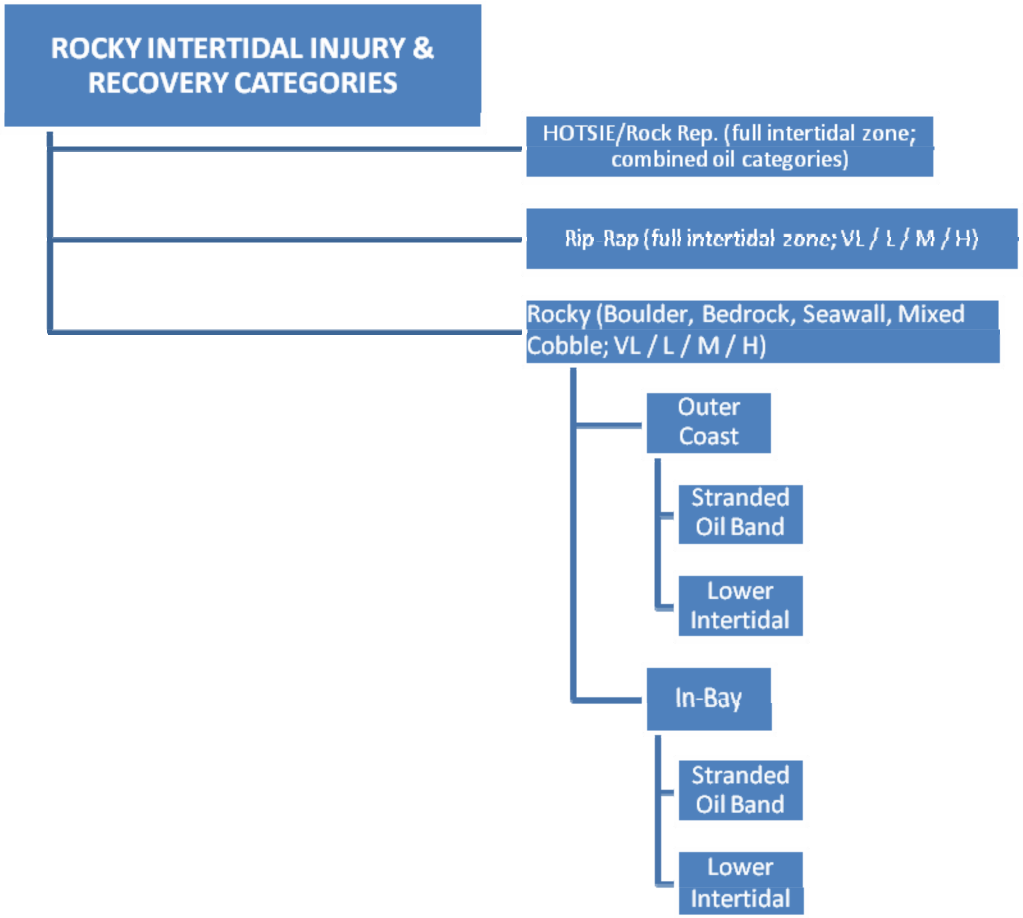

Figure 5. Rocky intertidal injury and recovery categories for the *Cosco Busan* incident

D. Summary of Pre-Spill Rocky Intertidal Data for San Francisco Bay

Limited pre-spill data were available to provide a quantitative description of intertidal biota within the Bay. Most of the pre-spill monitoring data were available for sites along the outer coast or for in-bay sites strongly influenced by marine conditions (*e.g.*, Alcatraz). Data on taxa for various sites within the San Francisco Bay from an Aquatic Invasives Inventory and the Jepson Herbarium indicate that prior to the spill four major assemblages were present throughout the Bay (Foss 2008; MLML, unpub. data, 2009; Tables 3-4). The subgroup used these four assemblages, a rockweed (*Fucus gardneri*), mussel (*Mytilus* spp.), mid-intertidal red algae (various species), and barnacles (various species), to derive estimated recovery rates.

Table 3. Taxa found by year at Central Bay sites prior to the *Cosco Busan* spill from the staff of the Jepson Herbarium (Silva 1979; Moe, unpub. data, 2009)

Locale	Habitat	*Fucus*	Mussels	Mid-Intertidal Red Algae	Barnacles
Fort Point	Seawall/boulders	ND	ND	1977	ND
Alcatraz	Bedrock bench	1977	ND	1977	ND
Yerba Buena	Riprap	1975	ND	1975	ND
Treasure Island	Riprap	ND	ND	1975	ND
Angel Island-Pt. Blunt		1972	ND	1972	ND
Berkeley Yacht Harbor	Riprap	1974	1974	1974	1974
Pt Richmond-Keller Beach-Cypress Point	Sandstone outcrops and cobbles	1997	ND	1997	ND
East Brother Island	Bedrock	1984	1984	1984	1984
Golden Gate Fields	Sandstone outcrop	Noted as absent 1976	1976	1976	1976
Point Isabel	Riprap	1976	1976- heavily populated	1976	ND

ND, no data

Table 4. Taxa found at Central Bay sites prior to *Cosco Busan* spill from Moss Landing Marine Laboratories (MLML) in 2005 (Foss 2008; MLML, unpub. data, 2009)

Locale	Habitat	*Fucus*	Mussels	Mid-Intertidal Red Algae	Barnacles	# Algae Taxa	Total # Taxa
Fort Point	Riprap	ND	x	x	x	45	159
Yerba Buena	Bedrock, some cobble & riprap	x	x	x	x	37	141
Pt. Cavallo	Bedrock	x	x	x	x	40	140
Tiburon	Bedrock, some riprap	x	x	x	x	27	113
Richmond Marina	Riprap	x	x	x	x	15	90
Angel Island-Ayala Cove	Riprap	x	x	x	x	27	135
Alcatraz	Bedrock bench	x	x	x	x	34	146

ND, no data

In addition, UC Davis has several long-term native oyster monitoring sites in the Bay for which there were pre-spill data on larval recruitment and growth and mortality of tagged oysters (Table 5, Figures 6-7).

Table 5. UCD native oyster long-term monitoring sites with pre-spill 2006 and/or 2007 data on recruitment, growth, and mortality of native oysters

Site	Substrate Type	Tidal Height
Alameda (Encinal Boat Launch)	rip-rap	+/- 0.5 ft. MLLW
Angel Island	natural cobble	+/- 0.5 ft. MLLW
Berkeley, Shorebird Park	rip-rap	+/- 0.5 ft. MLLW
Oyster Point	rip-rap	+/- 0.5 ft. MLLW
Point Orient	natural cobble (SCAT rip-rap)	+/- 0.5 ft. MLLW
Tiburon-Belvedere	cement cobble	+/- 0.5 ft. MLLW

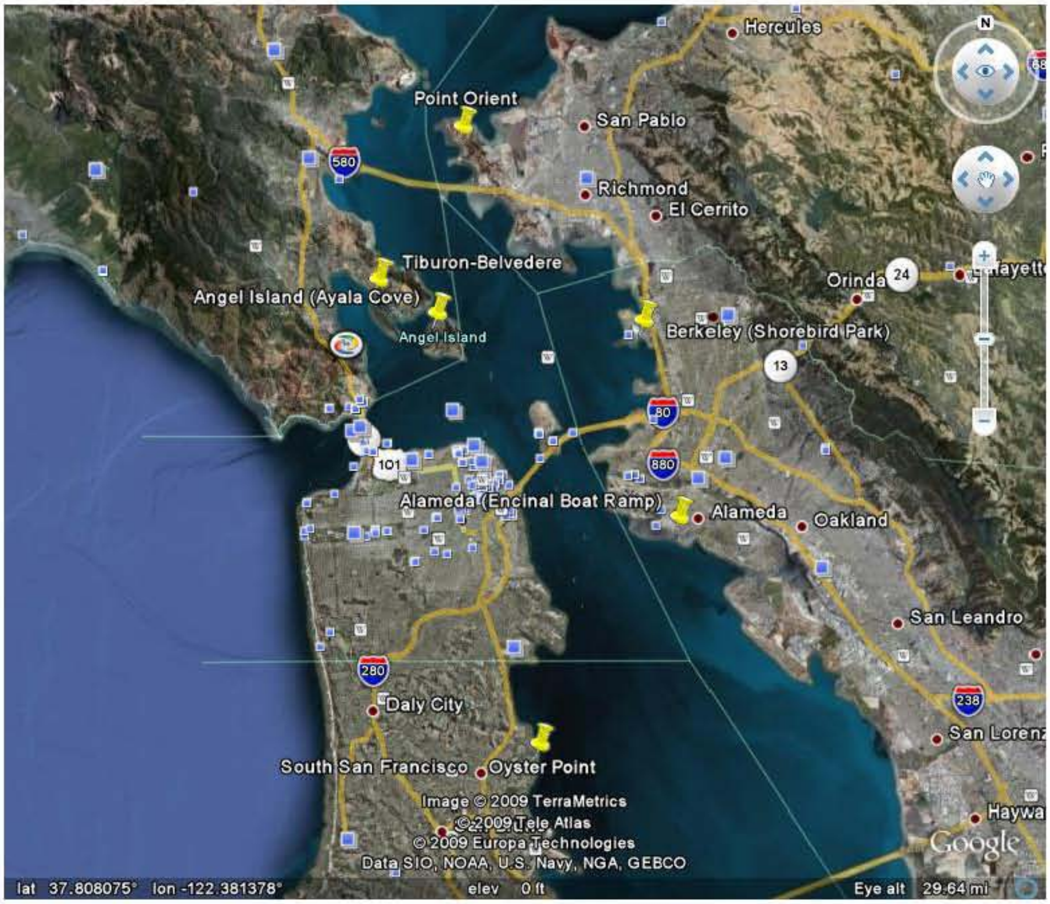

Figure 6. UCD native oyster long-term monitoring sites

Figure 7 a & b. UCD native oyster long-term monitoring site at Berkeley Marina East. Photos: Chela Zabin, July 2006

E. Summary of Preliminary Studies Documenting Exposure and/or Injury (Tier I Data)

UC Santa Cruz, Polaris and National Park Service staff collected field data to document the amount of exposure and/or injury (Tier I data) within a month of the spill at both outer coast and in-bay rocky intertidal sites. Table 6 provides a list of taxa that were found during field surveys to be either exposed to oil as evidenced by physical contact, injured, or dead (Figures 8-9). In addition, we aggregated these data by SCAT oiling category and cleanup type (Table 7). We used these data to verify the appropriateness of using rocky intertidal injury and recovery categories (Figure 5). The data indicate that the highest degree of exposure and/or injury of taxa were associated with the level of oiling and clean-up impacts (as described by SCAT oiling categories and HOTSIE sites).

Table 6. Exposure and/or documented injury to key rocky intertidal taxa by intertidal zone

Intertidal Zone	Species and Impact
Low intertidal	Coralline algae (bleaching) *Gymnogongrus* sp. (bleaching) *Ostrea lurida* (exposure) *Phyllospadix* sp. – in-Bay (clearing) , - in-Bay (exposure), - outer coast (exposure) *Prionitis sp.* (bleaching)
High to Low intertidal (Interstitial) [1]	*Chthamalus/Balanus* (smothering) *Cancer* - low intertidal (dead) *Hemigrapsus nudus* - mid intertidal (exposure) *Pachygrapsus crassipes* - high intertidal (exposure)
Mid intertidal	*Mytilus* spp. (exposure) *Pisaster sp.* (dead)
Mid to high intertidal	*Fucus gardneri* (exposure/clearing) *Ulva/Enteromorpha* (exposure) *Mastocarpus* spp. (exposure) *Endocladia muricata* (exposure)
High intertidal	*Chthamalus/Balanus* (smothering) Limpets (exposure/smothering)

[1] Note: dead Cancer and oiled shore crabs at all Heavy oiled bedrock [Alcatraz (Fig. 4) and Pt. Blunt - MR R01] sites as well as Light (Potrero Point - CCZ011) and Very Light (Yellow Bluff - MRP02) sites.

Table 7. Mean percentage of observed taxa that were exposed, injured or killed (excluding PAH body burden data) during Tier I sampling at outer coast and in-bay sites.

Oiling Category	% Taxa
No Observable Oil	1
Very Light	10
Light	20
Moderate	32
Heavy	48
HOTSIE	62

Figure 8. Oiled lined shore crab (*Pachygrapsus crassipes*) at Alcatraz Island (Heavy oiling). Photo: Darren Fong, November 13, 2007

Figure 9. Dead barnacles (*Balanus*/*Chthamalus*) and residual tar at Horseshoe Cove - 1.5 years post-spill (Marin Co., Moderate oiling). Photo: Darren Fong, May 1, 2009

F. Additional Studies (Tier II)

Additional follow-up studies to evaluate potential effects on native oysters (Zabin *et al.*, 2009) and rocky intertidal communities (Raimondi *et al.*, 2009) were completed by UCD and UCSC researchers, respectively. The individual reports summarizing these studies and their results are included in the *Cosco Busan* administrative record. Their data was used to help with assessment of initial injuries.

G. Initial Injuries

We determined the magnitude of initial injuries based on field data (Tier I and II), field observations, and supplemented with scientific literature. Initial injury resulting from the *Cosco Busan* spill is associated with trampling from spill assessment and clean-up activities, physical cleaning of rocky intertidal habitats, sublethal effects from exposure to petroleum, direct smothering/fouling of individual organisms and tissue necrosis/bleaching. The level of initial injury also relied in part, on one of our assumptions (See Section B, #6) that the degree of impacts associated with manual cleaning varied according with the amount of oiling (e.g., sites with "moderate" oiling have more cleaning related impacts than "lightly" oiled).

With regards to literature on the impacts from trampling, many of the California human use impact studies at publicly accessible sites have documented impacts of high visitation over prolonged periods of time. Many of the studies are a composite of harvesting and trampling impacts (e.g., mussels) or just trampling. The trampling impacts associated with the spill involve short-term but concentrated foot traffic. The literature indicates direct impacts to fucoids even under low intensities (Schiel and Taylor 1999) or to a wide suite of invertebrates for a single trampling event (Casu *et al.*, 2006). Trampling impacts may even extend beyond the footprint; a study has looked at cascading influences on the rocky intertidal communities to shorebirds and algal after manipulations to limpet densities (Lindberg *et al*., 1998).

H. Recovery Times

The recovery trajectory for each of the categories has been developed based on nearby rocky intertidal disturbance and recovery data from UCSC and supplemented by relevant scientific literature. The emphasis on UCSC field data was in response to initial review of Trustees' HEA (presented in September 2008) that recovery trajectory be focused on local data, if available.

As part of her UCSC dissertation work, Tish Conway-Cranos (with graduate advisor Pete Raimondi) studied the recovery of rocky intertidal assemblages along the Central California coast from different sized disturbances (clearing) within an intact habitat. The UCSC disturbance study involved clearing all biota from areas of eight different patch sizes (ranging from 8 x 12 to 50 x 75 sq. cm) within intact habitats at three outer coast sites in California. Table 8 gives estimated recovery times for four main assemblages: barnacles, mid-intertidal red algae, mussels, and fucoid algae (*Silvetia*). Time to recovery was based on attainment of community composition similar to control plots (using a Bray-Curtis index of similarity comparison). For mussels and fucoid algae, the recovery times varied with the size of the disturbance, whereas there was no difference for barnacles and mid-intertidal red algae.

Since recovery times for mussels and fucoid algae varied with disturbance size, the disturbance size most similar to the general pattern of oiling for each oiling category was selected. For sites with Moderate or Heavy oiling or HOTSIE treatment, the recovery estimates for the larger scale disturbance (50 x 75 sq. cm area) were used for fucoid algae assemblage. The recovery time for mussels with intermediate patch size (60 months) was considered the most applicable given the impacts to mussels at sites with Moderate and Heavy oiling and HOTSIE treatment within the Bay where most of the heavier oiling and cleanup impacts occurred. For Lightly and Very Lightly oiled sites, the recovery estimates for the smaller scale disturbance (8 x 12 sq. cm area) were used for both mussels and fucoid algae to be consistent with the pattern of oiling in these areas.

Table 8. Recovery estimates from UCSC dissertation work (Conway-Cranos and Raimondi, pers. comm., 2009)

Community	Disturbance Size Dependent?	Months to recovery	Notes
Barnacles	No	24	
Mid-intertidal red algae	No	60	
Mussel	Yes	33-94	Increasing time with increasing disturbance size.
Fucoid Algae	Yes	47-65	Increasing time with increasing disturbance size

The overall recovery times used were the weighted averages of the values for the four communities based on the proportion of occurrence and expected susceptibility to injury from oiling and cleanup. The recovery times for barnacles, mid-intertidal red algae, and fucoid algae were weighted equally (30%), while the value for mussels was weighted lower (10%).

The generalized Service Loss trajectory is as follows:

$$ServiceLoss_{t_i} = 0.3 * \left(\frac{\text{InitialFucusLoss}_{t_i}}{\text{FucusRecovTime}} + \frac{\text{InitialBarnacleLoss}_{t_i}}{\text{BarnacleRecovTime}} + \frac{\text{InitialRedLoss}_{t_i}}{\text{RedRecovTime}} \right) + 0.1 * \frac{\text{InitialMusselLoss}_{t_i}}{\text{MusselRecovTime}}$$

where t_i represents inflection time points.

I. Specific Injury and Recovery Trajectories by Oiling Category

The following Tables 9-15 described the amount of injury (by acres) to rocky intertidal habitat and specific recovery trajectories for our injury and recovery categories. In addition, lower intertidal recovery trajectory have been developed using relevant scientific literature for affected taxa. The acreages were calculated based on SCAT team shoreline oiling data and habitat widths (Holton and Dunagan, 2010). The habitat services at each time point represent an amalgamation of the ecological services of affected taxa and area.

Table 9. Summary of Injury to Rocky Intertidal Habitats

Habitat/Category	Acres injured	Time to full recovery (yrs)
In-Bay		
HOTSIE / Rock Replacement	5.8	5.4
Riprap - Heavy	0.9	5.4
Riprap - Moderate	5.8	5.4
Riprap - Light	21.3	5

Habitat/Category	**Acres injured**	**Time to full recovery (yrs)**
Riprap - Very Light	49.6	5
Stranded Oil Band - Heavy	0.5	5.4
Stranded Oil Band - Moderate	0.8	5.4
Stranded Oil Band - Light	4.4	5
Stranded Oil Band -Very Light	3.2	5
Rest of Intertidal - Heavy	1.1	4
Rest of Intertidal - Moderate	4.7	2
Rest of Intertidal - Light	29.4	1
Rest of Intertidal - Very Light	30.6	0.08
Bay Subtotal	*158.1*	*0.08 - 5.4*
Outer Coast		
Stranded Oil Band - Heavy	0.6	5.4
Stranded Oil Band - Moderate	0.9	5.4
Stranded Oil Band - Light	2.4	5
Stranded Oil Band - Very Light	18.3	5
Rest of Intertidal - Heavy	0.7	3
Rest of Intertidal - Moderate	3.7	1
Rest of Intertidal - Light	37.2	0.25
Rest of Intertidal - Very Light	162.5	0.08
Outer Coast Subtotal	*226.2*	*0.08 - 5.4*
Total	***384.3***	***0.08 - 5.4***

In-Bay HOTSIE/ Rock Replacement

HOTSIE activities occurred primarily on riprap shorelines with a variety of oiling categories ranging from Very Light (Middle Harbor Shoreline Park) to Heavy (South Albany Bulb). We assumed HOTSIE impacts overwhelmed any impacts associated with the degree of oiling category based on data associated with the Exxon Valdez spill. The injury and recovery inputs applied to the entire intertidal zone and HOTSIE areas regardless of SCAT oiling category.

Table 10. In-Bay HOTSIE/ Rock Replacement

Time / Habitat Services Present
0 yr / 10%
2 yr / 61%
5 yr / 98%
5.4 yr / 100%

Initial Service Loss. To estimate services present at time zero we used data from both rock replacement work at Keil Cove (0% services) and at Berkeley Marina / Pt.Isabel (10-15% services). Terrestrial rocks were placed in the intertidal zone at Keil Cove and were assumed to have 0% services initially. Pre-spill photos of Berkeley Marina show approximately 80% cover of biota (mostly *Ulva/Enteromorpha*) in intertidal zone (Figures 7 a&b and 11 a-e). In November 2007, approximately 15-20% biotic cover was present at both Berkeley Marina and Pt. Isabel. This represents a decline of about 80% of biotic cover. The additional 5-10% loss in services is associated with injury to motile species (net 10% habitat services present at 0 yr).

Recovery. We assumed that the four common assemblages were present at the HOTSIE sites prior to the spill, although only qualitative information is available (Tables 4-5). We used recovery trajectory information from UCSC, as described previously. This approach may underestimate recovery time since HOTSIE treatments removed organisms from much broader areas than the treatment patches from the Conway-Cronos (2009) studies that were within intact rocky intertidal habitat. Field data immediately after the spill and at 1.5 years (2009) at Berkeley Marina indicate little change in community structure while Pt. Isabel had some significant differences. Published data are available for recovery of *Fucus* disturbed by HOTSIE treatments as well as from clearing studies. The recovery periods for HOTSIE from the literature are generally longer than recovery time cited by UCSC study. Initial cover of *Fucus* at HOTSIE sites may recover quickly but large oscillations in cover persist as age classes are lost en mass over time (Kimura and Steinbeck 1999, Hoff and Shigenaka 1999) presumably until a mixed age-class structure develops.

Figure 10. Recovery of Keil Cove rocky intertidal (with *Balanus/Chthamalus* recruitment) following rock replacement. Photo: Natalie Cosentino-Manning, May 7, 2009

Berkeley Marina East

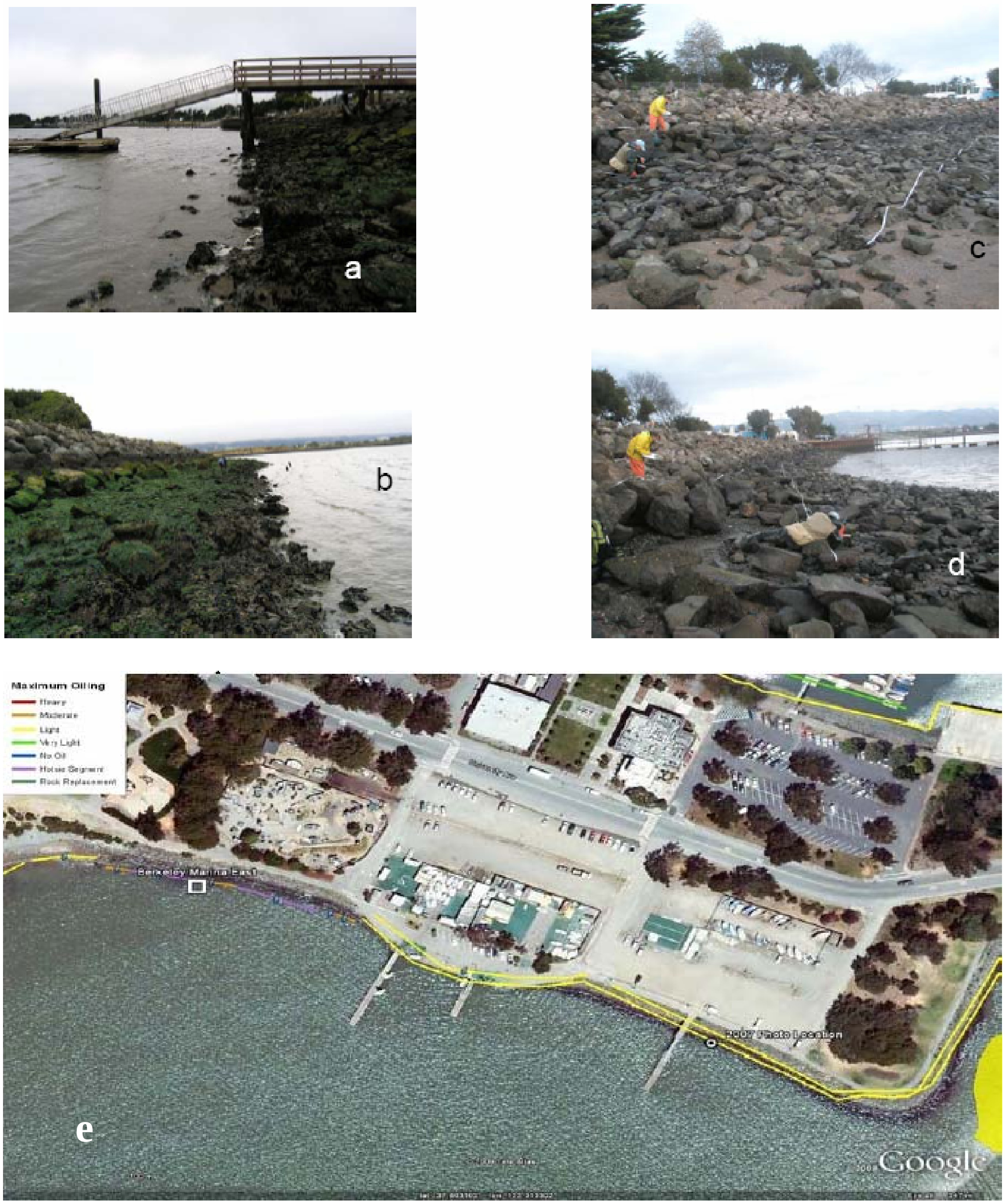

Figure 11. Pre-spill (a&b, UCD, July 2006) and post-spill (c&d, UCSC / Polaris, February 2009) images of Berkeley Marina and overview map (e) showing photo locations (a&b-box, c&d-circle)

In-Bay -Riprap

Injury and recovery inputs for the in-Bay rip-rap sites applied to the full intertidal zone.

Table 11. In-Bay - Riprap

Very Light	Light	Moderate	Heavy
0 yr / 95%	0 yr / 75%	0 yr / 40%	0 yr / 30%
2 yr / 98.2%	2 yr / 91%	2 yr / 74%	2 yr / 70%
2.75 yr / 98.9%	2.75 yr / 94%	5 yr / 99%	5 yr / 98%
3.9 yr / 99.7%	3.9 yr / 98%	5.4 yr / 100%	5.4 yr / 100%
5 yr / 100%	5 yr / 100%		

Initial Service Loss. Storms during January 2008 resulted in significant re-oiling across much of the East Bay and re-exposure of fauna to PAHs. Several *Mytilus* samples collected from Stege, Emeryville, Albany and Brooks Island in 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 December 2007. PAH concentrations in mussel samples indicated a return to ambient levels by March-June 2008, depending on location. At Tiburon and Pt Orient (Very Light, rip-rap), the UCD oyster study (low intertidal to subtidal) had 40-60% increased oyster mortality versus controls (Zabin *et al*., 2009); post-spill oyster tissues had PAHs matching *Cosco Busan* oil and increased concentrations compared to pre-spill.

Recovery. We assumed that the four common assemblages were present at the riprap sites prior to the spill, although only qualitative information is available (Tables 4-5). The recovery trajectory approach was the same as described above. At Berkeley Marina, a lightly oiled riprap site still had visible tar present in the high intertidal and splash zones in the interstitial spaces (approximately <1and 5% cover, respectively) at 1.5 years post-spill.

In-Bay - Stranded Oil Band

This habitat category includes stranded oil band in boulder, cobble-mixed gravel, seawalls, and bedrock within the Bay. We assumed that most of these habitats had surficial oiling and that recovery trajectories are similar enough to lump. This excludes in-bay riprap sites with interstitial oiling. The light category was mostly seawall. The moderately oiled category was dominated by cobble-pebble (mostly by ephemeral algae and shore crabs which have a relatively quick recovery).

Table 12. In-Bay - Stranded Oil Band

Very Light	Light	Moderate	Heavy
0 yr / 90%	0 yr / 70%	0 yr / 30%	0 yr / 20%
2 yr / 96.5%	2 yr / 89%	2 yr / 70%	2 yr / 66%
2.75 yr / 97.8%	2.75 yr / 93%	5 yr / 98%	5 yr / 98%
3.9 yr / 99.4%	3.9 yr / 98%	5.4 yr / 100%	5.4 yr / 100%
5 yr / 100%	5 yr / 100%		

Initial Service Loss. UCD oyster mortality data had 20% increased mortality post spill for Angel Island (Light, bedrock); post-spill oyster tissues had PAHs matching *Cosco Busan* oil and increased concentrations compared to pre-spill.

Recovery. Again, recovery trajectory was based on UCSC research data, as previously described. Field observations are consistent with the expected recovery trajectory. Following the spill, tar patches have persisted after 1.5 years within the Bay, generally in protected locations (crevices between riprap or large boulders), and have minimal recruitment of intertidal organisms (Figure 9). Studies have indicated recovery period of persistent tar patches occurring on time frame of months to years with a site near San Luis Obispo with tar persisting for more than 2 years (Roe *et al.*, 2003). Locations in more exposed locations outside the Bay (*e.g.*, North Rodeo Beach) have minimal amounts of tar patches.

In-Bay - Rest of Intertidal

These injury and recovery inputs apply to the lower intertidal zone below the stranded oil band at in-Bay sites.

Table 13. In-Bay - Rest of Intertidal

Very Light	Light	Moderate	Heavy
0 yr / 95%	0 yr / 80%	0 yr / 70%	0 yr / 50%
0.08 yr / 100%	0.5 yr / 95%	0.5 yr / 80%	2 yr / 75%
	1 yr / 100%	1 yr / 95%	3 yr / 95%
		2 yr / 100%	4 yr / 100%

Initial Service Loss. Based on UCD oyster mortality data, there was a 20% increased mortality post spill at Angel Island, a Lightly oiled, bedrock site (Zabin *et al.*, 2009). In addition, the post-spill oyster tissues had PAHs matching *Cosco Busan* oil and had increased concentrations compared to pre-spill oyster tissues. Exposure of biota within the low intertidal zone was documented by elevated PAH levels in native oysters post-spill and visual evidence of oil on oysters (Zabin *et al.*, 2009). We assumed less injuries associated with cleaning occurred within the lower intertidal zone since cleaning actions occurred primarily in mid to high intertidal zones. However, removal of oiled vegetation did occur at Pt. Blunt and possibly other locales.

Recovery. The communities used to estimate recovery in the UCSC research are generally less common in lower intertidal areas. Therefore, the model would not be applicable here. However, there was limited to no active cleanup impacts in this lower intertidal zone as well as less oil exposure. Therefore, we anticipated quicker recovery than for the stranded band where active cleanup and trampling impacts occurred.

Outer Coast - Stranded Oil Band

For outer coast sites, including similar sites within the bay, Alcatraz Island (Heavy) had a relatively large amount of pre- and post- spill data and therefore was used to estimate injury to biota in the stranded oil band with Heavy oiling. Data from Alcatraz included photographs (before, during and after the spill) and transect and photoplot data.

Table 14. Outer Coast - Stranded Oil Band

Very Light	Light	Moderate	Heavy
0 yr / 90%	0 yr / 75%	0 yr / 50%	0 yr / 30%
2 yr / 96.5%	2 yr / 91%	2 yr / 79%	2 yr / 70%
2.75 yr / 97.8%	2.75 yr / 94%	5 yr / 99%	5 yr / 98%
3.9 yr / 99.4%	3.9 yr / 98%	5.4 yr / 100%	5.4 yr / 100%
5 yr / 100%	5 yr / 100%		

Initial Service Loss. At Alcatraz, there was 60% oil coverage and approximately 60% loss of *Fucus* post-spill (Fall 2006 vs. Fall 2008). Sites with lower levels of oiling had an associated higher level of initial services. Additional losses were associated with manual cleaning of the rocky intertidal zone (*e.g.*, Pt. Blunt) that was also considered proportional to the level of oiling.

Recovery. We assumed that the four common assemblages were present at the sites prior to the spill and had used recovery trajectories described previously. Both field data and photo panoramas indicate that Alcatraz Island had not recovered to pre-spill conditions one year after the spill (Raimondi *et. al.*, 2009 and Figures 12-14).

Figure 11. Heavy oiling of Alcatraz Island, a sandstone rocky intertidal bench (non-oiled areas are light tan color). Photo: Darren Fong, November 13, 2007

Figure 12. Pre-spill Alcatraz Island rocky intertidal photopan looking east to Bay Bridge (bare rocks are grey, mid-intertidal red algae are textured red covered rocks and *Fucus* are textured, green-black covered rocks). Photo: Darren Fong, February 2005

Figure 13. Immediate post-spill Alcatraz Island rocky intertidal photopan looking east to Bay Bridge (shiny rocks are oil covered) Photo: Darren Fong, November 12, 2007

Figure 14. One year post-spill Alcatraz Island rocky intertidal photopan looking east to Bay Bridge (grey rocks are bare, early colonizing green algae are bright green) Photo: Darren Fong, November 2008.

Outer Coast - Rest of Intertidal Zone

These injury and recovery inputs apply to the lower intertidal zone below the stranded oil band at Outer Coast sites.

Table 15. Outer Coast - Rest of Intertidal Zone

Very Light	Light	Moderate	Heavy
0 yr / 95%	0 yr / 90	0 yr / 85%	0 yr / 70%
0.08 yr / 100%	0.25 yr / 100%	1 yr / 100%	0.5 yr / 80%
			1 yr / 90%
			3 yr / 100%

Initial Service Loss. Outer coast sites near the spill with surfgrass (generally at +0 ft MLLW) had oil on blades commensurate to the level of oiling (Pt. Blunt on Angel Island - Heavy, South Rodeo Beach – Very Light). Surfgrass at Pt. Blunt was removed during cleaning actions, although information about whether blades were cut or rhizomes removed is not available. We documented bleaching of low intertidal algae (*Gymnogongrus*) after tar sloughed off (Rodeo Beach) over two month period (Figure 13). *Prionitis* in affected areas were bleached (Alcatraz Island) and some may have been removed at sites like Pt. Blunt where species at same tidal elevations (*e.g.*, surfgrass) were removed by cleaning (but no documentation is available).

Recovery. As with the in-Bay, the communities used to estimate recovery in the UCSC research are generally less common in lower intertidal areas. Therefore, the model would not be applicable here. Scientific literature was available to look at recovery for some taxa in the lower intertidal areas. A manipulative experiment indicates slow recovery for surfgrass following disturbance (Turner 1985) with recovery slower for large disturbance areas that allow algal communities to persist (> 3 years) (Turner 1985). Surfgrass treatments that removed just the blades and left the rhizomes intact recovered within 2 years (Dethier 1984). We assume that oiling injuries in the Very Light to Moderate oiling range for surfgrass were associated with blade loss commensurate with the level of oiling and would recover quickly. Recovery is long (>7 yrs) for *Prionitis* following experimental removal (Foster *et al*., 1988), but no information is available about recovery due to oiling impacts. Duration of exposure and relative oiling is expected to be less than stranded zone; therefore we assumed faster recovery.

Figure 12. Pt. Blunt (lower intertidal) with oiled *Phyllospadix* (in center). Photo: SCAT, November 20, 2007

Figure 13. Low intertidal rocks at Rodeo Beach - Bird Island (Fort Cronkhite, Marin County, in background). Oiled *Gymnogongrus* is black, unoiled *Gymnogongrus* is red. Photo: Darren Fong, November 23, 2007

Figure 14. Close-up of oiled *Gymnogongrus* thallus (black base), un-oiled thallus (brownish-red), and bleached thallus (white) at Rodeo Beach - Bird Island (Fort Cronkhite, Marin County). Photo: Darren Fong, January 17, 2008

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